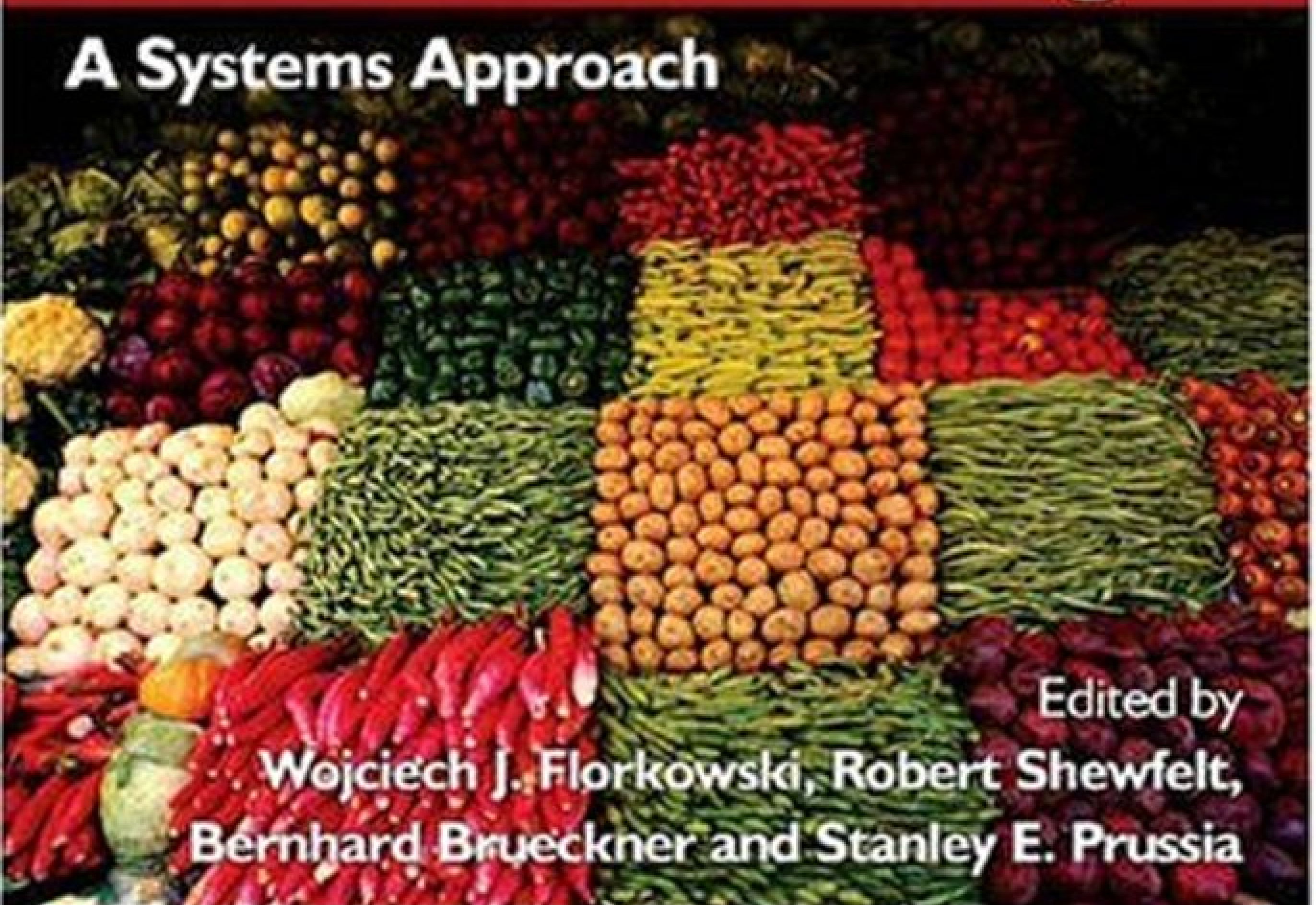
Second Edition

Postharvest Handling

A Systems Approach



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Preface

This book is a revised and expanded version of the book titled *Postharvest Handling: A Systems Approach* published in 1993. Following the publication of the first book, the application of systems thinking and a systems approach to postharvest handling of fruits and vegetables has generated enough interest to stimulate the emergence of a multidisciplinary group of scientists interested in the topic. The systems approach applied to the fresh fruit and vegetable supply chain treats it as a single entity focused on the delivery of quality desired by consumers. The entity consists of individual businesses that increase benefits because they share the same values and recognize the effects of cooperation for their individual trade reputation. Attributes such as trust and reputation improve the competitive position of the fresh fruit and vegetable industry relative to other segments of the food market.

The consumer is viewed as the ultimate powerbroker in systems approach. Therefore, the sequence of this book's chapters follows the path of information flow beginning with the consumer and tracking back through the supply chain to the production and breeding programs. Transparency of information flow about consumer preferences reflected in purchasing decisions changes expectations along the supply chain. Uninhibited information flow is vital to the sustainability of the whole industry.

A number of postharvest handling tasks remain narrowly defined and require an advanced disciplinary approach to find solutions. Innovation of processes and products takes place and accelerates, new technologies are applied, and the range of fruit and vegetable products broadens and diversifies into segments. However, any proposed solution must find acceptance with consumers. Since the publication of the first edition of this book, consumer preferences have gradually been altered. The role of fresh fruits and vegetables in nutrition, and their potential in disease prevention and health maintenance has captured consumer attention and become a focus of international organizations (e.g. WHO), national governments and the private sector. The rapidly growing scientific evidence linking fresh fruit and vegetable consumption to well-being has altered the decision-making process and behavior of people and institutions.

International and national programs have been formulated to increase the consumption of fresh fruits and vegetables. However, the recommended consumption still falls short of the recommended level in many parts of the world. International trade in fresh fruits and vegetables is likely to increase significantly to offset changing seasonal production, increase the variety offered and meet consumer expectations with regard to desired attributes. Long-distance shipment of fresh produce brings with it the emerging need to prevent contamination, especially microbial contamination.

The ability to trace back any shipment quickly and accurately is the current issue within the industry. It is traceability that provides the much needed justification to tighten the cooperation among various links in the supply chain, turning the systems approach from a management training tool to reality.

The informal multidisciplinary group of scientists interested in the practical side of systems thinking application in the supply chain of fresh fruits and vegetables organized the First International Conference on Fruit and Vegetable Quality in Potsdam, Germany, in 1997. It created a series of triennial conferences with the meeting in Griffin, Georgia, USA, in 2000, Wageningen, the Netherlands in 2003, and Bangkok, Thailand, in 2006. Since 2003 the group has been meeting under the auspices of the ISHS. The group has recognized the critical importance of both physiology and technology in improving the quality and handling of fresh fruits and vegetables. Its mission has been to place this technical information in a broader systems context. It is the desire of the editors of this current edition to stimulate, advance and channel research in postharvest of fresh fruits and vegetables to the ultimate benefit of consumers, by increasing the awareness of interdependencies within this emerging global sector.

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1

Postharvest Handling: A Discipline that Connects Commercial, Social, Natural and Scientific Systems

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Scinnova Limited, Tauranga, New Zealand

I. Perceptions, needs and roles

Talk to any consumer and you'll soon understand the rationale for the technologies, science and systems described in this book. You'll learn that they are seeking certainty (Owen et al., 2000; Batt, 2006; van der Vorst et al., 2007):

- certainty that the visual appearance of their purchases will be matched by a rewarding sensory experience at the time of consumption;
- certainty that their produce purchases are safe, healthy and nutritious for themselves and their families;
- certainty that their purchases are supporting a sustainable and ethically sound production system.

The information they seek is largely invisible at the time the produce is bought; their purchases are made mostly on the basis of trust. This book is about the systems that measure, monitor and manage the invisible things that consumers most value.

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Talk to any grower and they will stress the central importance of postharvest systems to their livelihoods and lifestyles (Bijman, 2002). Through these systems, they secure:

- information that enables them to grow and harvest intrinsically valuable crops;
- access to, and information about, consumers who will value the quality of the crop they have grown, often distant in terms of time and space from sites of production;
- ways to be able to characterize their crop that generate trust in buyers and consumers.

The technologies you will read about in this book are tools with which value is created in the grower's crop.

Talk to any fresh produce marketer about how they create value for both consumers and growers and they will tell you that they need to be able to design a high-value proposition and to realize that value in the marketplace (Hughes, 2005). They will also tell you that they are managing three interconnected opportunities and avoiding their associated risks:

- achieving "managed scarcity" by avoiding the oversupply that is disastrous for prices;
- matching differentiated product to appropriate market niches to avoid the high opportunity cost of sending superior product to low-value markets and inferior product to demanding, high-value markets;
- growing, segregating and delivering consistently superior quality to avoid the negative impact of variable quality.

This book synthesizes knowledge about the disciplines that underpin the capacity of a marketer, and the managers they work with, to address these opportunities.

The systems view of postharvest handling pioneered by the team at Georgia (Prussia et al., 1986; Prussia and Mosqueda, 2006) that lies behind this book provides insight into ways to manage risks and uncertainties in produce supply and information systems ("supply chains"), and how to turn each of them into an opportunity for developing valuable points of difference. The systems approach (Senge, 1990; Capra, 2002; Senge et al., 2005) provides rich, hierarchical and interactive perspectives of all aspects of existence. Here, focused on postharvest handling, you will augment your own tools for understanding, managing and innovating in fresh produce supply chains.

II. Effects are causes

The systems view makes it clear that the outcomes of making changes in a system are themselves influential in further evolution of that system. The classic case of this that benefits both consumers and growers, and is sought by marketers, is the "virtuous cycle" (Senge, 1990). In a virtuous cycle, the valuable consequences of a change

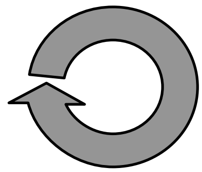

Figure 1.1 Virtuous cycle in delivery of superior product to market.

become reinforcers of that same change (Figure 1.1). Fresh produce supply chains can enter a virtuous cycle of change when the positive effects of consumers having superior experiences are fed right back through the chain, encouraging all participants to support initiatives that will deliver superior product. This concept has been the guiding principle for ZESPRI's "Taste ZESPRI" program, aimed at consistently providing superior tasting fruit to its most discerning markets (Banks, 2003). Here, the capacity of the market to respond to good quality with a positive signal (high volume at high price) augments the capacity and willingness of growers to invest in delivering superior quality. Implementation of the Taste ZESPRI strategy has been paralleled by a 75% increase in volume of the company's kiwifruit sales in key, high-return markets since its introduction in 2001 (Jager, 2008).

Development of a virtuous cycle by such participants requires a common language that they all understand. At its core, this involves a number of measures of success that make it clear what each participant must do for the supply chain to excel. These measures of success include a metric for describing and segregating product on the basis of its intrinsic quality, a description of financial rewards that result from increased consumer demand, and a payment mechanism that appropriately links these two to incentivize delivery of superior product. When all of this is formalized, it becomes part of an overall marketing and quality assurance system (Carriquiry and Babcock, 2007), providing clarity on the value proposition for all participants in the supply chain – a common feature of successful produce supply chains (Figure 1.2).

Trust among participants is a key ingredient for promoting effective communication in successful supply chains (Cadilhon et al., 2007; van der Vorst et al., 2007). Reputations of individual participants are often influential to the willingness of others to collaborate with them in forming or maintaining a supply chain; their ability to support outstanding performance by others in the system is central to establishing a virtuous cycle and driving success for the system as a whole. The hurdle of initial uncertainty associated with unfamiliarity with new parties that exists in traditional modes of business can now be overcome in electronic commerce through independent ratings from users, or from widely known and trusted third parties (Fritz et al., 2007). Brands provide a complementary mode of generating trust. Acting as shorthand for perceived aspects of value for the best part of a century in fruit markets around the world (Swan, 2000); brands support rapid decision-making by consumers facing a plethora of complex information as they make fresh fruit purchases (Figure 1.3). By acting as vehicles for integrating what is valued throughout marketing and production systems, they build reputation throughout the supply chain (Florkowski, 2000).

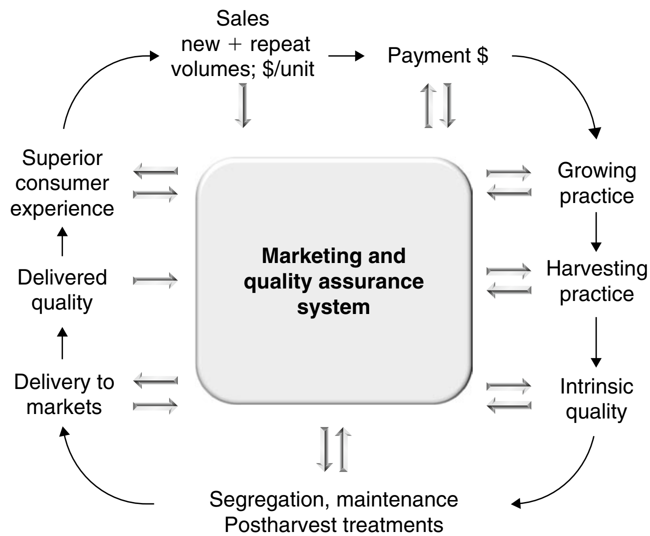

Figure 1.2 Flows of resources (product, physical, financial: outer flows) and information (inner flow) in a fresh produce supply chain that create responsiveness to the needs of its participants and the capacity for learning.

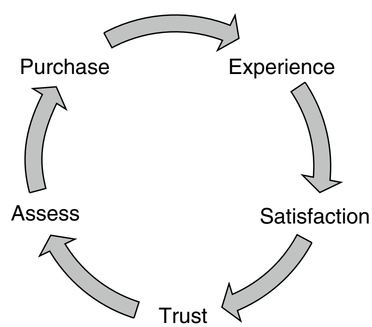

Figure 1.3 Learning with a brand: with each cycle of purchase and consumption, the consumer's level of trust in the brand promise is modified according to experience. Simplified from: Andani and MacFie (2000).

III. Creating extraordinary value

Over the past few decades, there have been many examples of horticultural investors pursuing opportunities to capture the lucrative returns of growing and marketing exclusive, protected cultivars with highly desirable characteristics. By managing the volume of production in relation to demand, investors can capture the benefits of "managed scarcity," and avoid the collapse in prices that follows from oversupply. The success stories illustrate the new marketing space that can be created with well-designed, branded new cultivars (e.g. Pink Lady™ apple, Chiquita Mini™ banana, Dole Tropical Gold™ and Del Monte Gold super-sweet pineapples, Driscoll's™ strawberries, Sun-World™ peaches, ZESPRI GOLD™ kiwifruit). However, owning the protected plants in the ground is just the first of many hurdles to be overcome in

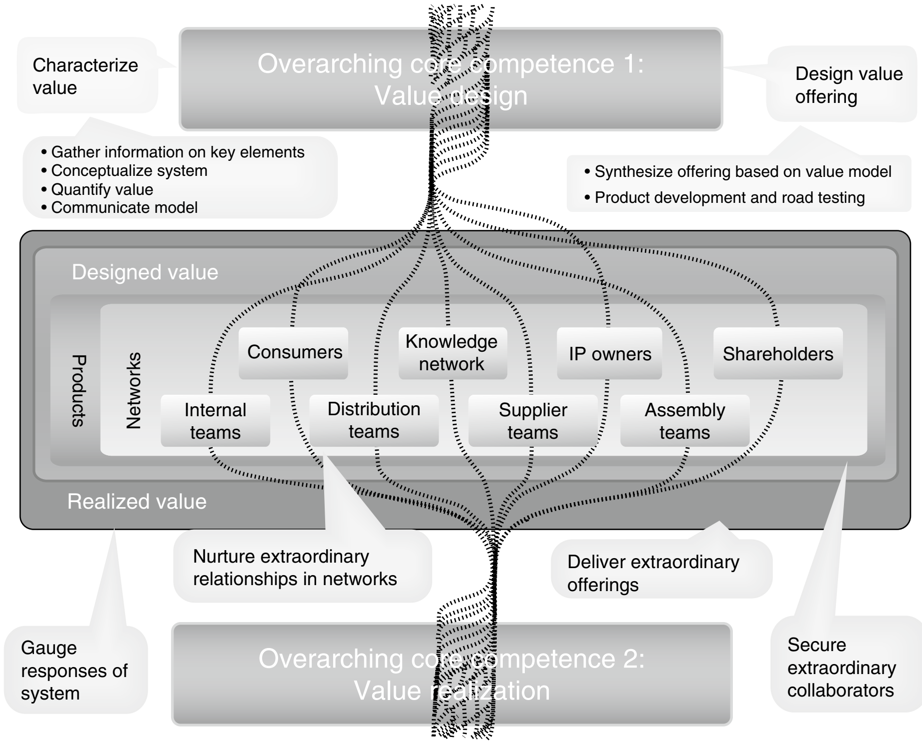

Figure 1.4 Creating extraordinary value. The capacities to be able to design high-value propositions and to be able to realize their potential are the two overarching core competencies of an effective supply chain. These core competencies are emergent properties of the complex system of supply and information flow that the supply chain comprises. They are the fundamental requirements for creating extraordinary value. The figure has been developed from a generic overview of business models presented by Osterwalder (2004), the concepts of co-creation of value (Prahalad and Ramaswamy, 2004) and the virtuous cycle (Senge, 1990). (It is licensed by Scinnova Limited under the Creative Commons Attribution-Share Alike 3.0 New Zealand Licence. To view a copy of this licence, visit http://creativecommons.org/licenses/by-sa/3.0/nz.)

securing high returns. In addition to the marketing costs of creating awareness of a new offering in international markets and discovering the strongest market for the new product, there is a diverse range of other sources of cost in establishing a successful supply chain. Over the first few years, best practice for production must be developed, characterized and implemented. Postharvest handling operations (segregation, labeling and packing, cool storage, transport) are developed and optimized, taking into account impact on consumer satisfaction, and levels of losses and returns for participants in the supply chain. Consumers have to be made aware of the offering and its special features, and a distribution network must be established.

For any new peach or banana, the design of the offering and supply chain is central, as in all business systems (Osterwalder, 2004; van der Vorst et al., 2007). At the same time, capacity for implementation is what takes the proposition from the drawing board to commercial reality. These two capabilities are emergent competencies of successful supply chains (Figure 1.4).

In the systems view of a fresh produce supply chain, consumers and markets are no longer simply targets. Growers and suppliers are no longer simply producing goods to sell. All are participants in a system for creating value. It is the integrated capacity of a supply chain for recognizing and responding to shared perceptions of value amongst its participants that enables both design and continually increasing realization of extraordinary value (Prahalad and Ramaswamy, 2004; Shewfelt, 2006).

Successful supply chains are those in which outstanding design and delivery work in a virtuous cycle to create and maintain extraordinary value. Functioning as learning systems (Wysocki et al., 2006), they generate self-sustaining patterns of flow that respond appropriately to challenges, providing ongoing high returns. Such supply chains address the opportunity to deliver rewarding eating experiences to appreciative consumers in the form of safe, healthy and nutritious produce sourced from sustainable systems. They create scope for growers to respond to market signals, producing crops that consumers will value and reward them for. They enable marketers and managers to provide frameworks for sharing valuable information and for matching product quality and quantity with market opportunities. When the supply chain is working well, all of its participants understand why they are succeeding and value their success.

IV. Making a difference

We all want to make a difference. Whether our focus is on the commercial, social, natural or scientific world, we seek to enhance the well-being of what we care about. Postharvest handling is a discipline that connects all of these systems, providing so many opportunities to change things for the better. This book is about developing understanding of how health-giving fresh produce is currently delivered into the homes of people around the world. It is also about developing insight into a future in which the opportunities for doing this more reliably, more profitably and more meaningfully have been realized, to the benefit of consumers, growers and marketers alike.

Bibliography

Andani, Z., MacFie, H.J.H. (2000). Consumer Preference. In: Fruit and Vegetable Quality, R.L. Shewfelt, B. Bruckner (eds). Technomic, Lancaster, PA, USA, pp. 158–177.

Banks, N. (2003). Consistency – horticulture's perpetual opportunity. Australasian Postharvest Horticulture Conference, 1–3 October. Brisbane, Australia, pp. 70–76.

Batt, P.J. (2006). Fulfilling customer needs in agribusiness supply chains. Proceedings of the 1st International Symposium on Supply Chains in Transitional Economies, P.J. Batt (ed.). Acta Hort., 699, 83–89.

Bijman, J. (2002). Essays on agricultural co-operatives: governance structure in fruit and vegetable chains. PhD Dissertation, Erasmus University, Rotterdam, The Netherlands.

Cadilhon, J.J., Fearne, A.P., Giac Tam, P.T., Moustier, P., Poole, N.D. (2007). Business-to-business relationships in parallel vegetable supply chains of Ho Chi Minh City (Viet Nam): reaching for better performance. Proceedings of the International Symposium on Fresh Produce Supply Chain Management. P.J. Batt, J.J. Cadhilon (eds). Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific, Publication 2007/21.

Capra, F. (2002). The Hidden Connections: A Science for Sustainable Living. Random House, New York, NY, USA.

Carriquiry, M., Babcock, B.A. (2007). Reputations, market structure, and the choice of quality assurance systems in the food industry. American Journal of Agricultural Economics, 89, 12–23.

Florkowski, W.J. (2000). Economics of Quality. In: Fruit and Vegetable Quality, R.L. Shewfelt, B. Bruckner (eds). Technomic, Lancaster, PA, USA, pp. 227–245.

Fritz, M., Hausen, T., Schiefer, G. (2007). Trust and e-commerce in the agrifood industry: configuration of a trust environment for e-commerce activities. In: Quality Management in Food Chains, L. Theuvsen, A. Spiller, M. Peupert, G. Jahn (eds). Wageningen Academic Publishers, The Netherlands, pp. 463–474.

Hughes, D. (2005). Understanding customer wants: the starting point for farmers when adding value and innovating. Farm Policy Journal, 2(1), 38–44.

Jager, L. (2008). ZESPRI International Limited, personal communication.

Osterwalder, A. (2004). The business model ontology: a proposition in a design science approach. Doctoral Dissertation, University of Lausanne, Switzerland.

Owen, K., Wright, V., Griffith, G. (2000). Quality, uncertainty and consumer valuation of fruits and vegetables. Australasian Agribusiness Review, 8, Paper 4.

Prahalad, C.K., Ramaswamy, V. (2004). The Future of Competition: Co-creating Unique Value with Customers. Harvard Business School Press, Boston, MA, USA.

Prussia, S.E., Jordan, J.O., Shewfelt, R.O., Beverly, R.B. (1986). A systems approach for 3 interdisciplinary postharvest research on horticulture crops. Georgia Agricultural Experimental Station Research Report No. 514. Athens, GA, USA.

Prussia, S.E., Mosqueda, M.R.P. (2006). Systems thinking for food supply chains: fresh produce applications. Proceedings of the Fourth International Conference on Managing Quality in Chains. A.C. Purves, W.B. McGlasson, S. Kanlayanarat (eds). Acta Hort., 712, 91–104.

Senge, P.M. (1990). The Fifth Discipline. The Art and Practice of the Learning Organisation. Random House, London, UK.

Senge, P., Scharmer, C.O., Jaworski, J., Flowers, B.S. (2005). Presence – Exploring Profound Change in People, Organizations, and Society. Nicholas Brearley Publishing, London, UK.

Shewfelt, R.L. (2006). Defining and meeting consumer requirements. Proceedings of the Fourth International Conference on Managing Quality in Chains. A.C. Purves, W.B. McGlasson, S. Kanlayanarat (eds). Acta Hort., 712, 31–38.

Swan, L. (2000). Fyffes – The World's Oldest Fruit Brand. http://www.fyffes.com/includes/pdfs/bluelabel.pdf

van der Vorst, J.G.A.J., da Silva, C., Trienekens, J.H. (2007). Agro-industrial supply chain management: concepts and applications. Agriculture Management, Marketing and Finance Occasional Paper 17. FAO, Rome, Italy.

Wysocki, A.F., Peterson, H.C., Harsh, S.B. (2006). Quantifying strategic choice along the vertical coordination continuum. Implications for agri-food chain performance. In: Quantifying the Agri-Food Supply Chain, C.J.M. Ondersteijn, J.H.M. Wijnands, R.B.M. Huirne, O. van Kooten (eds). Springer, The Netherlands, pp. 173–188.

Challenges in Handling Fresh Fruits and Vegetables

2

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I. Handling of fruits and vegetables from farm to consumer

Scientific research is usually directed at narrowly defined problems, using hypothesis testing or empirical observation to draw conclusions. Efficient handling and distribution of fresh fruits and vegetables is the direct result of the current understanding of postharvest physiology and the development of new technologies from highly focused studies. Before studying the handling system, the component handling steps must be understood and integrated to optimize the system, rather than to optimize a specific handling step.

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A. Production phase operations

Although the emphasis of this book is postharvest handling, conditions in the field before harvest influence quality and shelf life after harvest. Genetic potential, growing conditions and cultural practices all influence quality at harvest, as well as shipping and storage stability. The relationship between preharvest factors and postharvest quality is complex, and not well-understood. For example, Lee and Kader (2000) conclude that the vitamin C content of fruit and vegetable crops is affected by cultural factors, genotype and weather conditions. Woolf and Ferguson (2000) emphasize the critical role preharvest temperature plays in postharvest quality of fruits, such as avocado.

Plant breeders must satisfy many requirements in the breeding and selection of commercial cultivars. Most importantly, a cultivar must produce high yields under a wide range of growing conditions. Current attention is focused on greater resistance to stress, disease and insects, because of increasing consumer concern about the safety of agricultural chemicals. Uniformity of maturity at harvest permits the use of once-over harvest techniques. Resistance to mechanical damage during harvesting or subsequent handling operations improves shipping and storage stability. Flavor and nutrient composition are important to the consumer, but maintenance of acceptable appearance and firmness or turgor is more important to other buyers within the handling system. Achieving all these desirable characteristics in a single genotype is a difficult task and thus, a cultivar usually is judged by its most limiting characteristic.

Most commercial cultivars are selected primarily on the basis of potential yield over a range of growing conditions, with the idea of maintaining an acceptable level of shipping quality. Biotechnological techniques, such as cell culture and genetic engineering, greatly accelerate the breeding and selection process. Cell culture techniques have the potential to provide a means to screen large numbers of genotypes for specific traits, but the journey from culture tube to commercial cultivar is a long and difficult one. Advances in genetics and genetic engineering offer potential for improved quality, but further advances will be limited by a lack of understanding of many basic physiological processes and unexpected modification of unrelated traits.

Growing conditions play an important role in postharvest performance of harvested crops. Preharvest stress conditions can affect the flavor, microbial quality and composition of a fruit or vegetable. Cultural practices are chosen for other reasons, including maximizing yield, minimizing visual damage and improving efficiency of farm operations. Row spacing and training regimes facilitate field operations, such as harvest or the application of agricultural chemicals. Growth regulators promote common growth patterns of crops, resulting in greater uniformity of maturity at harvest. The pressure to reduce the use of agricultural chemicals resulted in development of a strategy of integrated pest management (IPM), which seeks to apply chemicals only when required to prevent economic damage (Kogan, 1998). IPM helps reduce pesticide use, but requires close monitoring and a good understanding of the biology of the crop and the pests.

B. Harvest

By definition, postharvest handling begins at harvest. Numerous reviews point to the importance of the maturity of the crop at harvest on subsequent postharvest quality and shelf life (Ahumada and Cantwell, 1996; Crisosto et al., 1997; Dixon and Hewitt, 2000; Lee and Kader, 2000; Shewfelt, 2000). Determination of the harvest date is based on yield, visual appearance, anticipated prices, estimated culling losses to achieve shipping quality and field conditions. Harvesting is accomplished by hand, by mechanically assisted picking devices, or by mechanical harvesters (Prussia and Woodroof, 1986; Shewfelt and Henderson, 2003). Robotics offers the long-term potential of combining the efficiency of machines with the selectivity of humans (Edan, 1995; Hayashi et al., 2002; Van Henten et al., 2003). Factors during harvesting operations that can influence postharvest quality include the degree of severity of mechanical damage induced by machine or human, the accuracy of selecting acceptable and unacceptable fruit, the time of day of harvest and the pulp temperature at harvest (Prussia and Woodroof, 1986).

C. Packing

Placement of the harvested crop into shipping containers is one of many activities described as packing operations. Packing may occur directly in the field, or in specially designed facilities called packing houses. Most packing operations include a means of removing foreign objects, sorting to remove substandard items, sorting into selected size categories, inspecting samples to ensure that the fruit or vegetable lot meets a specified standard of quality and packing into a shipping container. Some commodities are washed to remove soil and decrease microbial load. Many commodities are pre-cooled to remove field heat and slow down physiological processes (Talbott et al., 1991; Tetteh et al., 2004). Some special functions, such as the removal of trichomes (fuzz) from peaches, are also part of packing operations (Kays and Paull, 2004). Each operation is designed to achieve a product of uniform quality, but each handling step provides the opportunity to induce damage or disease.

D. Transportation

The wide availability of fresh fruits and vegetables year round, and the availability of items for sale where they cannot be grown, is a triumph of modern transportation systems. The primary transportation step carries the crop from the growing region to the selling region. This trip may be cross-continent by truck or rail, overseas by ship or plane, or across the county line in a pickup truck. Minimizing mechanical damage, maintaining proper temperatures, and ensuring commodity compatibility are the most important considerations in transportation operations. Mechanical damage occurs during loading, unloading and stacking operations or from shock and vibration during transport (Crisosto et al., 1993; Chonhenchob and Singh, 2003). Shipment of a load at or near its optimal temperature is affected by the initial temperature, refrigeration capacity, condition of refrigeration equipment and degree of airflow around the product. Construction of the shipping container, proper alignment of the vent holes in the containers, and use of approved and appropriate stacking patterns ensures adequate airflow.

Attention must be given to commodity compatibility within a load. Ethylene-sensitive commodities, such as lettuce, should not be shipped with ethylene generators, such as apples. A complete description of compatible and incompatible commodities is available (Ashby, 1995). The most common cause of freight claims is load shifting and crushing, but the costliest claims are the result of inadequate temperature control (Beilock, 1988).

Other transportation steps are also important in quality maintenance, for example, from field to packing facility and from wholesale distribution point to retail outlet. The same principles that apply to long-distance shipments apply to short-distance ones, but handling practices tend to receive less attention when the shipping distance is short. Fields and rural roads are usually bumpier than highways, thus vehicles hauling the harvested crop from field to packing house are generally not as capable of preventing shock and vibration damage as are tractor–trailer rigs. The delay of cooling of a crop is affected by the time required to load a vehicle in the field, the distance from field to packing house, the speed of the vehicle and the number of vehicles waiting to be unloaded at the packing house (Garner et al., 1987). The trip from wholesale warehouse to retail outlet brings together a wide range of commodities arranged by store. Mechanical damage results from shifting of loads in transport or crushing of cartons, due to the unconventional stacking of containers with differing sizes, shapes and strengths. Quality losses can also result from inadequate temperature control or product incompatibility. Even the most careful attention to proper stacking methods and proper temperature management can be defeated on loading docks by rough handling or long delays in non-refrigerated conditions.

Local purchasing options are now being emphasized to improve the flavor and nutritional quality of fresh produce and to do less damage to the environment (Nestle, 2006; Pollan, 2006). The emphasis is on the reduction of food miles or the miles a food product travels from harvest to market (Jones, 2002; Pretty et al., 2005). As food miles decrease, the time between harvest and consumption should decrease, leading to a decrease in loss of vitamins and lower fossil fuel consumption. Local produce is more likely to be harvested at peak maturity, resulting in better flavor and higher vitamin content, than crops harvested at a less mature stage. The concept of food miles is over-simplistic, and may not accurately reflect the impact on quality or on carbon consumption. Fruits and vegetables picked at peak maturity also deteriorate more rapidly, particularly when they are stored under the less-than-optimal conditions typical of local handling systems (Lee and Kader, 2000). In addition, the fuel efficiency of vehicles carrying smaller loads of produce to markets, and trips in consumer's private vehicles to buy a single item (Pollan, 2006) or to shop at multiple markets for different items rather than one-stop shopping, are likely to decrease the benefit of local products in combating global warming. Overseas shipment by ship and transport by rail are more energy-efficient than truck transport. Farming systems in Europe and North America are frequently more carbon-intensive than in other growing locations, such that even long shipments may represent a smaller carbon footprint than those grown locally (Saunders et al., 2006).

E. Storage

Within the handling system, fruits and vegetables are placed in storage from a few hours up to several months, depending on the commodity and storage conditions. Storage of a commodity serves as a means to extend the season, to delay marketing until prices rise, to provide a reserve for more uniform retail distribution, or to reduce the frequency of purchase by the consumer or food service establishment. The commodity must have sufficient shelf life to remain acceptable from harvest to consumption.

The shelf life of a fruit or vegetable during storage is dependent on its initial quality, its storage stability, the external conditions and the handling methods. Shelf life can be extended by maintaining a commodity at its optimal temperature, relative humidity (RH) and environmental conditions, as well as by the use of chemical preservatives or gamma irradiation treatment (Shewfelt, 1986; Lee and Kader, 2000). An extensive list of optimal storage temperatures and RHs with anticipated shelf life is available (Gross et al., 2004). Controlled atmosphere storage is a commercially effective means of extending the season of apples (Lavilla et al., 1999). Atmosphere modification within wholesale or retail packages is a further extension of this technology. Modification of the atmosphere is achieved by setting initial conditions and using absorbent compounds to limit carbon dioxide (CO_2) and ethylene (C_2H_4) concentrations (Kader et al., 1989; Labuza and Breene, 1989). Use of gamma irradiation extends the shelf life of some commodities, particularly strawberries (Yu et al., 1996; Prakesh et al., 2000). The application of 1-methylcylclopropene (1-MCP) can delay ripening by slowing respiration and volatile compound generation (Golding et al., 1999).

Physiological disorders that reduce the acceptability of susceptible commodities can develop during storage. Chilling injury (damage incurred at low temperatures above the freezing point) leads to a wide range of quality defects (O'Conner-Shaw et al., 1994; Butz et al., 2005). Crops may also be sensitive to high levels of CO_2 or C_2H_4, low levels of oxygen, water stress due to high transpiration, high temperatures and irradiation (Kays and Paull, 1987).

F. Retail distribution

The ultimate destination of most fresh fruits and vegetables is the retail market, where a consumer makes the final decision to accept or reject the product. Retail distribution is the most visible of all handling steps, and frequently the least controlled. Merchandising displays are designed to enhance quick, impulsive purchases, not necessarily to maintain quality. Conditions within the outlet (temperature, RH, lighting), close display of incompatible commodities (e.g. ethylene producers with ethylene-susceptible species), length of exposure to conditions or incompatible commodities (e.g. highly perishable items and chilling-susceptible fruits), and the degree and severity of handling by store personnel or consumers all affect quality and acceptability. Addition of ice, to lower temperatures and maintain high RH, and timed water misting are examples of techniques used to maintain quality. The most effective way to prevent quality losses at retail, however, is a rapid turnover of stock on the shelves. Because it is the only part of the process most consumers see, retail distribution provides an excellent opportunity to communicate with the consumer.

II. Towards a more integrated approach to handling

As a result of physiological and technological studies, guidelines for the efficient management of fresh fruits and vegetables are available for each handling step described earlier. Although these guidelines are not always followed, postharvest technologists do know how to handle produce correctly at each step. A basic premise of this book however, is that many handlers of produce within the postharvest system do not have a good understanding of the interaction between handling steps. Optimization of each handling step does not necessarily result in the best handling system. In extreme cases, an emphasis on individual handling steps results in poorer final quality. Questions that need to be answered to improve postharvest handling that have not been adequately studied by conventional approaches include:

1. How do preharvest cultural factors affect consumer acceptability?
2. How does storage at non-optimal conditions affect quality and consumer acceptability?
3. Are handlers who adopt new methods that result in enhanced consumer acceptability properly rewarded for their improvements?

To answer these and other questions that require an understanding of the interaction of various handling steps, a greater integration of specialized expertise and research perspectives is needed. We propose emphasis on integrated studies between:

- postharvest technologists and postharvest physiologists;
- crop production (horticulture, entomology, pathology) and utilization (economics, engineering, food science) disciplines;
- university laboratories and commercial establishments; and
- field and quality assurance departments within food processing companies.

Such studies require a better definition of commercially relevant goals (economics, quality, shelf life) within the confines of environmental and economic constraints. Successful interaction of "basic" and "applied" research is synergistic. Technological problems require immediate attention, which stimulates basic inquiry into underlying physiological mechanisms. New basic knowledge suggests, in turn, new approaches and solutions to old problems.

With an improved knowledge of interactions between handling steps, and a clearer understanding of the ultimate goals, integrated handling systems can be developed that incorporate answers to the questions posed earlier (Figure 2.1). Traditional postharvest studies alone are not capable of answering these questions. The adoption of a systems approach provides a context for future advances in postharvest science and its commercial application.

Operations research is the scientific discipline that emerged from the need to provide troops with necessary supplies at appropriate times in World War II (Karnopp and Rosenberg, 1975). A systems approach, derived from operations research, seeks to provide a means of studying broader issues than those addressed by the typical, narrowly-focused approaches employed by most scientists (Ikerd, 1993;

Figure 2.1 An integration of handling steps from farm to retail is the key to quality.

Checkland, 2000; Shewfelt and Brückner, 2000; Tijskens and Vollebregt, 2003; Purvis et al., 2006).

III. Challenges amenable to systems solutions

Research with selected fruits and vegetables (Prussia and Shewfelt, 1985; Shewfelt et al., 1986; Jordan et al., 1990; Hampson and Quamme, 2000; Jaseger et al., 2003; Crisosto et al., 2006) reveals several critical problems that require systems studies to provide meaningful solutions. Particular attention is required to identify conditions encountered in postharvest handling that affect consumer acceptability, as well as preharvest factors that influence postharvest quality. Research challenges that are particularly amenable to systems solutions include stress physiology, quality management, marketing and food safety.

A. Stress physiology

An "aberrant change in physiological processes brought about by one or a combination of environmental biological factors" is known as the stress response (Hale and Orcutt, 1987). Almost any handling technique used to keep harvested crops fresh for an extended period of time causes some stress to that tissue. Temperature extremes, desiccation, microbial invasion, gaseous atmosphere, light and mechanical handling can all induce stress in a harvested fruit or vegetable. Certain fruits and vegetables are susceptible to disorders, such as chilling, freezing and CO_2 injury. Many factors are implicated in the syndromes associated with stress response, but the physiological mechanisms of these responses remain elusive. Advances in molecular biology promise to provide techniques that will help unravel the physiological basis of quality degradation (Davey et al., 2006; Toivonen, 2006; Inaba, 2007).

B. Quality management

Quality assurance is an integral part of most manufacturing industries, including food processing. There is less motivation to develop quality management programs for fresh produce than for other food items, partly because of the generic nature of produce marketing and the difficulty of applying principles developed for processed foods to living, respiring tissue. The primary differences between fresh and processed foods that affect quality management factors include:

- fresh fruits and vegetables are maintained in recognizable form, whereas processed products are modified;
- variability in response to storage conditions among different items in the same lot is much greater in fresh fruits and vegetables than in processed products;
- the relationship between physiological processes and food quality has not been defined clearly in many fresh fruits and vegetables; and
- latent damage is a greater factor in quality losses in fresh produce than in processed products.

The fruit and vegetable processing industry is able to avoid these problems by (1) treating the crop as raw material, thus mixing lots of varying composition to produce a product that meets uniform product specifications, and (2) inactivating physiological processes during food processing operations. Despite these drawbacks, frameworks from Australia (Holt and Schoorl, 1981), Israel (Lidror and Prussia, 1990), Germany (Huyskens-Keil and Schreiner, 2003; Brückner, 2006) and The Netherlands (Tijskens and Vollebregt, 2003) provide a basis for quality management of fresh produce.

C. Marketing

Fresh produce is a major profit center for supermarket food chains. Fierce competition among chains is changing the merchandising of fresh items. With the exception of a few commodities, most fresh fruits and vegetables are marketed at retail in bulk displays without brand identification. Brands are used in marketing schemes of shippers directed at wholesale distributors, but whether brands will have an impact at retail distribution points is still uncertain (Shewfelt, 2000b; Hayward and Le Heron, 2002; Fernandez-Barcala and Gonzalez-Diaz, 2006).

Displays of consumer information, including nutritional composition, handling and preparation suggestions, point of origin and "best if consumed by" dates are part of the merchandising process in many outlets. Price look-up codes (PLUs) are being used to track fresh produce for category management at the retail outlet (Calvin et al., 2001), but they are not being full exploited in communicating information to the consumer or back through the handling system. Retail distribution is arguably the most important step of the entire postharvest system for determining consumer acceptability, yet this step may be the least understood in physiological and technological terms.

D. Food safety

The growing demand for fresh fruits and vegetables by health-conscious consumers also results in increased concern about food safety. Media attention to the use of agricultural chemicals to maintain "cosmetic" quality of fresh produce has heightened this concern. It is not clear how much pesticide use can be reduced without loss of visual quality of fresh fruits and vegetables, nor is it clear how lower visual quality would affect consumption (Institute of Food Technologists (IFT), 1990; Bushway et al., 2002).

It is becoming more apparent that the true safety dangers of fresh produce come from pathogenic microorganisms, and not from pesticides (Brandl, 2006). Preharvest contamination from manure, sludge and run-off water is a major factor in outbreaks (Beuchat, 2006), but evidence is not conclusive on whether organic produce presents greater risk of food-borne outbreaks (Magkos, 2006). Better control of irrigation water has been suggested as a means of decreasing food-associated outbreaks (Tyrell et al., 2006). Sanitizers in the packing house can be effective for some items, but they should not be seen as a substitute for good sanitation practices within the handling system (Alvarado-Casillas et al., 2007). Refrigeration temperatures, once thought to guarantee the safety of fresh fruits and vegetables, do not protect fresh produce from psychotropic pathogens such as *Listeria* (Dallaire et al., 2006). Edible coatings can contain inhibitors to microbial growth on fresh and fresh-cut fruits and vegetables (Lin and Zhao, 2007).

E. Working at the interfaces of the postharvest system

When we initiated research on the application of the systems approach to the handling of fresh fruits and vegetables, we tended to study the postharvest system in isolation, and ignore what happened before harvest (production) or after retail sale (home storage and consumption). We soon learned the limitations of this perspective. Much of the variation observed during postharvest storage was attributable to preharvest factors. In addition, the key to increasing the amount of an item consumed and the economic value of the item lies in understanding consumer desires. Progress in quality improvement of fresh fruits and vegetables will be made possible by working at the interfaces of the system (Figure 2.2) and providing:

- a clearer specification of quality and value of an item from the consumer perspective;
- an ability to understand preharvest factors that contribute to sample variability and predetermine storage stability; and
- a means to predict mathematically the period of optimum marketability under a specified set of handling conditions.

The remainder of this book places postharvest handling in a systems context. In the original edition of this book (Shewfelt and Prussia, 1993) we proposed a systems approach as a new paradigm for postharvest research. A series of international conferences based on this concept have been held in Potsdam, Germany (Shewfelt and Brückner, 2000), Griffin, GA, USA (Florkowski et al., 2000), Wageningen, The Netherlands (Tijskens and Vollebregt, 2003) and Bangkok, Thailand (Purvis et al., 2006).

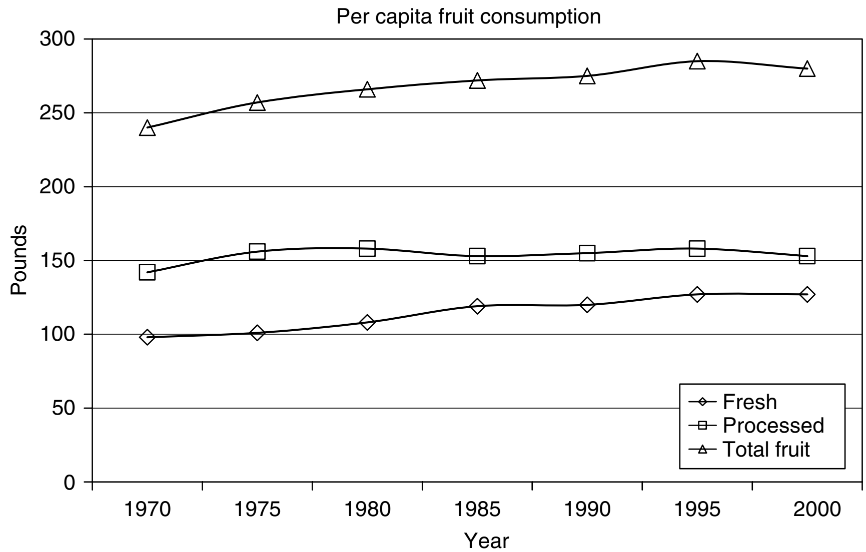

Figure 2.2 A generalized postharvest handling system and its interfaces with production systems and the consumer.

Bibliography

Ahumada, M., Cantwell, M. (1996). Postharvest studies on pepino dulce (*Solanum muricatum* Ait.): Maturity at harvest and storage behavior. Postharvest Biol. Technol., 7, 129–136.

Alvarado-Casillas, S., Ibarra-Sanchez, S., Rodruguez-Garcia, O., Martinez-Gonzales, N., Castillo, A. (2007). Comparison of rinsing and sanitizing procedures for reducing bacterial pathogens on fresh cantaloupes and bell peppers. J. Food Protect., 70, 655–660.

Ashby, B.H. (1995). Protecting perishable foods during transport by motor truck. USDA Handbook No. 669. U.S. Government Printing Office, Washington, DC, USA, (reprinted 2006).

Beilock, R. (1988). Losses in the logistical system: The case of perishables. J. Food Dist. Res., 19(2), 20–28.

Beuchat, L.R. (2006). Vectors and conditions for preharvest contamination of fruits and vegetables with pathogens capable of causing enteric diseases. Brit. Food J., 108, 38–53.

Brandl, M.T. (2006). Fitness of human enteric pathogens on plants and implications for food safety. Ann. Rev. Phytopath., 44, 367–392.

Brückner, B. (2006). Addressing consumer notions and individuality. Acta Hort., 712, 121–130.

Bushway, A.A., Hu, W., Schupp, J.R., Work, T., Koller, S.I. (2002). Quality characteristics of five disease-resistant apple cultivars. J. Am. Pomol. Soc., 56, 84–105.

Butz, P., Hofmann, C., Tauscher, B. (2005). Recent developments in noninvasive techniques for fresh fruit and vegetable internal quality analysis. J. Food Sci., 70, R131–R141.

Calvin, L., Cook, R., Denbaly, M., Dimitri, C., Glaser, L., Handy, C., Jekanowski, M., Kaufman, P., Krissoff, B., Thompson, G., Thornsbury, S. (2001). U.S. fresh fruit and vegetable marketing: emerging trade practices, trends, and issues. USDA Agricultural Economic Report No. 795.

Checkland, P. (2000). Soft systems methodology: A thirty year retrospective. Systems Res., 17, S11–S58.

Chonhenchob, V., Singh, S.P. (2003). A comparison of corrugated boxes and reusable plastic containers for mango distribution. Packaging Technol. Sci., 16, 231–237.

Crisosto, C.H., Garner, D., Doyle, J., Day, K.R. (1993). Relationship between fruit respiration, bruising susceptibility, and temperature in sweet cherries. HortScience, 28, 132–135.

Crisosto, C.H., Johnson, R.S., DeJong, T., Day, K.R. (1997). Orchard factors affecting postharvest stone fruit quality. HortScience, 32, 820–823.

Crisosto, C.H., Crisosto, G.M., Echeverria, G., Puy, J. (2006). Segregation of peach and nectarine (*Prunus persica* (L.) Batsch) cultivars according to their organoleptic characteristics. Postharvest Biol. Technol., 29, 10–19.

Dallaire, R., LeBlanc, D.I., Tranchant, C.C., Vasseur, L., Delaquis, P., Beauliey, C. (2006). Monitoring the microbial populations and temperatures of fresh broccoli from harvest to retail display. J. Food Protect., 69, 1118–1125.

Davey, M.W., Kenis, K., Kuelemans, J. (2006). Genetic control of fruit vitamin C contents. Plant Physiol., 142, 343–352.

Dixon, J., Hewitt, E.W. (2000). Factors affecting apple aroma/flavour volatile concentration: A review. N.Z. J. Crop Hort. Sci., 28, 155–173.

Edan, Y. (1995). Design of an autonomous agricultural robot. Applied Intell., 5, 41–50.

Fernandez-Barcala, M., Gonzalez-Diaz, M. (2006). Brand equity in the European fruit and vegetable sector: A transaction cost approach. Int. J. Res. Market., 23, 31–44.

Florkowski, W.J., Prussia, S.E., Shewfelt, R.L. (2000). Integrated View of Fruit and Vegetable Quality: International Multidisciplinary Conference. Technomic Pub. Co, Lancaster, PA, USA.

Garner, J.C., Prussia, S.E., Shewfelt, R.L., Jordan, J.L. (1987). Peach quality after delays in cooling. American Society of Agricultural Engineers Tech. Paper #87–6501 St. Joseph, MI, USA.

Golding, J.B., Shearer, D., McGlasson, W.B., Wyllie, S.G. (1999). Relationships between respiration, ethylene, and aroma production in ripening banana. J. Agric. Food Chem., 47, 1646–1651.

Gross, K.C., Wang, C.Y., Saltviet, M. (2004). The commercial storage of fruits, vegetables, and florist and nursery stocks. USDA Agriculture Handbook No. 66. U.S. Government Printing Office, Washington, DC, USA.

Hale, M.G., Orcutt, D.M. (1987). The Physiology of Plants Under Stress. John Wiley & Sons, New York.

Hampson, C.R., Quamme, H.A. (2000). Use of preference testing to identify tolerance limits for fruit visual attributes in apple breeding. HortScience, 35, 921–924.

Hayashi, S., Ganno, K., Ishii, Y., Tanaka, I. (2002). Robotic harvesting for eggplants. JARQ, 36(3), 163–168.

Hayward, D.J., LeHeron, R.B. (2002). Horticultural reform in the European Union and New Zealand: further developments towards a global fresh fruit and vegetable complex. Australian Geog., 33, 9–27.

Huyskens-Keil, S., Schreiner, M. (2003). Quality of fruits and vegetables. J. Appl. Bot., 77, 147–151.

Ikerd, J.E. (1993). The need for a systems approach to sustainable agriculture. Agric. Ecosyst. Environ., 46, 147–160.

Inaba, A. (2007). Studies on the internal feedback regulation of ethylene biosynthesis and signal transduction during fruit ripening, and the improvement of quality. J. Japan. Soc. Hortic. Sci., 76, 1–12.

Jaeger, S.E., Rossiter, K.L., Wismer, W.V., Harker, F.R. (2003). Consumer-driven product development in the kiwifruit industry. Food Qual. Pref., 14, 187–198.

Jones, A. (2002). An environmental assessment of food supply chains: A case study on dessert apples. Environ. Management, 30, 560–576.

Jordan, J.L., Prussia, S.E., Shewfelt, R.L., Thai, C.N., Mongelli, R. (1990). Transportation management, postharvest quality, and shelf-life extension of lettuce. University of Georgia Agricultural Bulletin No. 386, Athens, GA, USA.

Kader, A.A., Zagory, D., Kerbel, E.L. (1989). Modified atmosphere packaging of fruit and vegetables. Crit. Rev. Food Sci. Nutr., 28, 1–30.

Kantor, L.S., Lipton, K., Manchester, A., Oliviera, V. (1997). Estimating and addressing America's food losses. Food Review, 20, 1–12.

Kays, S.J., Paull, R.E. (2004). Postharvest Biology. Exon Press, Athens, GA, USA.

Kogan, M. (1998). Integrated pest management: Historical perspectives and contemporary developments. Annu. Rev. Entomol., 43, 243–270.

Labuza, T.P., Breene, W.M. (1989). Applications of "active packaging" for improvement of shelf-life and nutritional quality of fresh and extended shelf-life foods. J. Food Proc. Pres., 13, 1–69.

Lavilla, T., Puy, J., López, M.L., Recasens, I., Vendrell, M. (1999). Relationships between volatile production, fruit quality, and sensory evaluation in Granny Smith apples stored in different controlled-atmosphere treatments by means of multivariate analysis. J. Agric. Food Chem., 47, 3791–3803.

Lee, S.K., Kader, A.A. (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biol. Technol., 20, 207–220.

Lidror, A., Prussia, S.E. (1990). Improving quality assurance techniques for producing and handling agricultural crops. J. Food Qual., 13, 171–184.

Lin, D., Zhao, Y.Y. (2007). Innovations in the development and application of edible coatings for fresh and minimally processed fruits and vegetables. Comp. Rev. Food Sci. Food Safety, 6, 60–75.

Magkos, F., Arvanti, F., Zampelas, A. (2006). Organic food: Buying more safety or just peace of mind? A critical review of the literature. Crit. Rev. Food Sci. Nutr., 46, 23–56.

National Academy of Sciences (1978). Postharvest Food Losses in Developing Countries. National Academy Press, Washington, DC, USA.

Nestle, M. (2006). What to Eat. North Point Press, New York.

O'Connor-Shaw, R.E., Roberts, R., Ford, A.L., Nottingham, S.M. (1994). Shelf life of minimally processed honeydew, kiwifruit, papaya, pineapple and cantaloupe. J. Food Sci., 59, 1202–1206.

Pollan, M. (2006). The Omnivore's Dilemma: A Natural History of Four Meals. Penguin Press, New York.

Prakash, A., Guner, A.R., Caporaso, F., Foley, D.M. (2000). Effects of low-dose gamma irradiation on the shelf life and quality characteristics of cut romaine lettuce packaged under modified atmosphere. J. Food Sci., 65, 549–553.

Pretty, J.N., Ball, A.S., Lang, T., Morrison, J.I.L. (2005). Farm costs and food miles: An assessment of the full cost of the UK weekly food basket. Food Pol., 30, 1–19.

Prussia, S.E., Shewfelt, R.L. (1985). Ventilation cooling of bulk shipments of shelled southern peas. Trans. ASAE, 28, 1704–1708.

Prussia, S.E., Woodroof, J.G. (1986). Harvesting, handling, and holding fruit. In: Commercial Fruit Processing, J.G. Woodroof, B.S. Luh (eds). AVI/Van Nostrand Reinhold, New York, NY, USA, pp. 25–97.

Purvis, A.C., McGlasson, W.B., Kanlavanarat, S. (2006). Proceedings of the Fourth International Conference on Quality in Chains: The integrated view on fruits and vegetables quality. Acta Hort., 712.

Putnam, J., Allshouse, J., Kantor, L.S. (2002). U.S. per capita food supply trends: More calories, refined carbohydrates and fats. Food Review, 25(3), 1–15.

Saunders, C., Barber, A., Taylor, G. (2006). Food miles – Comparative energy/emissions performance of New Zealand's agriculture industry. Lincoln University Research Report, No. 285, Canterbury, NZ.

Schoorl, D., Holt, J.E. (1982). Fresh fruit and vegetable distribution – Management of quality. Sci. Hort., 17, 1–8.

Shewfelt, R.L. (1986). Postharvest treatment for extending the shelf life of fruits and vegetables. Food Technol., 40(5), 70–89.

Shewfelt, R.L. (2000a). Fruit and vegetable quality. In: Fruit and Vegetable Quality: An Integrated View, R.L. Shewfelt, B. Brückner (eds). Technomic Press, Lancaster, PA, USA, pp. 144–157.

Shewfelt, R.L. (2000b). Consumer-friendly specifications to meet the demands of a global market. Food Australia, 52, 311–314.

Shewfelt, R.L., Brückner, B. (2000). Fruit and Vegetable Quality: An Integrated View. Technomic Press, Lancaster, PA, USA.

Shewfelt, R.L., Henderson, J.D. (2003). The future of quality. Acta Hort., 604, 49–59.

Shewfelt, R.L., Prussia, S.E. (1993). Postharvest Handling: A Systems Approach. Academic Press, New York, NY, USA.

Shewfelt, R.L., Prussia, S.E., Jordan, J.L., Hurst, W.C., Resurreccion, A.V.A. (1986). A systems analysis of postharvest handling of fresh snap beans. HortScience, 21, 470–472.

Talbott, M.T., Sargent, S.A., Brecht, J.K. (1991). Cooling Florida sweet corn. L Univ. Florida Coop. Ext. Serv. Circular, 941, FL, USA.

Tetteh, M.K., Prussia, S.E., NeSmith, D.S., Verma, B.P., Aggarwal, D. (2004). Modeling blueberry firmness and mass loss during cooling delays and storage. Trans. ASAE, 47, 1121–1127.

Tijskens, L.M.M., Vollebregt, H.M. (2003). Proceedings of the International Conference on Quality in Chains. An Integrated View on Fruit and Vegetable Quality. Acta Hort., 604.

Toivonen, P.M.A. (2006). Fresh-cut apples: Challenges and opportunities for multidisciplinary research. Can. J. Plant Sci., 86, 1361–1368.

Tyrrel, S.F., Knox, J.W., Weatherhead, E.K. (2006). Microbiological water quality requirements for salad irrigation in the United Kingdom. J. Food Protect., 69, 2029–2035.

U.S. Dept. of Agriculture and U.S. Dept of Health and Human Services (2005). Dietary Guidelines for Americans 2005. U.S. Government Printing Office, Washington, DC, USA.

Van Henton, E.J., van Tuijl, B.A.J., Hemming, J., Kornet, J.G., Bontsema, J., van Os, E.A. (2003). Field test of an autonomous cucumber picking robot. Biosystems Eng., 86, 305–311.

Woolf, A.B., Ferguson, I.B. (2000). Postharvest responses to high fruit temperatures in the field. Postharvest Biol. Technol., 21, 7–20.

Yu, L., Reitmeier, C.A., Love, M.H. (1996). Strawberry texture and pectin content as affected by electron beam irradiation. J. Food Sci., 61, 844–846.

3

Consumer Eating Habits and Perceptions of Fresh Produce Quality

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I. Current fresh produce eating habits

The absolute availability of fresh fruits and vegetables is closely associated with their consumption (Ritson and Hutchins, 1991), and as such can dictate fresh produce eating habits. Per capita availability of fruits and vegetables is highest in the Mediterranean (Mitchell, 2004). Greece, for instance, has reported that 282 kilograms of vegetables and 175 kilograms of fruit are available per person per annum, respectively, while the respective availabilities in the United Kingdom (UK) are only 89 kilograms of vegetables and 86 kilograms of fruit per person per annum (Mitchell, 2004).

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The importance of climate, as it relates to the availability of fruits and vegetables, is well-appreciated in Scotland, where poor growing conditions exist for most fruits and vegetables, and consumer habits force grocers to sell only the fruits which are most popular (Anderson et al., 1994).

Dietary patterns in Finland and Sweden have historically been low in fruit and vegetable consumption, due to the lack of a good climate and the necessary land available to grow these products cheaply (Mitchell, 2004). Climate, availability, product familiarity and price are closely linked to consumption and a country's traditional dietary pattern. Recently however, with both increased incomes and trade in the European Union, these traditional diets are changing and often converging, resulting in increased fruit and vegetable consumption in countries where historically it has been low.

A. Global

Although the World Health Organization (WHO) recommends 400 grams of fruits and vegetables per person per day to reduce the risk of non-communicable diseases and improve overall health, WHO data suggest that inhabitants of most African countries and some Eastern European, Asian and South American countries consume less than this amount. Residents of the remainder of South America, as well as Australia, Greenland and Western Europe, consume slightly more than the WHO guidelines (400 to 600 grams per person per day), while consumption in North America and China, as well some Middle Eastern countries, is greater than the WHO guidelines (600 to 800 grams per person per day). Fruit and vegetable consumption is highest in Mediterranean countries, where it may exceed 1000 grams per person per day.

B. North America

In Canada, the available amount of fresh fruit and vegetables increased from the 1970s to the early 1990s, by 39% and 24%, respectively, from 1972 to 1992. Since then, the amount of fresh fruits has increased steadily, while vegetable availability has remained constant (Statistics Canada, 2007). Canadians consumed 37.6 kilograms of fresh fruit per person in 2005 and 37.8 kilograms of fresh vegetables. The percentage of vegetables consumed as fresh in Canada has stayed constant, at around 80%, during the 1970 to 2005 period (Statistics Canada, 2007). Domestic produce remains popular (for example, apples, carrots, potatoes), but consumption of more exotic fresh produce such as mangoes, papayas and pineapples has increased, and traditional imports such as bananas and grapes also remain popular (Statistics Canada, 2007). The increase in fruit and vegetable consumption in all forms suggests a potential market for increased sales (Faye, 2004).

A similar consumption trend is observed in the US, where the total amount of fruits and vegetables available for consumption has increased by 20% from 1970 to 2005 (Wells and Buzby, 2007). Fresh vegetable consumption was approximately 60% of total vegetable consumption during the same period (USDA ERS, 2007). The respective availabilities of fruits and vegetables are 134 kilograms and 109 kilograms per person per annum with apples, potatoes and tomatoes available in the greatest quantities (Wells and Buzby, 2007).

According to the Food and Agriculture Organization (FAO) statistics, fruit and vegetable consumption in Mexico is 400–600 grams per person per day (FAO, 2003). Fresh fruit consumption was 113 kilograms per person per year from 1999 to 2001, while fresh vegetable consumption was 72 kilograms. Oranges, bananas, mangoes, coconuts, limes and lemons were the most popular fruits, while potatoes, tomatoes and chilli peppers were the most popular vegetables (Stout et al., 2004).

Despite the easy availability of fruits and vegetables, the Centers for Disease Control and Prevention (CDC) report that Americans continue to struggle to consume at least five portions a day (Mitchell, 2004; CDC, 2007), as do Canadians (Garriguet, 2004). The WHO suggests that worldwide fruit and vegetable consumption is 20–50% of the recommended minimum (FAO, 2006).

The inability to consume sufficient fresh produce on a daily basis to maintain a healthy diet and prevent major diseases, such as cardiovascular disease and some cancers, is of concern to the WHO, whose mandate is to improve global public health (WHO, 2004). To promote the consumption of fruits and vegetables the WHO is working with a variety of programs, both national (e.g. "Go for 2&5®" in Australia, "5 al día" in Chile) and regional (e.g. IFAVA, International Fruit and Vegetables Alliance; EPBH, European Partnerships for Fruits, Vegetables and Better Health). The WHO "Fruit and Vegetable Promotion Initiative" (WHO, 2003) has identified that, in addition to monitoring fruit and vegetable production and consumption and evaluating promotion programs, the knowledge of supply and demand factors that influence consumption must also be studied. Personal and situational variables that influence fresh produce consumption, including accessibility, price, income, gender and age are discussed further in this chapter in Section IV.

A further challenge to the interpretation of fruit and vegetable consumption data is that the reported amount of consumption does not account for fruit and vegetable waste between the grocery store and the dining table, as well as subsequent household waste (WHO, 2003). The WHO estimates this loss to be 33% on average (WHO, 2003). During household preparation fruits and vegetables are trimmed of inedible or undesirable portions, and the resulting edible portion is a percentage of the weight of the "as purchased" product that can range from 66% for leaf lettuce to 99% for tomatoes (Molt, 2001). After a meal, the food remaining on a plate to be discarded is measured as "plate waste" (Engström and Carlsson-Kanyama, 2004), and this measure gives an insight into the desirability of the served food products (Connors and Rozell, 2004). Plate waste assessments often indicate that fruits and vegetables are not consumed to the same extent as other foods served. Engström and Carlsson-Kanyama (2004) measured food loss from food service institutions in Stockholm, Sweden. They observed that plate waste was the largest contributor to food waste in institutions and restaurants, and on average was 11% to 13% of the amount of food served. In restaurants, vegetables represented the majority of plate waste. In a study of meals served in an acute care hospital in North Texas, a plate waste assessment revealed that all vegetables served to adult patients were consumed at less than the desirable benchmark value of intake, while fruit consumption exceed the benchmark value (Connors and Rozell, 2004). Plate waste of sixth-graders ($n = 743$) in a school lunch program in Kentucky was approximately 30% for vegetables, and 36–52%

for fruits (Marlette et al., 2005). Plate waste was influenced by the food preparation method (i.e. apple sauce was preferred to whole apples), and in particular, fruit waste was negatively influenced by the availability of competitive food items in the school which were often high in fat and/or sugar and served to decrease the nutritional value of lunch.

The comparison of fruit and vegetable consumption on the global scale illustrates the diversity of regional eating habits, and suggests the presence of different regional factors influencing fruit and vegetable consumption habits. Geographic factors, such as climate and arable land usage, are related to availability and consumption of fresh fruits and vegetables. National trade policies regarding imports and exports and other government strategies also impact the availability of fruits and vegetables (Mitchell, 2004). Regional availability dictated by climate and geopolitical factors influencing fruit and vegetable consumption provides the background for the complex analysis of consumer eating habits of fresh fruits and vegetables.

There are a multitude of paradigms by which food choice and eating variables can be related. For the purposes of this chapter, the paradigm of consumer-perceived quality is a useful method for grouping these variables, because quality is a core concept of consumer satisfaction (Oude Ophuis and van Trijp, 1995). As Harker et al. (2003) and Poole et al. (2007) suggest quality, in the eyes of the consumer, should be the focus for advancing the horticultural industry.

II. How do consumers define quality?

Steenkamp (1990) suggested that successful industries will generate products of a quality that is defined by consumers, quality that is "dependent on the perceptions, needs and goals of the consumer" rather than objective quality that is based on an innate measurable and predetermined standard. Oude Ophuis and van Trijp (1995) apply the principle of consumer-perceived quality to successful consumer-driven food product development. They describe quality as a "multi-faceted concept" for which consumers use both quality attributes and quality cues to form their assessment of perceived quality. Quality cues are observable product characteristics that can be intrinsic (e.g. appearance, color, shape, size, structure) or extrinsic (e.g. price, brand, nutritional information, production information, country of origin). Quality attributes are abstract, and can be based on experience (e.g. taste, freshness, convenience) or perceived benefits (e.g. healthfulness, naturalness, animal and/or environmentally friendly). The perceived benefit quality attributes are known as credence quality attributes, as the benefits cannot be experienced directly and information or judgment by others forms the basis of the perceived benefits. Together these dimensions of quality, the intrinsic and extrinsic quality cues and the experience and credence quality attributes, are integrated to develop a picture for the consumer of perceived quality.

The horticultural industry has traditionally focused on intrinsic quality cues, such as appearance and the assessment of texture by instrumental methods, and has only relatively recently promoted fresh produce's extrinsic quality cues, such as nutritional and production information, brand name and price. Given the preceding description of consumer-perceived quality, with its numerous quality dimensions and the knowledge that the importance of these dimensions differs among individuals, it follows that there is not a single universal definition of quality for any product, food or nonfood. Consumer-perceived quality is clearly an individual assessment however; groups of individuals with similar values and demographics may represent consumer segments with similar expectations of fruit and vegetable quality. These consumer segments, or niche markets, represent both the challenges and opportunities for the horticultural industry of matching products with people. A variety of techniques from the field of sensory and consumer science have been used to match the product quality cues (i.e. appearance) and experiential attributes (i.e. taste) to preferences of target markets. Currently, a number of such techniques are being used successfully to select markets for kiwifruit (Jaeger et al., 2003a) and pears (Jaeger et al., 2003b; Gamble et al., 2006). The intrinsic quality cue information, combined with knowledge of the consumer segment's perceived quality attributes, is currently suggested as the preferred method of meeting consumer expectations of products (Lundahl, 2006).

III. Consumer perceptions of fresh produce quality

External sensory attributes of fresh produce, such as appearance, color, shape, size and hand-evaluated texture, are intrinsic quality cues that are evaluated by the consumer prior to consumption, while flavor (taste and aroma) and oral texture are experience-quality attributes evaluated at the time of consumption. Although the composite evaluation of sensory attributes generates an overall opinion of the sensory qualities of the produce, this perception is not generated at a single point in time, and is continuously modified with every consumption experience.

In addition, the sensory attributes of fresh fruit and vegetables are variable, reflecting the diversity inherent to a biological commodity, exacerbated by a variety of postharvest handling protocols. For example, the inherent biological diversity is illustrated by Dever et al. (1995), who noted that different sensory characteristics could occur in two sides of a single apple (blush versus nonblush) and from top to bottom of an apple. A variety of accounts of the influence of postharvest handling protocols on produce sensory attributes exist in the literature. Crisosto et al. (2002) substituted SO_2 with a range of CO_2 and O_2 concentrations in early- and late-harvested Redglobe grapes. Atmospheres above 10 kPa CO_2 combined with 3, 6 or 12 kPa O_2 effectively limited botrytis decay during 12 weeks cold storage, but accelerated stem browning and "off-flavor" development, while atmospheres less than 10 kPa CO_2 did not result in off-flavor development. The sensory quality of Clemenules mandarins was observed to decrease due to the reduction of mandarin-like flavor and development of off-flavor when fruit were held for 12 days at 1.5°C as a quarantine treatment for Mediterranean fruit fly (Palou et al., 2008). In these examples, the undesirable sensory attribute of off-flavor is given consideration as part of the evaluation of fruit quality.

A. Intrinsic quality cues: the influence of appearance

Appearance is the first sensory attribute evaluated by consumers. "The eyes are the gatekeeper to the mouth," and if the appearance of a product is not liked, then the product is not further evaluated. Appearance is a major factor in the quality assessment of fruits and vegetables (von Alvensleben and Meier, 1990; Abbott, 1999), and is an important determinant in the purchase of fruits and vegetables in the grocery store (Kays, 1991; Gamble et al., 2006).

Kays (1999) has reviewed preharvest factors of fresh fruits and vegetables that affect appearance. Of all appearance attributes, color was suggested to be the most influential quality factor, as consumers have expectations of overall quality based on color, such as color cues for banana ripeness. Kays (1999) notes that at times, color expectations of quality may not be valid because, for example, some orange (*Citrus* spp.) cultivars are at their optimum when they are green, not orange as most consumers perceive. Stommel et al. (2005) presented tomato samples to consumers under white light and then under red light to mask sample color differences. It was observed that consumers favored the more highly pigmented fruit, and perceived a greater intensity of tomato quality attributes such as tomato-like flavor, juiciness and overall eating quality. While the appearance factors of shape and form are considered to be generally of minor influence in the consumer evaluation of quality, size is an important quality determinant related to end use (Kays, 1999).

Cliff et al. (2002) demonstrated that digital imagery could be used successfully to control the visual attributes of apples to determine consumer liking for apple appearance factors, such as color, shape, type and background color. Digitally modified photographic images were presented to consumers in New Zealand, and in British Columbia and Nova Scotia in Canada. Red colored apples were generally preferred by consumers in all locations, while preferences for blush and stripes were geographically linked. Cliff et al. (2002) suggest that the evaluation of digital images by consumers in different markets can help breeders and marketing agents direct produce with the appropriate external quality cues to selected markets. Desired product appearance is principally achieved through cultivar selection (Kays, 1999).

B. Experiential quality attributes: taste, texture and perceptions of freshness

Taste, texture and freshness are attributes evaluated by consumers as the product is consumed (see also Chapter 4). Consumers may be intending to consume fruit because of its beneficial health consequences, but taste and texture are fundamental qualities that must be satisfied for continued consumption (Harker et al., 2003). The memory of the experiential quality attributes influences future assessments of quality, and consumers have been observed to remember day-to-day differences in apple firmness as small as 5N (Harker et al., 2002a).

The taste or flavor attributes of horticultural products are frequently evaluated as a measure of consumer acceptance as new varieties are developed for the marketplace, and identifying flavor targets for fruit breeding for specific markets has generated commercial success for kiwifruit by matching fruit to markets with different taste preferences (Wismer et al., 2005). Taste/flavor is ranked more highly than texture and appearance as a contributor to overall liking for food products in general (Moskowitz and Krieger, 1995). However, color and texture of horticultural products are more frequently cited as consumer quality attributes.

Texture is an important attribute of fresh fruit and vegetables; many of these products are desired for their crispy or crunchy characteristics, but others are appreciated for their juicy, soft and easy-to-chew and swallow characteristics (Roininen et al., 2004). Instrumental measurements of fruit and vegetable texture are common and desirable in industry and research, because they reduce variation in measurement (relative to human texture assessments) and provide a measure of output that is able to be interpreted (Abbott, 1999). Thus, the horticultural industry defines textural quality by instrumental firmness measures. In some instances, such as the evaluation of apple texture, penetrometer measurements can reliably be used to predict sensory perception of apple texture (Harker et al., 2002b). Instrumental evaluations provide practical targets for rapid and large volume assessments and generate data of a quality that can be mathematically related to pre- and postharvest treatment factors. However, instrumental evaluations do not capture the multi-attribute profile of textural qualities consumers expect of fresh produce, nor can such evaluations be related easily to other quality attributes or emotive quality dimensions.

Consumers who regularly purchase specific apple cultivars have a firm expectation of the quality and sensory attributes of the cultivar (Harker et al., 2003), although they are accepting of variations in quality, e.g. firm textures in apples (Harker et al., 2002a). Roininen et al. (2004) completed laddering interviews with young adults (25 years' to 40 years' old) and elderly (60 plus years' old) in Finland and the United Kingdom to elicit perceptions of the consequences of positive and negative textural properties of fruits and vegetables. Age groups in both countries indicated that seeds and peel, as well as hard and fibrous textures, were textural qualities of fruit that made them troublesome to eat, while vegetable attributes that were troublesome were "hard" and "contained peel." Fruits and vegetables were preferred if they required no preparation, were ready-to-eat or not too difficult to eat. It was suggested that fruits and vegetables that were preprocessed to alleviate the negative attributes would likely promote the consumption of these products.

Freshness is an important quality criterion for the acceptance of fruit and vegetables (Péneau et al., 2007). Kays (1991) described freshness, along with cleanliness and maturity, as part of the appearance factor of condition, a "somewhat nebulous quality consideration" that embodies many properties, including the general physical condition of the product. Péneau et al. (2006, 2007) have explored consumer perceptions of freshness of strawberries, carrots and apples with European consumers. A set of attributes were used to evaluate the freshness of each product, with appearance attributes dominating the assessment of strawberries, and both texture and appearance attributes used for carrots. Many of the attributes were negative (i.e. should not be present in a fresh product), which suggested that observed sensory properties are used to evaluate the physiological ageing of horticultural products to generate an assessment of product freshness (Péneau et al., 2007).

Postharvest technologies aimed at extending the shelf life of fresh fruits and vegetables may support consumer-perceived freshness, and influence the likelihood of their purchase and increase consumption opportunities. Modified atmosphere packaging and irradiation techniques to extend shelf life and resistance to handling damage during transportation and sale may prove useful in this regard. New packaging technologies, including edible coatings on fresh-cut fruits, may both prolong freshness and enhance convenience (Olivas and Barbosa-Canovas, 2005).

C. Credence quality attributes: perceptions of agricultural practices

The increase in consumer preference for fruits and vegetables produced using organic agricultural practices is an example of food product selection based on credence quality attributes. By selecting organic produce, consumers perceive they have selected products that deliver health benefits, and that they have contributed to lesser environmental damage than that generated by the purchase of conventionally produced agricultural products (Schifferstein and Oude Ophius, 1998; Saba and Messina, 2003). Environmental damage cannot be experienced directly as a result of product purchase, and there is no immediate health benefit observed after product consumption, thus both of these perceived benefits are credence quality attributes (Oude Ophius and van Trijp, 1995). Just as there is person-to-person variation surrounding the perception of the sensory attributes of products, there is individual variation in the perceived quality of credence attributes, as they resonate only if the purported benefits appeal to an individual's personal value system (Oude Ophius and van Trijp, 1995).

Consumers who purchase organic foods do so because of the perceived health superiority over conventional foods, based on the absence of pesticides, growth hormones and genetically modified organisms (Sloan, 2007). The organic food sector is the largest of the ethical foods category, which also encompasses fair trade, local and natural foods, and products sold in recycled packaging (Sloan, 2007). Watching one's food miles and the interest in locally-grown produce satisfies the credence attribute of reduced environmental damage (Harper and Makatouni, 2002). Emerging interest in fruits and vegetables produced from heirloom seeds may satisfy both the need for increased variety in the diet and the consumer value of maintenance of genetic diversity. Ozcaglar-Toulouse et al. (2006) caution that ethical consumers cannot be considered to be a homogeneous group, although they are often considered to represent a single market niche. In addition, the improved effectiveness of marketing organic foods to consumers based on perceived health benefits rather than spiritual concerns about the environment, both credence attributes, suggests that motivations and the consumers themselves who purchase these products have changed since the emergence of the ethical consumerism movement (Sloan, 2007).

IV. Personal and situational variables that influence fresh produce eating habits

A. Accessibility, price and income

Local access to fruits and vegetables, their price and household income have been evaluated as variables influencing eating habits of fresh produce. Socioeconomically disadvantaged groups are frequently cited as less likely to purchase and consume fruits and vegetables (Mishra et al., 2002; Turrell et al., 2004), and less likely to spend more on produce when income increases (Blisard et al., 2004). In much of Africa, lower-income families spend little of their income on vegetables and, as money becomes tighter, the range or quality of vegetables consumed is reduced (Anonymous, 2008).

However, in a study of environmental factors in a disadvantaged area of Brisbane, Australia, price, availability and variety were not associated with reduced opportunities to purchase fresh produce (Winkler et al., 2006). Similarly, using a mail survey of residents of a poor community in the United Kingdom, Pearson et al. (2005) found that fruit and vegetable price, socioeconomic deprivation and limited local grocery store access did not influence fruit and vegetable consumption, but that age and gender were consumption determinants.

Price is the primary factor used by consumers to determine selection of fruits and vegetables in the grocery store (Gamble et al., 2006). The price of fruits and vegetables is elastic relative to other commodities, such as shelf-stable, prepared products, especially in countries where the local agriculture industry is not protected from international trade (Mitchell, 2004). The relationship between fruit and vegetable price and income is a strong predictor of consumption in poorer countries, but the relationship between price and income is a weaker predictor of consumption in wealthier countries (Mitchell, 2004).

In the US, high-income households spend more of their income on fruits and vegetables than low-income households and increase expenditures on fruits and vegetables when faced with theoretical additional income (Blisard et al., 2004). In Canada, low-income households purchase proportionally fewer fruits and vegetables compared to high-income households and are more sensitive to the price changes of fruits and vegetables in comparison to other commodities, such as meat (Kirkpatrick and Tarasuk, 2003).

A variety of studies in the literature indicate that fruits compete with each other, and that as the cost of one type of fruit increases, consumers will substitute another fruit in its place, such as the substitution of citrus and banana, and citrus and apple (Lee et al., 1992). Some fruits are purchased out of habit, and as price changes there is little change in the quantity purchased (Richards and Patterson, 2000).

Harker et al. (2003) reviewed consumer behavior aspects of price versus quality with a focus on the apple market. The authors describe several studies that use the experimental technique of conjoint analysis to observe consumer trade-offs of price and quality attributes. The contingent valuation literature includes a variety of studies that use the willingness-to-pay (WTP) approach to model the probable increase in WTP as a function of both consumer demographics and measured attitudes and values, which form the basis of quality perceptions. Among others, WTP has been determined for consumers of blemished organic apples (Chengyan-Yue et al., 2007) and pesticide residue limit compliant "safe" vegetables in northeast Thailand (Wilatsana et al., 2007).

B. Age and gender

Fresh fruit and vegetable consumption statistics have been generated in a number of developed countries in order to describe the relationships between age, gender and fruit and vegetable consumption, while research studies have been performed to explore and model the relationship among these factors.

The National Diet and Nutrition Survey (NDNS) of residents of Great Britain (2000/2001) concluded that no males and only 4% of females aged 19 years' to 24 years' old consume the recommended daily servings of fruits and vegetables (Henderson et al., 2002). Similarly, the Australian National Health Survey revealed that only 16% of females and 11% of males over the age of 12 consumed the recommended five servings of fruits and vegetables per day, with the highest proportion of compliance seen in people 55 years of age and older (Australian Bureau of Statistics, 2006).

In the US, an estimated 40% of the population consumes at least five servings of fruits and vegetables per day (Guenther et al., 2006). Compliance with the recommended intake varies by age group; 48% of children aged 2 to 4 years' old and 60% of adults aged 51 to 70 years' old meet the recommended five daily servings of fruits and vegetables (Guenther et al., 2006), while only 10% of girls aged 4 to 8 years' old met this target. When reframed to reflect recent increases in recommended fruit and vegetable consumption, only 17% of men and women aged 51 to 70 years' old meet the new minimum recommendations of seven servings, and 11% of individuals in other age groups meet the minimum requirements (Guenther et al., 2006).

In Canada, average fruit and vegetable servings for adults are 5.2 per day and 4.5 for children and adolescents (Garriguet, 2004). In the age range of 9 to 13 years, 68% of boys and 62% of girls do not meet the minimum serving requirement of five per day, and from the age of 14 to 50 years, males are significantly less likely than females to consume minimum requirements (Garriguet, 2004).

Differences in the fruit and vegetable recommendations and data collection and documentation methods can make direct cross-country comparisons of consumption statistics difficult. However, the brief statistics reported here demonstrate some international commonalities: females are more likely to consume the recommended number of daily fruit and vegetable servings than men, while the greatest compliance in meeting the recommended intake is often seen among children and seniors. It has been suggested that because children are more likely to consume juice than any other age group, they more easily meet fruit and vegetable recommendations (Henderson et al., 2002).

Perceptions of fruits and vegetables differ among children and adults. Factors associated with their consumption have been studied generally for the purpose of understanding current consumption habits and increasing consumption through the influence of favorable factors.

Factors affecting childhood consumption

Food consumption and eating habits develop in the formative years of childhood. A number of theories have been proposed to describe behavior formation and continuation. Ecological models expand the theoretical perspective by considering direct environment–individual interactions, and may offer an explanation for consumption habits.

Reinaerts et al. (2007) studied fruit and vegetable consumption in Dutch children aged 4 to 12 years. Habit was found to influence fruit consumption to a far greater extent than vegetable consumption, as children likely eat fruit of their own volition, while they are frequently prompted to eat vegetables. It was suggested that familiarizing children with fruits and vegetables by presenting them more frequently could lead to higher consumption, and that because parental consumption was influential, parents must be involved in interventions aimed at children.

The environment that is established and maintained by parents, childcare providers and schools influences childhood fruit and vegetable consumption, and a combination of interventions by all of these groups is more effective at increasing fruit and vegetable consumption than the efforts of one group alone (Blanchette and Brug, 2005). Parental role-model behavior exerts a strong influence on childhood fruit and vegetable consumption (Blanchette and Brug, 2005). In the home, a readily available fruit bowl allows children to form positive fruit and vegetable consumption habits on a regular basis (Reinaerts et al., 2007). The frequency of meals consumed as a family is positively associated with fruit and vegetable consumption (De Bourdeaudhuij and van Oost, 2000). Blanchette and Brug (2005) reviewed 38 publications regarding determinants of fruit and vegetable consumption in children and interventions targeted at increased consumption. In addition to the impact of positive parental influence mentioned above, they concluded that access to school snack bars and television viewing negatively influenced fruit and vegetable consumption, while knowledge of food preparation and specifics of five-a-day promotion programs were positive influences.

Programs targeting increased fruit and vegetable consumption in the school environment have been successful through increased accessibility and exposure to fresh produce. The USDA Fruit and Vegetable Pilot program, initiated during the 2002 to 2003 school year, resulted in an increase in fruit and vegetable exposure and associated consumption for school-aged children (Buzby et al., 2003). School-based intervention strategies have taken on a number of different forms, including increased availability and variety, improved taste and portion size of fruits and vegetables offered in school food service, and marketing strategies in school cafeterias (Blanchette and Brug, 2005). All appear to have a positive affect on fruit and vegetable consumption, with fruit consumption more easily improved than vegetable consumption, likely due to the innate appeal of the sensory attributes of fruit (Blanchette and Brug, 2005).

Previously identified statistics and longitudinal studies have demonstrated that fruit and vegetable consumption habits are dynamic during childhood and adolescence. Age is a contributing factor to fruit and vegetable consumption, along with gender, socioeconomic status, ethnicity and urbanization (Rasmussen et al., 2006).

A decrease of 0.7 and 0.4 servings, respectively, have been observed for females and males between middle and late adolescence (Larson et al., 2007). The important role of parental fruit and vegetable consumption during childhood, and the subsequent distancing of children from their parents as they progress into adulthood, may contribute to these changes. Evidence suggests that changes in fruit and vegetable consumption during adolescence are the result of an increasing school-related influence (e.g. other adults, teachers and peers) and decreasing amounts of time at home (Kubik et al., 2003).

Klepp et al. (2005) developed a conceptual framework to summarize the broad range of ecological and personal contributions to fruit and vegetable consumption (Figure 3.1). Children's determinants of fruit and vegetable consumption were grouped under the headings of cultural environment, physical environment, social environment and personal factors, and were also described as distal or proximal relative to the individual. For example, "socioeconomic status" is considered to be a distal cultural environment influence, while "habit" and "preference" are both proximal personal factors. Based on this model, and a review of the literature regarding determinants of fruit and vegetable consumption among children and adolescents, Rasmussen et al. (2006) concluded that several previously presumed determinants lacked evidence, while socioeconomic position, preferences, parental intake and home availability were all positively associated with fruit and vegetable consumption.

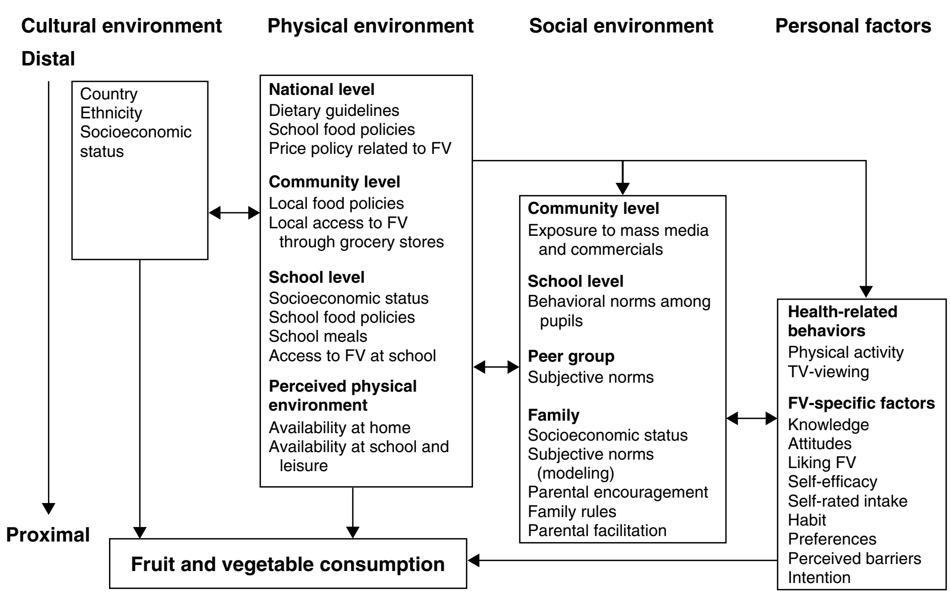

Figure 3.1 Conceptual framework applied to children's fruit and vegetable consumption. Reprinted with permission from: Klepp, K.I., et al. (2005). Promoting fruit and vegetable consumption among European school children: rationale, conceptualization and design of the pro children project. Ann. Nutr. Metab., 49(4), 212–220.

Factors affecting adult consumption

Although childhood patterns of fruit and vegetable consumption persist into adulthood (Lien et al., 2001), the overall factors which contribute to adult consumption differ from the factors which contribute to childhood consumption. Positive attitudes towards healthy eating behaviors generally result in greater fruit and vegetable consumption rates (Hearty et al., 2007), and also influence the likelihood of behavior change in the future. In Scotland, for example, where adult dietary change is viewed with a negative attitude, the likelihood of an increase in fruit and vegetable consumption is relatively low (Anderson et al., 1994).

Household income influences adult fruit and vegetable consumption, and lower incomes are consistently associated with lower fruit and vegetable consumption (Kamphuis et al., 2006). The location of a home (suburban, urban or rural) determines the vicinity of substitute foods, such as fast foods (MacDonald et al., 2007). Higher fruit and vegetable consumption rates have been observed in rural rather than urban populations (Inchley et al., 2001), and in populations with greater levels of education (Shimakawa et al., 1994). Being married is also associated with increased fruit and vegetable consumption (Billson et al., 1999).

The psychosocial determinants of fruit and vegetable consumption elicited from Dutch adults using focus groups were determined to be satisfaction (with an emphasis on taste), perceived health consequences, social influences, skills and barriers, habit and lack of awareness of health benefits from recommended intakes (Brug et al., 1995). The motivation for that study, funded by the Dutch Cancer Society, was ultimately one of improved population health through nutrition education regarding fruit and vegetable consumption. However, the beliefs about fruits and vegetables generate a picture of the quality expectations and quality perceptions of these products in the population surveyed. Information such as this can be used by the horticultural industry to describe perceptions of fresh produce quality within a population. Fruit and vegetable breeding, placement and promotion can then be targeted to meet quality perceptions.

V. Concluding comments

Descriptions and evaluations of consumer eating habits of fruit and vegetables appear in academic studies, trade publications and mass media with increasing frequency, in response to the mounting evidence that the consumption of fresh fruits and vegetables is beneficial for maintaining health and preventing a variety of diseases (see also Chapter 5). To date, fruit and vegetable consumption has been associated with decreased risk of diabetes, cardiovascular disease and cancer, and associated with beneficial relationships with chronic obstructive pulmonary disease, eye health, asthma, bone health and neurodegenerative diseases of aging (Anonymous, 2005). Much of this health benefit research is observational therefore, controlled clinical interventions and mechanistic studies are necessary to clarify the observed benefits between fruit and vegetable consumption and disease prevention (Anonymous, 2005).

Would the establishment of stronger evidence of the link between increased fruit and vegetable consumption and health benefits motivate consumers to increase their consumption of fresh produce? This would be desirable, as very few individuals meet the minimum suggested daily serving recommendations for fruits and vegetables. However, health is only one motivator of fruit and vegetable consumption, and an emphasis on making healthy choices serves as a “disciplinary stick” and neglects “the pleasure of healthy eating” (Poole et al., 2007). In addition, Lin (2004) suggests that, by 2020, a generally higher income for many Americans that results in increased dietary knowledge, and thus a potential health-based increase in fruit consumption, will be negated by the dietary choices associated with dining out.

The evaluation of the determinants of consumer eating habits of fruits and vegetables describes the environmental and psychosocial factors that contribute to their consumption. Price, income and availability, gender and age, and motivations of ethical consumerism are all part of the complex of determinants of eating behaviors and perceptions of quality that determine individual eating habits. Studies of the determinants of fruit and vegetable consumption of both adults and children often yield conflicting results, and overall summaries of these studies reveal complex maps of factors that influence the decision-making process to eat these products. Perhaps because of this complexity of factors influencing food choice, promotional campaigns to increase fruit and vegetable consumption have not always met with the success anticipated at their inception. However, interventions appear to result in some degree of improved consumption, and further studies of psychosocial determinants of fruit and vegetable consumption linked to the design of promotional activities may result in enhanced fruit and vegetable consumption.

The horticultural industry can maximize benefits from both the increased knowledge about consumer eating habits and the predicted increased demand for fresh fruits and vegetables, using the consumer-perceived quality paradigm to develop, target and promote products to consumers. Although in the past, consumer-perceived quality has been simply described by phrases such as “fitness for intended use,” the market driven and consumer-oriented approach to quality (Oude Ophius and Van Trijp, 1995) describes consumer-perceived quality as containing the elements of intrinsic and extrinsic quality cues, experience quality attributes and credence quality attributes. This paradigm of quality has the advantage of tangibly relating quality attributes to physical product parameters, such as sensory attributes, and to consumer trends such as the desire for organic and locally grown produce, which are motivated by personal values. As Oude Ophius and Van Trijp (1995) suggest, anyone who wants to make and sell food products should understand consumer perceived quality.

Peri (2006) presents an analytical model of food quality in which six of the 13 quality attributes are presented as being related to “the product as a food” and the remainder are presented as “the product as an object of trade.” The model is a good reminder of both the complexity of the consumer quality paradigm, and the need for the horticultural industry to consider not only industry-related quality attributes that frame fruits and vegetables as objects of trade, but also to evaluate produce quality with consideration of consumer food use. Advances in postharvest technologies must continue to evaluate product quality using the consumer-oriented approach to quality, as advances are of limited commercial value unless they result in products with attributes desired by the consumer.

An additional challenge to be considered is the dissemination of quality-related information to consumers. As Poole et al. (2007) note in their study of citrus fruit, and Harker et al. (2003) describe in their review of apple quality, product-specific information about fruits, such as variety specific information, can help consumers with their purchase decisions.

Descriptions of global consumer eating habits of fresh fruit and vegetables, health benefits associated with fruit and vegetable consumption, and the multitude of fruit and vegetable promotion campaigns, confirm that increased fruit and vegetable consumption is a public health issue, and an opportunity for the fresh fruit and vegetable industry. However, the complexity of the determinants of eating habits and the multitude of factors involved in the evaluation of consumer perceived quality of fruits and vegetables present a challenge to this expansion. Continued monitoring of eating habits and further studies to elucidate determinants of eating habits and increase understanding of consumer perceived quality, coupled with awareness, appreciation and monitoring of these factors by the fresh fruit and vegetable industry is key to overcoming this challenge.

Bibliography

Abbott, J.A. (1999). Quality measurements of fruits and vegetables. Postharvest Biol. Technol., 15, 207–225.

Anderson, A.S., Marshall, D., Lean, M., Foster, A. (1994). Five a day? Factors affecting fruit and vegetable consumption in Scotland. Nutr. Food Sci., 94(5), 14–16.

Anonymous (2008). Africa needs to up its fruit and vegetable consumption. FreshPlaza: Global Fresh Produce and Banana News. Available online at: http://www.freshplaza.com/news_detail.asp?id=15344 Accessed 1 March 2008.

Anonymous (2005). Fruits and vegetables and health: a scientific overview. Literature Review – Executive Summary. International Fruit and Vegetables Alliance (IFAVA). Available online at: http://www.ifava.org/science_overview.asp Accessed 1 March 2008.

Australian Bureau of Statistics (2006). 4364.0 National Health Survey: Summary of Results 2004–2005. Commonwealth of Australia. Available online at http://www.abs.gov.au Accessed 31 March 2007.

Billson, H., Pryer, J.A., Nichols, R. (1999). Variation in fruit and vegetable consumption among adults in Britain. An analysis from the dietary and nutritional survey of British adults. Eur. J. Nutr., 53(12), 946–952.

Blanchette, L., Brug, J. (2005). Determinants of fruit and vegetable consumption among 6–12-year-old children and effective interventions to increase consumption. J. Hum. Nutr. Dietet., 18, 431–443.

Blisard, N., Stewart, H., Jolliffe, D. (2004). Low-income household expenditures on fruit and vegetables. USDA, Econ. Res. Serv. Agricultural Economic Report No. 838. US Govt. Printing Office, Washington, DC, USA.

Brug, J., Debie, S., van Assema, P., Weijts, W. (1995). Psychosocial determinants of fruit and vegetable consumption among adults: results of focus group interviews. Food Qual. Pref., 6(2), 99–107.

Buzby, J.C., Guthrie, J.F., Kantor, L.S. (2003). Evaluation of the USDA Fruit and Vegetable Pilot Program: Report to Congress. USDA, Econ. Res. Serv. E-FAN No. (03-006), Washington, DC, USA.

Centers for Disease Control and Prevention (CDC). (2007). Fruit and vegetable consumption among adults – United States, 2005. MMWR Weekly, 56(10), 213–217. Available online at: http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5610a2.htm Accessed 15 March 2007.

Chengyan-Yue, Jensen, H.H., Mueller, D.S., Nonnecke, G.R., Bonnet, D., Gleason, M.L. (2007). Estimating consumers' valuation of organic and cosmetically damaged apples. HortSci., 42(6), 1366–1371.

Cliff, M., Sanford, K., Wismer, W., Hampson, C. (2002). Use of digital images for evaluation of factors responsible for visual preference of apples by consumers. HortSci., 37(7), 1127–1131.

Connors, P.L., Rozell, S.B. (2004). Using a visual plate waste study to monitor menu performance. J Am. Diet. Assoc., 104, 94–96.

Crisosto, C.H., Garner, D., Crisosto, G. (2002). Carbon dioxide-enriched atmospheres during cold storage limit losses from Botrytis but accelerate rachis browning of "Redglobe" table grapes. Postharvest Biol. Technol., 26(2), 181–189.

De Bourdeaudhuij, I., van Oost, P. (2000). Personal and family determinants of dietary behaviour in adolescents and their parents. Psychol. Health., 15, 751–770.

Dever, M.C., Cliff, M.A., Hall, J.W. (1995). Analysis of variation and multivariate relationships among analytical and sensory characteristics in whole apple evaluation. J. Sci. Food Agric., 69(3), 329–338.

Engström, R., Carlsson-Kanyama, A. (2004). Food losses in food service institutions: examples from Sweden. Food Policy, 29, 203–213.

Faye, S. (2004). Consumer trends for fruit and vegetable products. Alberta Agriculture, Food and Rural Development. Available online at: http://www.1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sis8439 Accessed 15 December 2007.

FAO (2003). Food and Agriculture Atlas: Map 6 Consumption of Fruits and Vegetables 1999–2001. FAO Statistics Division, Rome. Available online at: http://www.fao.org/es/ess/chartroom/gfap.asp Accessed 7 April 2007.

FAO (2006). Spotlight 2006: More fruits and vegetables. Agriculture and Consumer Protection Department, FAO. Available online at: http://www.fao.org/ag/magazine/0606sp2.htm Accessed 1 March 2008.

Gamble, J., Jaeger, S.R., Harker, F.R. (2006). Preferences in pear appearance and response to novelty among Australian and New Zealand consumers. Postharvest Biol. Technol., 41(1), 38–47.

Garriguet, D. (2004). Overview of Canadians' eating habits. Statistics Canada, Catalogue no. 82-620-MIE – No. 2. Available online at: http://www.statcan.ca/english/research/82-620-MIE/82-620-MIE2006002.pdf Accessed 2 January 2008.

Guenther, P.M., Dodd, K.W., Reedy, J., Krebs-Smith, S.M. (2006). Most Americans eat much less than recommended amounts of fruits and vegetables. J. Am. Diet. Assoc., 106(9), 1371–1379.

Harker, F.R., Gunson, F.A., Brookfield, P.L., White, A. (2002a). An apple a day: the influence of memory on consumer judgment of quality. Food Qual. Pref., 13, 173–179.

Harker, F.R., Maindonald, J., Murray, S.H., Gunson, F.A., Hallett, I.C., Walker, S.B. (2002b). Sensory interpretation of instrumental measurements 1: texture of apple fruit. Postharvest Biol. Technol., 24, 225–239.

Harker, F.R., Gunson, F.A., Jaeger, S.R. (2003). The case for fruit quality: an interpretative review of consumer attitudes, and preferences for apples. Postharvest Biol. Technol., 28, 333–347.

Harper, G.C., Makatouni, A. (2002). Consumer perception of organic food production and farm animal welfare. Brit. Food J., 104(3/4/5), 287–299.

Hearty, A.P., McCarthy, S.N., Kearney, J.M., Gibney, M.J. (2007). Relationship between attitudes towards healthy eating and dietary behavior, lifestyle and demographic factors in a representative sample of Irish adults. Appetite, 48(1), 1–11.

Henderson, L., Gregory, J., Swan, G. (2002). The National Diet and Nutrition Survey: Adults Aged 19 to 64 Years (Volume 1). Office for National Statistics, Norwich, UK. Available online at http://www.food.gov.uk/multimedia/pdfs/ndnsprintedreport.pdf Accessed 17 January 2007.

Inchley, J., Todd, J., Bryce, C., Currie, C. (2001). Dietary trends among Scottish schoolchildren in the 1990s. J. Hum. Nutr. Diet., 14, 207–216.

Jaeger, S.R., Rossiter, K.L., Wismer, W.V., Harker, F.R. (2003a). Consumer-driven product development in the kiwifruit industry. Food Qual. Pref., 14(3), 187–198.

Jaeger, S.R., Lund, C.M., Lau, K., Harker, F.R. (2003b). In search of the “ideal” pear (Pyrus spp.): results of a multidisciplinary exploration. J. Food Sci., 68(3), 1108–1117.

Kamphuis, C.B.M., Giskes, K., de Bruijn, G.-J., Wendel-Vos, W., Brug, J., van Lenthe, F.J. (2006). Environmental determinants of fruit and vegetable consumption among adults: a systematic review. Brit. J. Nutr., 96, 620–635.

Kays, S.J. (1999). Preharvest factors affecting appearance. Postharvest Biol. Technol., 15, 233–247.

Kays, S.J. (1991). Postharvest Physiology of Perishable Plant Products. Van Nostrand Reinhold, New York, NY, USA.

Kirkpatrick, S., Tarasuk, V. (2003). The relationship between low income and household food expenditure in Canada. Public Health Nutr., 6(6), 589–597.

Klepp, K.I., Pérez-Rodrigo, C., De Bourdeaudhuij, I., Due, P.P., Elmadfa, I., Haraldsdóttir, J., Konig, J., Sjostrom, M., Thórsdóttir, I., Vaz de Almeida, M.D., Yngve, A., Brug, J. (2005). Promoting fruit and vegetable consumption among European schoolchildren: rationale, conceptualization and design of the pro children project. Ann. Nutr. Metab., 49(4), 212–220.

Kubik, M.Y., Lytle, L.A., Hannan, P.J., Perry, C.L., Story, M. (2003). The association of the school food environment with dietary behaviors of young adolescents. Am. J. Public Health, 93(7), 1168–1173.

Larson, N.I., Neumark-Sztainer, D., Hannan, P.J., Story, M. (2007). Trends in adolescent fruit and vegetable consumption 1999–2004: Project EAT. Am. J. Prev. Med., 32(2), 147–150.

Lee, J.Y., Brown, M.G., Seale, J.L. (1992). Demand relationships among fresh fruit and juices in Canada. Rev. Agric. Econ., 14, 255–262.

Lien, N., Lytle, L.A., Klepp, K.I. (2001). Stability in consumption of fruit, vegetables, and sugary foods in a cohort from age 14 to age 21. Prev. Med., 33, 217–226.

Lin, B.-H. (2004). Fruit and vegetable consumption: looking ahead to 2020. USDA/ERS Agriculture Information Bulletin No. (AIB792-7). Available online at: http://www.ers.usda.gov/publications/aib792/aib792-7/ Accessed 29 February 2008.

Lundahl, D. (2006). A holistic approach to product development. Food Technol., 60(11), 28–33.

MacDonald, L., Cummins, S., Macintyre, S. (2007). Neighbourhood fast food environment and area deprivation – substitution or concentration? Appetite, 46, 251–254.

Marlette, M.A., Templeton, S.B., Panemangalore, M. (2005). Food types, food preparation, and competitive food purchases impact school lunch plate waste by sixth-grade students. J. Am. Diet. Assoc., 105(11), 1179–1182.

Mishra, G., Ball, K., Arbuckle, J., Crawford, D. (2002). Dietary patterns of Australian adults and their association with socioeconomic status: results from the 1995 National Nutrition Survey. European J. Clin. Nutr., 56, 687–693.

Mitchell, L. (2004). U.S. and EU consumption comparisons. In: U.S.–EU Food and Agriculture Comparisons, M.A. Normile, S.E. Leetmaa (coordinators). Agriculture and Trade Report No. (WRS04-04) USDA/ERS, Washington, DC. Available online at: http://www.ers.usda.gov/publications/WRS0404/ Accessed 7 March 2007.

Molt, M. (2001). Food For Fifty, 11th edn. Prentice Hall, Upper Saddle River, NJ, USA.

Moskowitz, H.R., Krieger, B. (1995). The contribution of sensory liking to overall liking: An analysis of six food categories. Food Qual. Pref., 6, 83–90.

Olivas, G.I., Barbosa-Canovas, G.V. (2005). Edible coatings of fresh-cut fruits. Crit. Rev. Food Sci., 45, 657–670.

Oude Ophuis, P.M., Van Trijp, H.C.M. (1995). Perceived quality: A market driven and consumer oriented approach. Food Qual. Pref., 6, 177–183.

Ozcaglar-Toulouse, N., Shiu, E., Shaw, D. (2006). In search of fair trade: ethical consumer decision making in France. Int. J. Consum. Stud., 30(5), 502–514.

Palou, L., Jacas, J.-A., Marcilla, A., Alonso, M., del Río, M.A. (2008). Physico-chemical and sensory quality of "Clemenules" mandarins and survival of the Mediterranean fruit fly as affected by complementary cold and carbon-dioxide quarantine treatments. Postharvest Biol. Technol., 48, 443–450.

Pearson, T., Russell, J., Campbell, M.J., Barker, M.E. (2005). Do "food deserts" influence fruit and vegetable consumption? – a cross-sectional study. Appetite, 45, 195–197.

Péneau, S., Brockhoff, P.B., Escher, F., Nuessli, J. (2007). A comprehensive approach to evaluate the freshness of strawberries and carrots. Postharvest Biol. Technol., 45, 20–29.

Péneau, S., Hoehn, E., Roth, H.-R., Escher, F., Nuessli, J. (2006). Importance and consumer perception of freshness of apples. Food Qual. Pref., 17, 9–19.

Peri, C. (2006). The universe of food quality. Food Qual. Pref., 17, 3–8.

Poole, N.D., Martinez, L.M.-C., Giménz, F.V. (2007). Quality perceptions under evolving information conditions: Implications for diet, health and consumer satisfaction. Food Policy, 32, 175–188.

Rasmussen, M., Krølner, R., Klepp, K.-I., Lytle, L., Brug, J., Bere, E., Due, P. (2006). Determinants of fruit and vegetable consumption among children and adolescents: a review of the literature. Part 1: quantitative studies. Int. J. Behav. Nutr. Phys. Activity, 3, 22. doi:10.1186/1479-5868-3-22.

Reinaerts, E., de Nooijer, J., Candel, M., de Vries, N. (2007). Explaining school children's fruit and vegetable consumption: The contributions of availability, accessibility, exposure, parental consumption and habit in addition to psychosocial factors. Appetite, 48, 248–258.

Richards, T.J., Patterson, P.M. (2000). New varieties and the returns to commodity promotion: the case of Fuji apples. Agric. Res. Econ. Rev., 29, 10–23.

Ritson, C., Hutchins, R. (1991). The consumption revolution. In: 50 Years of the National Food Survey 1940–1990, Proceedings of the Symposium held in December 1990, J. Slater (ed.). MAFF. HMSO, London, UK.

Roininen, K., Fillion, L., Kilcast, D., Lähteenmäki, L. (2004). Exploring difficult textural properties of fruit and vegetables for the elderly in Finland and the United Kingdom. Food Qual Pref., 15, 517–530.

Saba, A., Messina, F. (2003). Attitudes towards organic foods and risk/benefit perception associated with pesticides. Food Qual. Pref., 14, 637–645.

Schifferstein, H.N.J., Oude Ophius, P.A.M. (1998). Health-related determinants of organic food consumption in the Netherlands. Food Qual. Pref., 9, 119–133.

Shimakawa, T., Sorlie, P., Carpenter, M.A., Dennis, B., Tell, G.S., Watson, R., Williams, O.D. (1994). Dietary intake patterns and sociodemographic factors in the atherosclerosis risk in communities study. Prev. Med., 23(6), 769–780.

Sloan, A.E. (2007). New shades of green. Food Technol., 12(7), 16.

Statistics Canada (2007). Food Available For Consumption in Canada – 2006: Highlights. Available online at: http://www.statcan.ca/english/ads/23F0001XCB/highlight.htm#2 Accessed 3 January 2008.

Steenkamp, J.-B.E.M. (1990). Conceptual model of the quality perception process. J. Bus. Res., 21, 309–333.

Stommel, J., Abbott, J.A., Saftner, R.A., Camp, M.J. (2005). Sensory and objective quality attributes of beta-carotene and lycopene-rich tomato fruit. J. Am. Soc. Hortic. Sci., 130(2), 244–251.

Stout, J., Huang, S.W., Calvin, L., Lucier, G., Perez, A., Pollack, S. (2004). NAFTA trade in fruits and vegetables, Chapter 5. In: Global Trade patterns in Fruit and Vegetables, Agriculture and Trade Report No. (W4S0406). ESDA ERS. Available online at: http://www.ers.usda.gov/publications/wrs0406/wrs0406f.pdf Accessed 1 March 2008.

Turrell, G., Blakely, T.A., Patterson, C., Oldenburg, P. (2004). A multilevel analysis of socioeconomic (small area) differences in household food purchasing behaviour. J. Epidemiol. Commun. H., 58, 208–215.

USDA ERS (2007). Food availability (per capita) data sets. Available online at: http://www.ers.usda.gov/Data/FoodConsumption/FoodAvailIndex.htm Accessed 7 March 2007.

von Alvensleben, R., Meier, T. (1990). The influence of origin and variety on consumer perception. Acta Hort., 259, 151–161.

Wells, H.F., Buzby, J.C. (2007). Fruit and vegetable availability up 20 percent since 1970. Amber Waves, USDA/ERS, May. Available online at: http://www.ers.usda.gov/AmberWaves/Scripts/print.asp?page=/May07SpecialIssue/Indicators/food_inthelongrun2.htm Accessed 20 December 2007.

WHO (2003). WHO fruit and vegetable promotion initiative. Report of the meeting, Geneva, 25–27 August 2003. Available online at: http://www.who.int/hpr/NPH/fruit_and_vegetables/fruit_and_vegetable_report.pdf Accessed 3 March 2008.

WHO (2004). Promoting fruit and vegetable consumption around the world. Global Strategy on Diet, Physical Activity and Health. Available online at: http://www.who.int/dietphysicalactivity/fruit/en/print.html Accessed 28 February 2008.

Wilatsana, P., Bhavani, S., Supatra, C. (2007). Consumer attitudes towards and willingness to pay for pesticide residue limit compliant "safe" vegetables in northeast Thailand. J. Int. Food Ag. Marketing, 19(1), 81–101.

Winkler, E., Turrell, G., Patterson, C. (2006). Does living in a disadvantaged area entail limited opportunities to purchase fresh fruit and vegetables in terms of price, availability, and variety? Findings from the Brisbane Food Study, Health Place, 12, 741–748.

Wismer, W.V., Harker, F.R., Gunson, F.A., Rossiter, K.L., Lau, K., Seal, A.G., Lowe, R.G., Beaton, R. (2005). Identifying flavor targets for fruit breeding: A kiwifruit example. Euphytica, 141, 93–104.

4

Testing and Measuring Consumer Acceptance

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I. Introduction

The view on fruit and vegetable quality has changed. In the past, each member of the supply chain of fresh produce focused on attaining acceptance by following the links within the chain. In practice, it largely required maintenance of quality standards (see Chapters 8 and 9). The rationale was to have defined criteria which could facilitate communication during shipment or distribution and, to some extent, allow product stability assessment. Thus, the quality of fresh horticultural produce was usually evaluated against standards for grading. These standards included product attributes which can be readily determined, and are related to color, appearance and absence of defects. In the past, breeders successfully developed cultivars with improved yields and attributes laid down in the specifications. Besides yield and grades, other targets were the hardiness and resistance of the plants, uniformity and extension of the season and in a few cases shelf life or suitability for processing. Consumers were thought to be satisfied with the grades, season extension and varied choices at prices they could

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afford. However, this proved not to be the whole truth (see Chapter 3). For instance, in the 1990s German consumers were dissatisfied with the poor flavor intensity of fresh tomatoes originating from the Netherlands. Subsequently, Dutch tomatoes experienced a sustained decline in sales of 30% in Germany (Behr and Illert, 2002).

Much of the attractiveness to consumers of products of this origin was lost during those years, because of the characteristics of the fruit which were perceived through the senses of consumers. Flavor intensity is part of the consumption experience and thus, perceivable only after purchase. Other important drivers of acceptance among consumers include intrinsic attributes, such as appearance, color, odor and texture. They can be more readily perceived, and help in the search for attractive products before the final selection and purchase. Both quality assessed from experience, and quality used during the search, can be evaluated by consumers directly by comparing their expectations with the information received from their sensorial perceptions (Grunert, 2005).

II. Experience and credence attributes

It is argued that the quality of a product is assessed by the consumers only using direct sensory impressions very rarely (Meiselman, 2007). And of course, there are other factors which cannot be ascertained even by experienced consumers. Most health-related properties and their effect on the human body can not be experienced, felt or validated by a consumer. Process-quality – increasingly important and well-recognized by many consumers – is, in most cases, undetectable as an intrinsic property. Not only do consumers fail to detect differences between the use or non-use of genetically modified techniques, regard or disregard for social or environmental standards, or whether produce is conventionally or organically grown, but often even sophisticated instrumentation can hardly authenticate organically grown produce (Banasiak et al., 2004). These credence attributes are important to many consumers, who are unable to experience them and must rely on others' statements. Consumers, therefore, use cues which they recognize at and around the product, and infer the credence attributes from these (Grunert, 2005). All properties which can be observed may serve this purpose, e.g. appearance, color, size, visible structure, firmness to the touch, packaging and the information on it. They may also be communicated at a retail outlet, or through media, including Internet pages or forums. In the case of fruit and vegetables, the place of origin is an important cue for inferring quality. This cue can be so strong that it surpasses actual sensory perception, for instance, in the case of nationally or organically produced tomatoes over imported ones, although all three may be intrinsically the same, but differently labeled (Ekelund et al., 2007). Important cues can also be brands or product concepts, although these are more often associated with processed products.

Not only prior to, but also after purchase credence attributes will be perceived and may still influence the perceived quality of the product, which may fade with time. Especially in the case of repeated purchase and consumption, personal experience becomes more important than the indirectly assessed credence qualities. This gradual loss of quality dimensions may become a disadvantage, especially for products where a high proportion of extrinsic, credence quality is involved (e.g. functional foods).

The producer only partly controls the perception of credence attributes, as well as the perception of experience attributes. Situational variables change during transport, storage, preparation and consumption. Learning how to handle produce can stabilize or improve the experience of quality and therefore, information on maturity, storage conditions and preparation methods is helpful.

A comprehensive discussion of the influences on consumer acceptance can be found in the recent book by Meiselman (Meiselman, 2007). The relevant chapter contains a review of many models of food acceptance, with different emphases within the three classes of variables of eating research:

- food variables: palatability, appearance and flavor (Harper, 1981; Land, 1983; Cardello, 1996; Tuorila, 2007);
- people variables: responsiveness to food cues, restrained eating, expectations, human focused (Connors et al., 2001), human-product linked (Cardello, 1994; Krystallis, 2007); and
- environmental variables: physical, social context and economic factors (Marshall, 1995).

III. Acceptance

Depending on the inclusion of variables from one or more of the above classes (i.e. food, people or environment) acceptance can be understood in another way. The focus on food variables alone leads to the conclusion that food products are acceptable (1) when their attributes are acceptable. Including the people variables, food becomes acceptable (2) only when attributes and food cues meet responsive minds and match expectations. Finally, when environmental variables also are taken into account, acceptability (3) means an attractive product – in terms of (2) – is selected only in a favorable physical, social and economic situation or circumstance. The separation of effects into three classes, of course, is an idealization. Acceptance of attributes, for instance, depends not only on the attributes, but also on people factors. However, when consumers are considered as individuals the influence of product attributes triggers acceptance.

The classical definition (Amerine et al., 1965) reflects the two opposite scenarios: "actual utilization (purchase or eating)" by consumers and "experience or feature of experience, characterized by a positive attitude toward the food." The first states that for assessment of acceptance, knowledge of the product variables, personal variables, the situational variables and even the outcome of trade-offs between perceived quality and perceived price (Grunert, 2005) has been reached. The second refers to an experience, gained directly from the sensory interaction of consumer and product.

This interaction is the central focus of sensory acceptance tests. The investigator is interested in "whether the consumer likes the product, prefers it over another product, or finds the product acceptable based on its sensory characteristics" (Lawless and Heymann, 1998). Food acceptance is treated as a "perceptual/evaluative construct" (Cardello, 1996). It is a "phenomenological experience, best categorized as a feeling, emotion or mood with a defining pleasant or unpleasant character" (Cardello, 1996). Cardello adds two ways to measure acceptance. Self- or verbal-reports are used where a phenomenological approach prevails, whereas choice and consumption are observed when the focus is on the consequences of acceptance. Data from observed behavior can be collected electronically or through personal observation. Self-reporting includes group or face-to-face interviews, telephone interviews or mailed questionnaires (Fletcher et al., 1993).

IV. Qualitative tests

Qualitative tests often measure the subjective responses of a consumer sample to the sensory properties of a product. Consumers talk about their feelings in a small group setting or interview (Meilgaard et al., 1991). The initial response to a new concept, the general acceptance of a prototype, or information on other obvious problems is obtained and allows for project readjustment. Because of the personal interaction the consumer's terminology can be studied and consumer-oriented terms can be learned for use in questionnaires and advertisements. Another advantage is to learn about reasons for and practices of consumer behavior regarding product use, which could facilitate handling, etc. For fruit and vegetables, this is not only limited to innovation in package convenience, but also to new mix, size and properties of the produce for use in cooking.

Usually, an interviewer or moderator with skills in group dynamics, probing techniques, summarizing and reporting, meets a group of 10–12 persons (focus group). Group members are selected on the basis of product usage and sociodemographics, and they participate in two or three sessions, each for one to two hours. The subject of interest is presented, and the discussion facilitates obtaining as much information as possible. If the group meets on a regular basis, for instance to use a product at home between sessions, it is called a focus panel. If additional (or sensitive) information is sought from each individual, one-on-one consumer interviews are appropriate. Such interviews may be conducted at the interviewer's site or in consumer's homes. In some cases, observation of the consumer's product preparation, etc., yields very different information from the consumer's verbal statements (Meilgaard et al., 1991).

V. Quantitative tests

There are two approaches to quantitative consumer acceptance testing: tests that rely on choice or on rating. Relative preference is determined using the first method.

VI. Testing preference

Preference, classically used for testing in the food industry, can be defined in three ways (Amerine et al., 1965):

1. expression of a higher degree of preference;
2. choice of one object over others; and
3. basis of choice, psychological continuum of affectivity (pleasantness/unpleasantness).

However, preference tests are usually designed to measure the appeal of one food or food product over another (Stone and Sidel, 1993). The panellists receive two coded samples (usually simultaneously), and their task is to answer the question: “which sample do you prefer or like better?” (Meilgaard et al., 1991). The task is rather intuitive and can be performed easily even by semi- or illiterate consumers (Coetzee and Taylor, 1996).

It is usually recommended that the consumer must choose one product over the other (Stone and Sidel, 1985). Such a choice makes for easier interpretation (because tests rely on a binominal distribution), and enables the use of all answers. If a preference decision is not given, the researcher has to decide either to ignore or to split those answers 50:50, or to split them in proportion to other answers. Another possibility for large consumer numbers (>100) is to calculate confidence intervals based on multinominal distribution. With non-overlapping confidence intervals of respondents expressing a preference, and a small number of no preference answers, the significance level can be identified. Details of relevant procedures can be found in the literature (Lawless and Heymann, 1998; Moskowitz et al., 2006b).

Special cases of preference testing are repeated pair-wise preference tests and sequential preference ranking of a series of samples. The aim of both methods is to obtain information on the relative preference for an array of products. It is again an intuitive task for consumers to rank products according to their preference for visual, tactile and pronounced taste or flavor perception, but complex multi-flavor or taste samples can become stressful. A sequence of increased acceptance can be calculated not only from ranking, but also from the results of repeated pair-wise comparisons. In both cases, received data are ordinal and thus the absolute degree of liking and the relative distance of successive samples cannot be quantified. The reported liking is only relative between the samples and inherent to the presented set of samples.

These tests are less frequently used than measuring acceptance with fruit and vegetables. This is probably because the typical case is not comparing one cultivar, cultivation technique or maturity stage to another, but comparing a range of influences on the resulting quality. In very few cases only a single property may be changed, but physiological processes lead to a multitude of altered texture, taste, aroma or flavor attributes. To be able to explain differences in acceptance therefore, a larger data set which gives quantitative information on acceptance is necessary. There are cases where testing whether, for example, the use of a chemical or distinct postharvest alternatives have a positive or negative effect on preference. Here preference testing is most efficient (Harker et al., 2008).

VII. Testing acceptance

Most hedonic testing of fruit and vegetables is done using acceptance tests. Here panellists work as a measuring instrument not to measure products, but to quantify their own affective reaction which the sample evokes. Except in preference testing, acceptance tests can be performed using only one sample, but usually 10 or 12 samples are tested.

The samples are coded with a three to four digit number and are usually presented one after the other (monadic). The sequence of samples differs from panellist to panellist, because the constant position as an earlier or later presented sample will bias the results. The possible number of samples depends, as well as the type of samples and the composition of the panel, on the number and type of questions posed. The central question is "how much do you like the product?" or "how acceptable is the product?" (Meilgaard et al., 1991). However, detailed information on the acceptance of several attributes is often required, and can be included in the protocol. Additional questions ask consumers how much they like the appearance, aroma, flavor, texture or after-taste, or even more specific attributes such as color, sweetness or crunchiness. Answers allow responses as to whether, for example, the sweetness is not liked because the product is too sweet or not sweet enough. Therefore, just-about-right questions (JAR) are used where respondents have to rate whether the level of the sensory attribute is "too low," "just right" or "too high." Although the rating is also done on a hedonic scale, it forces panellists to form a fairly analytical judgement and is found to influence results (Popper et al., 2004). An even more analytical approach is required when, instead of hedonic questions, attribute intensity questions are included, but this is generally not recommended (Stone and Sidel, 1993). Again the more integrative, hedonic and naive (an approach not used by a specialist) approach is disturbed by a specific, analytical task. Another important reason for not recommending hedonic and analytic tasks in one test is the varying selection criteria for participants of hedonic and analytic tests. Panellists of acceptance tests are chosen to represent a target population. They are users of the product in question, but should be naive users not professionals in food issues. Discussion about the use of employees for in-company product testing can be found in Lawless and Heymann (1998). Other requirements are demographic characteristics, such as age or gender distribution, again with respect to the target population. In contrast, analytical testers are selected after successfully passing standardized tests for olfactory, taste and color sensibilities, as well as memory, verbal abilities and creativity. They do not need to be members of a target population (Stone and Sidel, 1993; Lawless and Heymann, 1998).

VIII. Scales

Information is obtained from assigned words, numbers or scale positions marked by a panellist. There has been much discussion about the best scale (Moskowitz et al., 2006b). Important points are the number and type of statements, the relative difference between single statements or a more-or-less unstructured line scale. Very often a nine-point hedonic scale is used. It consists of four, presumably equally spaced, categories for liking, a neutral point and four corresponding categories for disliking (e.g. dislike extremely, dislike very much, dislike moderately, dislike slightly, neither like nor dislike, like slightly, like moderately, like very much and like extremely). This scale has been suggested by Peryam and Pilgrim (Peryam and Pilgrim, 1957), and has been validated and successfully used (Stone and Sidel, 1993). It contains no additional information on possible consequences of the degree of liking or disliking, as for instance is found in the food action rating scale (FACT) suggested by Schutz

(Schutz, 1965). For testing children, an alternative scale has been developed which uses fewer points and displaces verbal statements with facial symbols for different degrees of liking (Chen et al., 1996). Data derived from the scales are ordinal, but results from unstructured line scales may be regarded as quantitative numerically, especially in tests with many panelists.

IX. Extracting information

Acceptance data are usually obtained from observations of consumer behavior (with all the interference of environmental factors) or the reporting of panelists, transferring their perceptions into words or numbers. To come even closer to the processes of sensation and perception, physiologists study the explanations how signals from food molecules are processed and transduced from receptor cells to the brain (Margolskee, 2004). An emerging field of new insights into the processing of signals in the brain offers functional magnetic resonance imaging (FMRI). The activity of brain areas in response to food (thinking of, smelling or eating) can be depicted and located, and assigned to those areas responsible for activity or emotions. The nature of this research is very fundamental and mostly qualitative, but may help to explain complex phenomena of perception, integration and hedonic consequences in the future (Kettenmann et al., 2005; Small and Prescott, 2005; Rolls, 2006).

X. Test sites

A sensory laboratory offers the best control over the preparation and handling of the samples, as well as control of environmental factors during the sessions. Light can be used to mask, for example, sample color differences or, most often, standardized light spectra can be utilized. Data entry can easily be computerized. Panellists work in screened booths, protected from influence from the surroundings, which could possibly draw attention away from the sample testing. A disadvantage is that the situation differs from normal product use in the home. The amount of food may be smaller in the unfamiliar laboratory situation than during in-home use, and the time the consumer is exposed to the product is shorter in the laboratory, where the focus is strongly on working off the testing sequence. Therefore, the repeated presentation of the same product may be used to investigate acceptance changes with time, which can decrease for some products when satiety begins. A detailed discussion of advantages and disadvantages can be found in Moskowitz et al. (2006).

Other often-used test sites are central locations, such as shopping centers or similar publicly-accessible locations. The advantage of this is the large number of subjects who can be selected and approached. The disadvantage is the limited control of the test conditions, sample preparation and handling. For fruit and vegetable testing, with limited preparation effort, it can be a feasible alternative. For improved testing facilities mobile sensory/chemical units have been used (Moskowitz et al., 2006b). Even more closely resembling actual consumption situations are home use tests (HUT), with the advantage of a natural, unbiased setting. Under these conditions information on the performance of products during preparation can also be collected by completion of a questionnaire. Testing of complex foods, whole meals and products with a high proportion of extrinsic or credence attributes takes advantage of the familiar social context. Fruit and vegetables have seldom been tested using home use tests.

XI. Consumer segments

As a good sensory practice for acceptance tests, a group of around 30 panelists is viewed as a minimum group size for testing (Moskowitz, 1997). If separation of different groups of the population is intended, e.g. income groups, or urban versus rural, a larger group is recommended. A large number of panelists are necessary, because consumers are individuals and differ from each other in what they regard as acceptable. The variability among consumers has long been recognized (Pangborn, 1981) and it has often been tried to relate it to sociodemographic background, but this has usually failed (Moskowitz et al., 2006a). The differences between single consumers can be even greater than the differences detected between consumers of European countries, as shown in the case of coffee (Moskowitz et al., 2006a). Addressing a target population also means analyzing consumer panelists' data for underlying preference segments, but this has rarely been applied in the area of fruit and vegetable studies.

Differences in the sweetness preferences among European grapefruit consumers have been found (Rozenbaum, 1989), sweet, hard apples or juicy, acidic apples were preferred by different consumer segments (Daillant Spinnler et al., 1996), similar segments were identified for peaches and mangoes (Malundo, 1996), preferences for levels of sugars and acids differed in table grapes (Crisosto and Crisosto, 2002), kiwifruit consumers were segmented into those who liked a new yellow-fleshed, sweet and fruity flavored cultivar or those preferring the familiar green-fleshed and sweet-tart tasting kiwifruit (Jaeger et al., 2003b). Despite a general liking for juicy and sweet pears, "ideal" color and shape was different among consumers (Jaeger et al., 2003a). Tomato consumer segments were identified (Brückner, 2000; Pagliarini et al., 2001) on the basis of the preference for red color and sweetness, acidity and texture, with at least two groups preferring fruit at different stages of ripening (Watada and Aulenbach, 1979). Among broccoli and cauliflower consumers, a small niche segment (22% of consumers) appreciating bitter and pungent notes was identified, while the majority of consumers preferred lower intensities of bitter and pungent notes, but liked sweet (33% of consumers) or crisp (44% of consumers) attributes (Bruckner et al., 2005).

There are also examples where produce details, such as cultivar, presence of a label, price and presentation (in several tray types or loose), were varied to optimize acceptance by segments of domestic and international markets (Mora et al., 2006). This research was done using conjoint analysis. Rather than measuring the acceptance of the product features alone, the contributory values of the features within this complex mix is determined through systematic variation (Moskowitz, 2005). If the inherent segmentation among consumers is neglected, differences are averaged and only a weak hedonic reaction of the panelists will be found, if any.

One possibility is to separate panelists into subgroups based on the preference or not for selected attributes of one or a few products (MacFie and Thomson, 1988), or on the pattern of preferences for the whole set of products (Moskowitz et al., 2006a). To level out individual differences in scale usage, usually the ratings of one subject are standardized (i.e. set to zero, standard deviation set to one), and a cluster analysis of the data will identify similar subjects, based on the way they scored for liking of the products or product attributes (if attribute liking was one of the questions). Another alternative is the possibility of internal and external preference mapping (Greenhoff and MacFie, 1994). In both methods individuals are identified on the basis of their preferences only (internal preference mapping) or combined with non-preference data (external preference mapping).

Overviews of consumer acceptance data analysis have been published recently, (see MacFie, 2007; Moskowitz, 2006).

XII. The necessity for acceptance testing

Four primary areas for the need to conduct acceptance tests were defined by Meilgaard et al. (1991):

- product maintenance;
- product improvement/optimization;
- development of new products;
- assessment of market potential.

One of the major reasons for recommending implementation of consumer acceptance tests is the fact that many newly launched products fail in the marketplace if they are not properly tested (MacFie, 2007). At first glance, a new product launch seems to be atypical for the fresh fruit and vegetable sector, but new varieties of exotic fruit and vegetables, new sizes, mixtures or convenience properties are being developed. Consumer needs are changing over time, influenced by demographic, socioeconomic and cultural change, leading to trends such as increased average age, smaller households, individualization and reduced willingness (and necessity) to spend time and effort preparing food. Retail chains now compete globally and have to attract increasingly sophisticated consumers. Large proportions of total food sales, e.g. in the US, are reported to consist of products introduced only recently (van Trijp and Steenkamp, 2005). New fruit and vegetable products often require advanced technology to maintain or sometimes even improve quality during storage, transport and processing, such as use of chemicals to affect ripening; storage and shipment techniques like ultra low oxygen (ULO) or dynamic controlled atmosphere (CA); modified atmosphere packaging (MAP) or new packaging materials; processing (e.g. for fresh-cut); high pressure treatments; or additives for microbial control. Besides prolonging shelf life, all of these technologies can affect attributes relevant to acceptance. To measure those changes instrumentally can be very difficult, if not impossible, as we have seen in experiments with peeled asparagus, where unsuitable packaging led to reduced consumer acceptance because of weak off-odors (Brueckner, 2004).

Recently, the top ten trends in food retailing have been identified as:

- multi-channel shopping;
- retailers as restaurateurs (food service);
- lifestyle stores and emerging formats;
- thinking small (in terms of store size);
- store brand-building;
- focusing on fresh and natural/organic produce;
- health and wellness;
- going green;
- tapping ethnic markets; and
- in-store media (Anonymous, 2008).

Almost all of these trends will include the need to develop fruit and vegetable products, and consumer acceptance will be a prerequisite.

Bibliography

Amerine, M.A., Pangborn, R.M., Roessler, E.B. (1965). Principles of sensory evaluation of food. Academic Press, New York, NY, USA.

Anonymous (2008). The future of retailing in the US. Packaged Facts, Rockville Pike, MD, USA.

Banasiak, U., Becker, B., Beer, H., Bergthaller, W., Betschke, T., Boess, C., Bognàr, A., Brückner, B. et al. Bewertung von Lebensmitteln verschiedener Produktionsverfahren-Statusbericht. Tauscher, B., Brack, G., Flachowsky, G., Henning, M., Köpke, U., Meier-Ploeger, A., Münzing, K., Niggli, U., Pabst, K., Rahmann, G., Willhöft, C., and Mayer-Miebach, E. 2004. Landwirtschaftsverlag GmbH, Münster Hiltrup. Schriftenreihe des Ministeriums für Verbraucherschutz, Ernährung und Landwirtschaft. Reihe A: Angewandte Wissenschaft.

Behr, H.C., Illert, S. (2002). ZMP-Bilanz Gemüse, Zentrale Markt- und Preisberichtstelle für Erzeugnisse der Land-, Forst- und Ernährungswirtschaft GmbH, Bonn, 1995–2002.

Brueckner, B. (2000). Acceptability of tomatoes defined by sensory attributes and consumer segments. In: Integrated View of Fruit and Vegetable Quality, W.J. Florkowski, R.L. Shewfelt, S.E. Prussia (eds). Technomic Publishing, Lancaster, PA, USA, pp. 229–240.

Brueckner, B., Schonhof, I., Kornelson, C., Schrodter, R. (2005). Multivariate sensory profile of broccoli and cauliflower and consumer preference. Italian Journal of Food Science, 17, 17–32.

Brueckner, B. (2004). Welche Verpackungsmaterialien bei ungeschältem und geschältem Spargel? Spargel&Erdbeerprofi, 6(2), 16–17.

Cardello, A.V. (1994). Consumer expectations and their role in food acceptance. In: Measurement of food preferences, H.J.H. MacFie, D.M.H. Thomson (eds). Blackie Academic and Professional, London, UK, pp. 253–298.

Cardello, A.V. (1996). The role of human senses in food acceptance. In: Food choice, acceptance and consumption, H.L. Meiselman, H.J.H. MacFie (eds). Blackie Academic and Professional, London, UK, pp. 1–82.

Chen, A.W., Resurreccion, A.V.A., Paguio, L.P. (1996). Age appropriate hedonic scales to measure food preferences of young children. Journal of Sensory Studies, 11, 141–163.

Coetzee, H., Taylor, J.R.N. (1996). The use and adaptation of the paired-comparison method in the sensory evaluation of hamburger-type patties by illiterate/semi-literate consumers. Food Quality and Preference, 7, 81–85.

Connors, M., Bisogni, C.A., Sobal, J., Devine, C.M. (2001). Managing values in personal food systems. Appetite, 36, 189–200.

Crisosto, C.H., Crisosto, G.M. (2002). Understanding American and Chinese consumer acceptance of "Redglobe" table grapes. Postharvest Biology and Technology, 24, 155–162.

DaillantSpinnler, B., MacFie, H.J.H., Beyts, P.K., Hedderley, D. (1996). Relationships between perceived sensory properties and major preference directions of 12 varieties of apples from the southern hemisphere. Food Quality and Preference, 7, 113–126.

Ekelund, L., Fernqvist, F., Tjarnemo, H. (2007). Consumer preferences for domestic and organically labelled vegetables in Sweden. Acta Agriculturae Scandinavica, Section C, Food Economics, 4.

Fletcher, S.M., Resurreccion, A.V.A., Misra, S.K. (1993). Measuring and modeling consumer acceptance. In: Postharvest handling – a systems approach, R.L. Shewfelt, S.E. Prussia (eds). Academic Press, San Diego, CA, USA, pp. 149–166.

Greenhoff, K., MacFie, H.J.H. (1994). Preference mapping in practice. In: Measurement of food preferences, H.J.H. MacFie, D.M.H. Thomson (eds). Chapman & Hall, Glasgow, pp. 137–166.

Grunert, K.G. (2005). Consumer behaviour with regard to food innovations: quality perception and decision making. In: Innovation in agri-food systems, W.M.F. Jongen, M.T.G. Meulenberg (eds). Wageningen Academic Publishers, Wageningen, The Netherlands, pp. 57–85.

Harker, F.R., Amos, R.L., White, A., Petley, M.B., Wohlers, M. (2008). Flavor differences in heterogeneous foods can be detected using repeated measures of consumer preferences. Journal of Sensory Studies, 23, 52–64.

Harper, R. (1981). The nature and importance of individual differences. In: Criteria of food acceptance: how man chooses what he eats, J. Solms, R.L. Hall (eds). Forester, Zürich, Switzerland, pp. 220–237.

Jaeger, S.R., Lund, C.M., Lau, K., Harker, F.R. (2003a). In search of the "ideal" pear (pyrus spp.): Results of a multidisciplinary exploration. Journal of Food Science, 68, 1108–1117.

Jaeger, S.R., Rossiter, K.L., Wismer, W.V., Harker, F.R. (2003b). Consumer-driven product development in the kiwifruit industry. Food Quality and Preference, 14, 187–198.

Kettenmann, B., Mueller, C., Wille, C., Kobal, G. (2005). Odor and taste interaction on brain responses in humans. Chemical Senses, 30, I234–I235.

Krystallis, A. (2007). Using means-end chains to understand consumers' knowledge structures. In: Consumer-led food product development, H.J.H. MacFie (ed.). Woodhead Publishing, Cambridge, UK, pp. 158–196.

Land, D.G. (1983). What is sensory quality?. In: Sensory quality in food and beverages: definition, measurement and control, A.A. Williams, R.K. Atkin (eds). Ellis Horwood, Chichester, UK, pp. 15–29.

Lawless, H.T., Heymann, H. (1998). Acceptance and preference testing. In: Sensory evaluation of food – principles and practices, H.T. Lawless, H. Heymann (eds). pp. 430–479.

MacFie, H.J.H. (2007). Consumer-led food product development. Woodhead Publishing, Cambridge, UK.

MacFie, H.J.H., Thomson, D.M.H. (1988). Preference mapping and multidimensional scaling. In: Sensory Analysis of Foods, Pigott (ed.). Elsevier, New York, NY, USA.

Malundo, T.M.M. (1996). Application of the quality enhancement (QE) approach to mango (*Magnifera indica* L.) flavour research. Thesis/Dissertation. University of Georgia, GA, USA.

Margolskee, R.F. (2004). Insights into taste transduction and coding from molecular, biochemical, and transgenic studies. Amer Chemical Soc., Washington, DC, USA, P. 44.

Marshall, D. (1995). Introduction: food choice, the food consumer and food provisioning. In: Food choice and the consumer, D. Marshall (ed.). Blackie Academic and Professional, Glasgow, pp. 3–17.

Meilgaard, M., Civille, G.E., Carr, T. (1991). Sensory evaluation techniques. CRC Press LLC.

Meiselman, H.L. (2007). Integrating consumer responses to food products. In: Consumer-led food product development, H.J.H. MacFie (ed.). Woodhead Publishing, Cambridge, UK, pp. 3–33.

Mora, M., Espinoza, J.A., Mino, R. (2006). Segments determination of fresh peaches consumers through the conjoint analysis: An approximation to the Chilean market. Proceedings of the VIth International Peach Symposium, pp. 521–525.

Moskowitz, H.R. (1997). Base size in product testing: A psychophysical viewpoint and analysis. Food Quality and Preference, 8, 24–255.

Moskowitz, H.R. (2005). Systematic variation of concept elements and the conjoint-analysis approach. In: Concept research in food product design and development, H.R. Moskowitz, S. Porretta, M. Silcher (eds). Blackwell Publishing, Ames, IA, USA, pp. 77–104.

Moskowitz, H.R. (2006). Sensory and consumer research in food product design and development. Blackwell Publishing, Ames, IA, USA.

Moskowitz, H.R., Beckley, J.H., Resurreccion, A.V.A. (2006a). High level product assessment. In: Sensory and consumer research in food product design and development, H.R. Moskowitz, J.H. Beckley, A.V.A. Resurreccion (eds). Blackwell Publishing, Ames, IA, USA, pp. 159–199.

Moskowitz, H.R., Beckley, J.H., Resurreccion, A.V.A. (2006b). What types of sensory tests do sensory researchers do?. In: Sensory and consumer research in food product design and development, H.R. Moskowitz, J.H. Beckley, A.V.A. Resurreccion (eds). Blackwell Publishing, Ames, IA, USA, pp. 219–293.

Pagliarini, E., Monteleone, E., Ratti, S. (2001). Sensory profile of eight tomato cultivars (Lycopersicon esculentum) and its relationship to consumer preference. Italian Journal of Food Science, 13, 285–296.

Pangborn, R. (1981). Individuality in responses to sensory stimuli. In: Criteria of Food Acceptance, J. Solms, R.L. Hall (eds). Forster Verlag AG, Zürich, Switzerland, pp. 177–217.

Peryam, D.R., Pilgrim, F.J. (1957). Advanced taste test method. Food Technology, 11, 9–14.

Popper, R., Rosenstock, W., Schraidt, M., Kroll, B.J. (2004). The effect of attribute questions on overall liking ratings. Food Quality and Preference, 15, 853–858.

Rolls, E.T. (2006). Brain mechanisms underlying flavour and appetite. Philosophical Transactions of the Royal Society B-Biological Sciences, 361, 1123–1136.

Rozenbaum, J. (1989). Consumer acceptance of a new brand of selected sweeter grapefruits. Citriculture. Proceedings of the Sixth International Citrus Congress, Middle East, March 6–11, 1988. Volume 4: economics, marketing and commercial trends; processing. Tel Aviv, Israel, pp. 1645–1650.

Schutz, H.G. (1965). A food action rating scale for measuring food acceptance. Journal of Food Science, 30, 365–374.

Small, D.M., Prescott, J. (2005). Odor/taste integration and the perception of flavor. Experimental Brain Research, 166, 345–357.

Stone, H., Sidel, J.L. (1985). Sensory evaluation practices. Academic Press, San Diego, CA, USA.

Stone, H., Sidel, J.L. (1993). Sensory evaluation practices. Academic Press, San Diego, CA, USA.

Tuorila, H. (2007). Sensory perceptions as a basis of food acceptance and consumption. In: Consumer-led food product development, H.J.H. MacFie (ed.). Woodhead Publishing, Cambridge, UK, pp. 34–65.

van Trijp, H.C.M., Steenkamp, J.E.B.M. (2005). Consumer-oriented new product development: principles and practice. In: Innovation in agri-food systems. Product quality and consumer acceptance, W.M.F. Jongen, M.T.G. Meulenberg (eds). Wageningen Academic Publishers, Wageningen, The Netherlands, pp. 87–124.

Watada, A.E., Aulenbach, B.B. (1979). Chemical and sensory quality of fresh market tomatoes. Journal of Food Science, 44, 1013–1016.

5

Nutritional Quality of Fruits and Vegetables

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I. Introduction

Horticultural crops are some of the main components of a healthy diet. The constituents obtained by the human body from fruits and vegetables include water, carbohydrates, fats, proteins, fiber, minerals, organic acids, pigments, vitamins and antioxidants, among others. Fruits and vegetables, especially, are a good source of fiber, selected minerals, vitamins and antioxidants. Most fruits and vegetables are available almost year-round in a wide variety and they not only taste good, but they also have favorable attributes of texture, color, flavor and ease of use. They can be fresh, cooked, hot or cold, canned, pickled, frozen or dried.

Fruits and vegetables are consumed at all times, and due to their convenient size; they are an excellent between-meal snack. They are relatively low in calories and fat (avocado and olives being the exceptions), they have no cholesterol, they are rich in carbohydrates and fiber, they contain vitamin C and carotene, and some are a good source of vitamin B_6. Fruits and vegetables are relatively low in sodium and high in potassium. Ascorbic acid in fruits and vegetables enhances the bioavailability of iron in the diet. Because of all these characteristics, fruits and vegetables have a unique role in a healthy diet. A growing body of research has shown that fruit and vegetable consumption is associated with reduced risk of major diseases, and possibly delayed onset of age-related disorders, promoting good health. However, in many cases fruit and vegetable consumption is still below the dietary guideline goal of consuming 5–10 servings each day. The nutritional value of fruits and vegetables depends on their composition, which shows a wide range of variation depending on the species, cultivar and maturity stage. The composition of fruits and vegetables includes a great number of metabolites however, it could be predicted that no single commodity might be rich in all these constituents. This chapter describes the general characteristics of the components of fruits and vegetables, related to their benefits as food sources.

II. Traditional components

A. Water

The most abundant single component of fruits and vegetables is water, which may account for up to 90% of the total mass. The maximum water content varies between individual fruits and vegetables, because of structural differences. Cultivation conditions that influence structural differentiation may also have a marked affect.

B. Organic acids

There are two types of acids, namely aliphatic (straight chain) and aromatic acids. The most abundant acids in fruits and vegetables are citric and malic (both aliphatic) acids. However, large amounts of tartaric acid occur in grapes. Malic acid is the major component in oranges and apples. The acid content of fruits and vegetables generally decreases during maturation. For example, the citric acid content of clingstone peaches decreases faster than the malic acid content, while the malic acid content of apples and pears decreases faster than the citric acid content. Aromatic organic acids occur in several fruits and vegetables, but in very low concentrations. Benzoic acid occurs in cranberries, quinic acid in bananas and chlorogenic acid in potatoes. Organic acids play an important role in the sugar to acid ratio, which affects the flavor of fruits and vegetables. The distribution of acids within a fruit is not uniform.

C. Proteins

Proteins represent less than 1% of the fresh mass of fruit and vegetable tissues. Leguminous seeds are rich in protein, containing 15% to 30%. The proteins of fruits and vegetables are built from amino acids, but other related simple nitrogenous compounds also occur. Fruits, vegetables and legumes account for 1.2%, 5.5% and 6.1%, respectively, of the protein in the US food supply (Hiza and Bente, 2007). Fruits are low in proteins, but tree nuts are a good source of high-quality proteins. The protein content of fresh fruits or vegetables is calculated by multiplying the total nitrogen content by a factor of 6.25. This calculation uses the fact that protein is comprised of about 16% nitrogen, and the assumption that all nitrogen present is protein. The conversion ignores the fact that appreciable amounts of simple nitrogenous substances can be present in an uncombined form. In potatoes, 50% to 60% of the nitrogen occurs in the form of simple soluble constituents, while in apples the estimates range from 10% to 70% (Salunkhe et al., 1991). Senescent tissues, such as those of overripe fruits, usually contain especially high proportions of non-protein nitrogen. Asparagine is abundant in potatoes and apples as non-protein nitrogen fractions. Pears and oranges are rich in proline, and black and red currants in alanine.

D. Lipids and fatty acids

Plant lipids represent a very broad group of compounds with functions that vary among products. Lipids are an energy source for plants during germination, forming components of cellular membranes and cuticular waxes, and they are mainly present as triglycerides (esters of glycerol and three fatty acids) or phospholipids (in which one fatty acid has been replaced by a phosphate group). Generally, most postharvest products are relatively low in total lipids, except for avocados, olives and many seeds. The fat content of fruits and vegetables is usually below 1% and varies with the product. Examples of fat content on a dry mass basis are:

- avocado: 35–70%;
- olive: 30–70%;
- grape: 0.2%;
- banana: 0.1%; and
- apple: 0.06%.

Many of the physical and chemical properties of lipids are due to the fatty acids present in their structure. Fatty acids are aliphatic monocarboxylic acids that may be saturated or unsaturated to varying degrees. Saturated fatty acids do not contain any double bonds along the chain. Monounsaturated fatty acids have a single double bond in the hydrocarbon chain, and polyunsaturated fatty acids have more than one double bond. Fatty acids in plants usually range from 4- to 26-carbons in size, but oleic acid (18:1) and linoleic acid (18:2) are the most prevalent in nature. Olive oil and other fats high in monounsaturated fatty acids are becoming well-known for helping to lower LDL-cholesterol (the so-called "bad" cholesterol), while protecting HDL-cholesterol ("good" cholesterol) when consumed in moderation in place of saturated fats. The difference among oils is not in their caloric content, but in their composition. Fats derived from animal sources (e.g. butter, cream, hard cheeses) have a high proportion of saturated fats, while oils from plant sources, such as olive and canola, have the lowest (Table 5.1).

Fatty acids are necessary for human bodily functions, where they are used primarily to produce hormone-like substances that regulate a wide range of functions including blood pressure, blood clotting, blood lipid levels, the immune response and the inflammatory response. The human body can produce most fatty acids, except for linoleic acid and α-linolenic acid, which are widely distributed in plant oils. These essential fatty acids are polyunsaturated fatty acid members of the omega-6 and omega-3 fatty acid series.

Each double bond, depending on its geometry, can be in either a *cis* or a *trans* conformation. In *cis* bonds, the two carbons next to the unsaturated site bond atoms are oriented to the same side. Therefore, in restricted environments, such as when fatty acids are part of a phospholipid in a lipid bilayer or triglycerides in lipid droplets, *cis* bonds limit the ability of fatty acids to be closely packed and therefore, could affect the melting temperature of the membrane or the fat. A *trans* configuration, by contrast, means that the two carbons next to the double bond are oriented to opposite sides. As a result, they do not cause the chain to bend much, and their shape is

Table 5.1 Fatty acid, vitamin E and cholesterol composition of some common dietary fats

	Saturated (%)	Monounsaturated (%)	Polyunsaturated (%)	Cholesterol (mg 100 g^{-1})
		Animal fats		
Lard	40.8	43.8	9.6	93
Butter	54.0	19.8	2.6	230
		Vegetable fats		
Coconut oil	85.2	6.6	1.7	0
Palm oil	45.3	41.6	8.3	0
Cottonseed oil	25.5	21.3	48.1	0
Wheat germ oil	18.8	15.9	60.7	0
Soya oil	14.5	23.2	56.5	0
Olive oil	14.0	69.7	11.2	0
Corn oil	12.7	24.7	57.8	0
Sunflower oil	11.9	20.2	63.0	0
Safflower oil	10.2	12.6	72.1	0
Canola oil	5.3	64.3	24.8	0

Source: Kays, S.J. 1997.

similar to straight saturated fatty acids. In plant sources, unsaturated fatty acids naturally occur in the *cis* form. *Trans* fatty acids might be present in some fats of animal origin, or might be the result of oil processing (e.g. hydrogenation of vegetable oils). The differences in geometry between the various types of unsaturated fatty acids, as well as between saturated and unsaturated fatty acids, play an important role in biological processes and in the construction of biological structures (such as cell membranes). Medical research suggests that amounts of *trans* fats correlate with circulatory diseases, such as atherosclerosis and coronary heart disease, more than the same amount of non-*trans* fats, for reasons that are not yet completely understood.

E. Metabolizable carbohydrates

After water, carbohydrates are the most abundant constituents in fruits and vegetables, representing 50% to 80% of the total dry weight. Carbohydrate functions include, among others, the storage of energy reserves and the make-up of much of the structural framework of cells. Simple carbohydrates, which are also the immediate products of photosynthesis, are important components of sensorial quality attributes. Carbohydrates, like proteins, yield $4\,kcal\,g^{-1}$, while fats yield $9\,kcal\,g^{-1}$. In many products, monosaccharides comprise a major portion of the total sugars. Glucose and fructose are the predominant forms of simple sugars found, especially, in fruits. Sucrose, the primary transport form of carbohydrate in most plants, is a disaccharide yielding glucose and fructose upon hydrolysis. Glucose, fructose and sucrose are water-soluble and together they comprise most of the sugars associated with the sweet taste of fruits and vegetables. The relative proportions of glucose and fructose vary from fruit to fruit and, to a lower extent, in the same fruit according to maturity. In many fruits (e.g. apple, pear, strawberry, grape) glucose and fructose are present in greater amounts than sucrose, but in certain vegetables, such as parsnip, beetroot, carrot, onion, sweet corn, pea and sweet potato, and in some ripe fruits such as banana, pineapple, peach and melon, the sucrose content is higher. Traces of other mono- and disaccharide sugars such as xylose, arabinose, mannose, galactose and maltose may also be present in small amounts (Salunkhe et al., 1991). Some fruits of the *Rosaceae* family could also have significant levels of the sugar alcohol sorbitol. Total carbohydrate content also includes starches, which are organized into small grains, either within the chloroplasts or in some cases in specialized plastids (amyloplasts). Some non-starchy root vegetables, such as parsnip, beetroot and carrot, are relatively rich in simple sugars, containing between 8% and 18% of total carbohydrates. However, most vegetables contain smaller amounts of metabolizable carbohydrates.

F. Dietary fiber

Definition and composition

Several definitions of fiber, either physiological or based on the measurement techniques used for its determination, have been put forward (Slavin, 2005). An expert panel adopted the term "dietary fiber consisting of non-digestible carbohydrates and lignin that are intrinsic and intact in plants" (Institute of Medicine, 2001).

Dietary fiber includes very diverse macromolecules exhibiting a large variety of physico-chemical properties. The main components included as fiber are cellulose, hemicelluloses, pectins, lignin, resistant starch and non-digestible oligosaccharides.

Cellulose is a cell wall polymer of β-1,4-linked glucose (Brett and Waldron, 1996). Within the cell wall, the glucan chains are associated with hydrogen bonds to form assemblages highly resistant to degradation, known as microfibrils (Carpita and McCann, 2000). In fruits and vegetables, the cell wall constitutes 1% to 2% of the fresh weight, and cellulose could be as much as 33% of that amount. In general, with the exception of avocado in which the whole cell wall seems to be degraded (O'Donoghue et al., 1994), little change in cellulose content occurs during ripening (Brummell, 2006).

Hemicelluloses Several cell wall polymers soluble in alkalis are classified as hemicelluloses or cross-linking glycans (Brummell and Harpster, 2001). Within the primary cell wall, hemicellulose levels are usually around 30% (Carpita and McCann, 2000). The most common hemicellulose polymer in dicotyledonous species is known as xyloglucan, composed as cellulose of a backbone of β-1,4-linked glucose, but with lateral chains of the pentose xylose (α-1,6 linked). These xylosyl residues can be modified further, with galactose, arabinose and/or fucose (Brummell, 2006). Xylans are hemicellulosic compounds more abundant in monocotyledonous species, having a backbone of β-1,4-linked xylose which could be decorated with side chains of arabinose and/or glucuronic acid. Other hemicellulosic compounds usually less abundant include glucomannans, galactomannans and galactoglucomannans (Carpita and McCann, 2000).

Pectins Fruit tissues are particularly rich in pectins, which can account for up to 40% of the total cell wall polysaccharides. Pectins are also a diverse group of polymers rich in galacturonic acid (Ridley et al., 2001). The most abundant pectic polysaccharide in the cell wall is homogalacturonan, a homopolymer of α-1, 4-linked galacturonic acid residues, with variable degrees of methyl esterification at C6 (Willats et al., 2001). The degree of polymerization and the proportion of methyl esters affect the solubility of pectins. Pectins are deposited in the cell walls, with a high degree of esterification, and methyl ester usually decreases during ripening. Another modification commonly observed in several fruits during ripening is a reduction in pectin polymer size (Brummell, 2006; Vicente et al., 2007b). The extent of pectin depolymerization is variable, ranging from fruits such as avocado showing a dramatic downshift in polyuronide size (Huber and O'Donoghue, 1993) to products in which these changes are negligible, such as pepper or some berries (Brummell, 2006; Vicente et al., 2007a). Rhamnogalacturonan I (RG I) and rhamnogalacturonan II (RG II) are pectic polysaccharides which are also present in the plant cell wall. RG I has a backbone of alternating α-1,2-rhamnosyl and α-1,4-galacturonosyl residues (Willats et al., 2001), with side chains rich in arabinose and galactose (Carpita and McCann, 2000). Losses in the side chains are a common feature in fruit ripening, which can also affect pectin solubility and hydration potential (Gross and Sams, 1984; Redgwell et al., 1997). RG II is the most complex polysaccharide present in the cell wall; it has the ability to form dimers via borate diester bonds (O'Neill et al., 2004; Kobayashi et al., 1996). Pectins, which are used in the commercial manufacture of jams and jellies, are extracted from certain fruits and vegetables such as citrus, apples and beets.

Lignin is one of the most abundant biopolymers in nature (Boerjan et al., 2003). It is an aromatic heteropolymer formed by the association of three hydroxycinnamyl alcohol derivatives (p-coumaryl, coniferyl and sinapyl alcohols) (Reddy et al., 2005). Lignin is a highly resistant polymer present in secondary cell walls, and is associated with fibers and xylem vessels. In the case of fruits and vegetables, lignin content is relatively low.

Resistant starch Starches are polysaccharides, composed of a number of glucose molecules linked together with α-D-(1-4) and/or α-D-(1-6) linkages (Sajilata et al., 2006). Resistant starch consists of starch and its degradation products that are not digested in the small intestine (Asp, 1994). Legumes are rich in resistant starch, and as much as 35% of their starch could escape digestion (Marlett and Longacre, 1996). Green bananas and potato are also relatively rich in resistant starch. Very little information is available about the resistant starch content of foods and the amount of resistant starch in a typical diet.

Non-digestible oligosaccharides (NDOs) Oligosaccharides are low molecular weight carbohydrates intermediate in nature between simple sugars and polysaccharides (Mussatto and Mancilha, 2007). While several oligosaccharides might be hydrolyzed in the digestive tract, others might resist the digestive process. Some of them include raffinose (trisaccharide composed of galactose, fructose, and glucose), stachyose (two galactose, one glucose and one fructose unit, linked sequentially) and verbascose (three galactose, one glucose and one fructose unit, linked sequentially). Legumes are rich in NDOs (Mussatto and Mancilha, 2007).

Benefits of fiber intake

One of the most well known benefits of dietary fiber is the modulation of function of the intestinal tract (Institute of Medicine, 2001). Meals rich in fiber promote satiety earlier, and are usually relatively low in calories compared to meals rich in other food types (Marlett et al., 2002). Several works have also associated diets rich in dietary fiber with positive effects in disease prevention (see Institute of Medicine, 2001). Some works have established an inverse association between fiber intake and coronary disease (Rimm et al., 1996; Wolk et al., 1999). Total fruit and vegetable consumption was inversely associated with colorectal cancer risk (Terry et al., 2001). Current national dietary guidelines recommend an increased dietary fiber intake and suggest that fiber, independent of fat intake, is an important dietary component for the prevention of some diseases. Recommendations for adult dietary fiber intake generally fall in the range of 20 to 35 grams per day. The average fiber intake of adults in the US is less than half of this recommended level (Marlett and Slavin, 1997).

Sources of fiber

Whole grains (especially the pericarp) and also fruits and vegetables are considered very good sources of fiber (Anderson et al., 2007). In 2004, the primary contributors of fiber to the food supply were fruits and vegetables (37.1%), followed by grain products (36.0%) and legumes (13.3%) (Hiza and Bente, 2007). Fiber content of

Table 5.2 Fiber content in selected fruits, vegetables and nuts

Product	Dietary fiber (%)
Almond	12.2
Apple	2.4
Asparagus	2.1
Avocado	6.8
Banana	2.6
Broccoli	2.6
Carrot	2.8
Kiwifruit	3.4
Lettuce	2.1
Onion	1.7
Orange	2.4
Pea	2.6
Peach	1.5
Peanut	8.5
Pear	3.1
Pepper	2.1
Pineapple	1.4
Plum	1.4
Potato	2.2
Prunes	7.1
Raisin	3.7
Spinach	2.2
Strawberry	2.0
Tomato	1.2
Walnut	6.7

Source: US Department of Agriculture, 2008.

fruits and vegetables is usually in the range of 1% to 3% (Table 5.2). Nuts, legumes and dried fruits have higher levels of fiber than fruits and vegetables. The nature of fiber varies among food sources. For instance, pectin is low in grains, but constitutes approximately 20% to 35% of the fiber in fruits, vegetables, legumes and nuts. Hemicelluloses account for about half of the total fiber in grains, and approximately 25% to 35% of the total fiber in other foods. Cellulose is one third or less of the total fiber in most foods (Marlett, 1992). Besides total fiber content, some relevant properties include particle size and bulk volume, surface area characteristics, hydration and rheological properties, and adsorption or entrapment of minerals and organic molecules (Guillon and Champ, 2000). The main modifications during storage of most fruits and vegetables occur because of changes in the solubility and molecular size of the cell wall constituents due to the action of several proteins (Brummell, 2006; Fisher and Bennett, 1991). In some products, modification in fiber fractions could negatively affect quality. For instance, asparagus shows rapid hardening of the basal portions of the spears during storage related to modifications of fiber, such as increased deposition of lignin (Saltveit, 1988). In general, preparation of fruits and vegetables by typical home methods or commercial processing does not seem to cause great loss of fiber (Zyren et al., 1983).

G. Vitamins

Vitamins are organic molecules required in trace amounts for normal development, which cannot be synthesized in sufficient quantity by the organism and must be obtained from the diet. The term "vitamin" derives from the words "vital amine" because the first vitamin discovered (thiamine) contained an amino group. The 14 vitamins known today are vitamin A (retinol), B complex [B1 (thiamine), B2 (riboflavin), B3 (niacin), B5 (pantothenic acid), B6 (pyridoxine), B9 (folate/folic acid), biotin, choline and B12 (cyanocobalamine)] and vitamins C, D, E and K. They do not have common functions or structure and are usually grouped into fat-soluble (A, D, E and K) and water-soluble (B group and C) molecules. The vitamins present in fruits and vegetables make an important contribution to human nutrition, as they have specific functions in normal body performance. The vitamin content of fruits and vegetables shows a wide variation among species (Salunkhe et al., 1991). Differences within cultivars occur, as well as between different batches of the same cultivar grown under different environmental and orchard conditions (Rodriguez-Amaya, 2001; Lee and Kader, 2000).

Vitamin A

Carotenoids are liposoluble pigments responsible for the yellow, orange and red color of several fruits and vegetables. Carotenoids are terpenoids formed by eight isoprene units (2-methyl-1,3-butadiene) and derived from isopentenyl diphosphate. Those having an unsubstituted β-ring with an 11-carbon polyene chain have provitamin A activity (Meléndez-Martínez et al., 2007), such as α-carotene, β-carotene and cryptoxanthin (Kopsell and Kopsell, 2006). The structural requirement for vitamin A is satisfied by around 60 carotenoids (Rodriguez-Amaya, 2001). Vitamin A plays an important role in vision, cell division and differentiation, bone development and reproduction. The average daily requirement for vitamin A for an adult is estimated at 5000 international units (1 IU = 0.3 μg retinol or 0.6 μg β-carotene).

Among this group there are, basically, two different classes: carotenes containing C and H (e.g. α-carotene, β-carotene, lycopene, etc.), and oxygenated derivatives known as xantophylls, such as lutein, violaxanthin and zeaxanthin. Carotenoids in plants have functions related to radiation interception, mainly in the blue–green region of the spectrum, which may be transferred to the photosynthetic centers (Kopsell and Kopsell, 2006). Moreover, these pigments protect the photosynthetic structures from excessive energy (Grusak and Della Penna, 1999). They are usually present in low concentrations and their levels are highly variable among species. Fruits and vegetables account for only 30% of the vitamin A in the American diet (Hiza and Bente, 2007). Vegetables that can supply useful amounts of carotene include carrots, pumpkins and squashes.

Compared to vegetables, fruits are generally not as good a source of carotenoids, although there are a few notable exceptions such as apricot, mango, citrus, papaya

Table 5.3 Carotene content (mean values) of selected fruits

Product	Carotene (μg 100 g^{-1})
Mango	1800
Cantaloupe	1000
Pawpaw	810
Guava	435
Apricot	405
Plum	295
Watermelon	230

Source: Rodríguez-Amaya, 2001.

and watermelon (Table 5.3). Tomatoes and peppers also contain high levels of carotenoids. Their distribution is not usually uniform and in general, their accumulation is higher in the peel than in the pulp (Rodríguez-Amaya, 2001). To date, over 600 different carotenoids have been identified, but only a few of them are commonly found in produce. β-carotene, the most widely studied carotenoid, accumulates in carrots; lycopene is common in tomato and watermelon. Other pigments within this group include α-carotene, β-carotene, lutein, cryptoxanthin and zeaxanthin. In tomatoes, peaches and carrots the synthesis of carotene can continue after harvest. There is no difference between the carotene content of cooked vegetables and that of raw vegetables. Absorption of carotene can only be effective if the diet includes a minimum of 15% fat. The manner in which the food is prepared also determines the amount of carotene that will be absorbed. Homogenized carrots allow for the best absorption, followed by shredded carrots and whole carrots.

Vitamin B complex

Thiamine is required in the human body for the metabolism of carbohydrates. A daily intake of 1–2 mg is generally considered as necessary for a normal adult. Legumes are especially rich in thiamine. Compared with ascorbic acid, thiamine is relatively stable at cooking temperatures, especially in a slightly acidic solution. However, losses of 25% to 40% may occur during cooking.

The average human requirement for riboflavin is estimated to be 1–2 mg per day. Green vegetables such as beans, beets, peppers and spinach are particularly rich in riboflavin. Starchy vegetables and fruits are relatively poor sources of riboflavin. Niacin, also known as nicotinic acid, is a precursor to NADH, NAD, NAD^+ and NADP, which play essential roles in living organisms. A daily intake of 10 mg to 15 mg niacin is recommended. There is evidence that niacin can be synthesized in the body from tryptophan. Almonds are a rich source, but no fruits or vegetables can be singled out as being rich in niacin except perhaps, cape gooseberry and avocado. Niacin is relatively stable.

Vitamin B_6 (pyridoxal phosphate) is a cofactor in many transamination, decarboxylation and deamination reactions (e.g. in plants, formation of ACC by ACC synthase requires pyridoxal phosphate as a cofactor) (Ramalingam et al., 1985). Common symptoms of vitamin B_6 deficiency include dermatitis around the eyes, elbows and mouth, along with soreness of the mouth and a red tongue. It can also lead to dizziness, vomiting, weight loss and severe nervous disturbances (Salunkhe et al., 1991). Vitamin B_6 is present in appreciable amounts in beans, cabbage, cauliflower, spinach, sweet potatoes, grapes, prunes, avocados and bananas. It is fairly heat stable.

Pantothenic acid can be obtained from fresh, canned or frozen fruits and vegetables containing this vitamin if they are included in the diet. Pantothenic acid occurs widely in peas, beans, nuts, broccoli, mushrooms, potatoes and sweet potatoes. Symptoms of pantothenic acid deficiency in the diet include fatigue, headaches, sleep disturbance, tingling of hands and feet and lack of antibody production.

Biotin is stable during cooking, processing and storage of fresh, canned and frozen fruits and vegetables. Deficiency leads to depression, sleeplessness and muscle pains. It is synthesized in the intestinal tract (Salunkhe et al., 1991).

Folic acid is essential for reproduction and normal growth. The vitamin is present in fruits, spinach, cabbage and other green vegetables. Lack of folic acid in the diet can cause a red tongue, diarrhea and anemia. Choline is heat-stable and occurs in dried legumes and vegetables. Choline deficiency in humans has never been reported.

Vitamin B_{12} does not occur in fruits and vegetables. Because vitamins of the B group are water-soluble, leaching losses occur during cooking.

Vitamin C

Ascorbic acid (AsA) and its first oxidation product dehydroascorbic acid (which can be reduced in the human body) might be considered as vitamin C. AsA is a water-soluble carbohydrate-derived compound showing antioxidant and acidic properties due to the presence of a 2,3-enediol moiety (Figure 5.1). Humans and a few other species are not able to synthesize AsA (Chatterjee, 1973), because the gene coding for the last enzyme in the pathway (L-gulono-1,4-lactone oxidase) is non-functional (Valpuesta and Botella, 2004). Plants synthesize AsA via a pathway that uses L-galactose as a precursor (Smirnoff and Wheeler, 2000; Smirnoff, 2000). Another pathway using galacturonic acid, which might be recycled from cell wall pectin degradation, has been suggested in plants (Agius et al., 2003). AsA has crucial biological functions in humans, such as its participation in collagen biosynthesis (Murad et al., 1981). Even though nutritional deficiencies are rare in modern western cultures, it is generally recognized that dietary AsA also has important health benefits for the consumer, and an increased intake of vitamin C has been associated with a reduced incidence of some diseases and disorders (Carr and Frei, 1999; Hancock

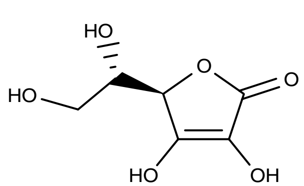

Figure 5.1 Structure of ascorbic acid, a main antioxidant present in fruits and vegetables.

and Viola, 2005). Furthermore, in meat-poor diets, dietary AsA can contribute to the improved uptake of iron (Frossard et al., 2000). The recommended dietary allowance of vitamin C for men is 75 mg daily, while the recommended dietary allowance for young women is higher, at 90 mg daily (Levine et al., 2001).

Fruits, vegetables and juices are the main dietary sources of vitamin C. Fruits and vegetables account for 90% of the vitamin C in the US food supply (Hiza and Bente, 2007). Its concentration depends on the product considered (Noctor and Foyer, 1998), ranging from 1 to 150 mg $100\,g^{-1}$ fresh weight (FW) (Lee and Kader, 2000). Vitamin C is present in fresh fruits and vegetables, as well as in fruit juices. Fruits, particularly tropical species, and leafy vegetables are rich in ascorbic acid. Rosehip, jujube and guava have very high levels of ascorbic acid. Other good sources of AsA include persimmon, strawberry, kiwifruit, peppers, and citrus fruit, and spinach, broccoli and cabbage among vegetables (Table 5.4).

Wide variations in vitamin C content also exist within cultivars. For instance, AsA content in *Actinidia deliciosa* fruit varies from 29 to 80 mg $100\,g^{-1}$ FW, depending on the cultivar (Nishiyama et al., 2004). Even more dramatic variations were found in berry fruits, with levels of AsA ranging from 14 to 103 mg $100\,g^{-1}$ FW among cultivars of raspberry, blackberry, red currant, gooseberry and cornelian cherry (Pantelidis et al., 2007). For any given product, the levels of AsA are highly variable, depending on genetic and environmental factors (reviewed in Lee and Kader, 2000). A main environmental factor determining the level of ascorbic acid is radiation interception. In general, the greater the amount of sunlight received during growth, the higher the ascorbic acid content. The retention of AsA is also markedly affected by storage and processing. Potatoes lose up to 75% to 80% of the original levels over nine months of storage. In most cases, other fruit and vegetable AsA levels decline during storage, because the losses are accelerated by storage at high temperatures. Bruising and mechanical damage greatly increase the rate of ascorbic acid loss. Ascorbic acid is highly susceptible to oxidation, either directly or through the enzyme ascorbate oxidase catalyzing the oxidation of AsA to dehydroascorbic acid, with the concomitant reduction of molecular oxygen to water (Sanmartin et al., 2007). Ascorbic acid can even be oxidized during eating, while food is being chewed. However, it is important to consider that the first breakdown product of AsA,

Table 5.4 Vitamin C content (mean values) of selected fruits

Product	Vitamin C (mg $100\,g^{-1}$ fresh weight)
Guava, raw	184
Kiwi, raw	118
Litchi, raw	72
Pawpaw, raw	62
Strawberry, raw	57
Citrus fruits	31–53
Cantaloupe	42

Source: Salunkhe et al., 1991.

dehydroascorbic acid, still has vitamin C activity and all activity is lost if oxidation proceeds beyond this stage (Salunkhe et al., 1991). When vegetables are cooked before eating, high losses of vitamin C can occur. For instance, starchy vegetables may lose between 40% and 80% of their vitamin C during cooking, because of leaching and oxidation. Loss of vitamin C can be reduced by steaming or by placing the vegetables directly into boiling water. Freezing reduces vitamin C slightly, but at the end of long-term frozen storage (12 months), a significant decrease (33% to 55%) in vitamin C can occur (de Ancos et al., 2000).

Vitamin E

Vitamin E includes tocopherols and tocotrienols. They can be in eight different forms (four tocopherols and four tocotrienols). All the isomers have aromatic rings with a hydroxyl group that can donate hydrogen atoms to reduce reactive oxygen species (ROS). The different isomers are named alpha (α), beta (β), gamma (γ) and delta (δ), and this is related to the number and position of methyl groups in the ring. Each of the forms has its own vitamin E activity, α-tocopherol being the most active (see Figure 5.2). Vitamin E deficiency results in stunted growth. In general, vitamin E levels are more abundant in oily seeds, olives, nuts, peanuts, avocados and almonds. Even though the levels of tocopherol in broccoli and leafy vegetables are lower than in fat-rich products, they are good sources compared to other fruits and vegetables. Vitamin E is highly susceptible to oxidation during storage and processing.

Vitamins D and K

Vitamin D is a group of fat-soluble compounds. The main forms of vitamin D are ergocalciferol and cholecalciferol. It occurs only in trace amounts in fruits and vegetables.

Vitamin K is essential for blood coagulation, but dietary deficiency is uncommon. The recommended daily intake is 120 μg. It occurs abundantly in lettuce, spinach, cauliflower and cabbage. As well as direct intake, it can also be produced by bacteria in the intestines.

III. Antioxidants in fruits and vegetables

A. Oxidative damage and antioxidants

Imbalance in the production of reactive oxygen species (ROS) leading to negative cellular alterations is known as oxidative damage, which is caused by several molecules

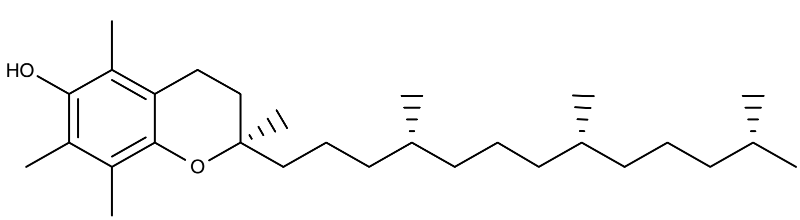

Figure 5.2 Structure of tocopherol.

(Mittler, 2002). Reactive oxygen species are partially reduced forms of oxygen such as singlet oxygen, hydrogen peroxide (H_2O_2), superoxide ($O_2^{-\bullet}$) or hydroxyl radical ($OH^{-\bullet}$) (Asada, 1999). Some, but not all of the components able to cause oxidative damage are free radicals (i.e. molecules with unpaired electrons, which determine their high reactivity). Currently, there is overwhelming evidence showing that the ROS can alter proteins, lipids and nucleic acids, causing deleterious modifications to normal metabolism, which can lead to several disorders and diseases (Waris and Ahsan, 2006), and eventually to cell death (Jeremy et al., 2004). From a biological perspective, an antioxidant is considered as any compound able to oppose cellular oxidation. Diets rich in fruits and vegetables have been shown to reduce the incidence of cardiovascular disease and some chronic and degenerative diseases associated with oxidative damage (Ames et al., 1993; Dragsted, 2003). The incorporation of fruits and vegetables in the diet may also help to eliminate certain toxins. The protective effects have been associated with the presence of antioxidant compounds (Cao et al., 1996; Wang et al., 1996). Antioxidants are present in all plant organs and include ascorbic acid, carotenoids, vitamin E and phenolic compounds, among others (Larson, 1988) (Figure 5.3). Here we briefly describe some characteristics of these components.

B. Ascorbic acid

As mentioned before (see Section II.G) ascorbic acid is one of the most important compounds for human nutrition present in fruits and vegetables. The role of AsA in disease prevention has been associated with its capacity to neutralize ROS.

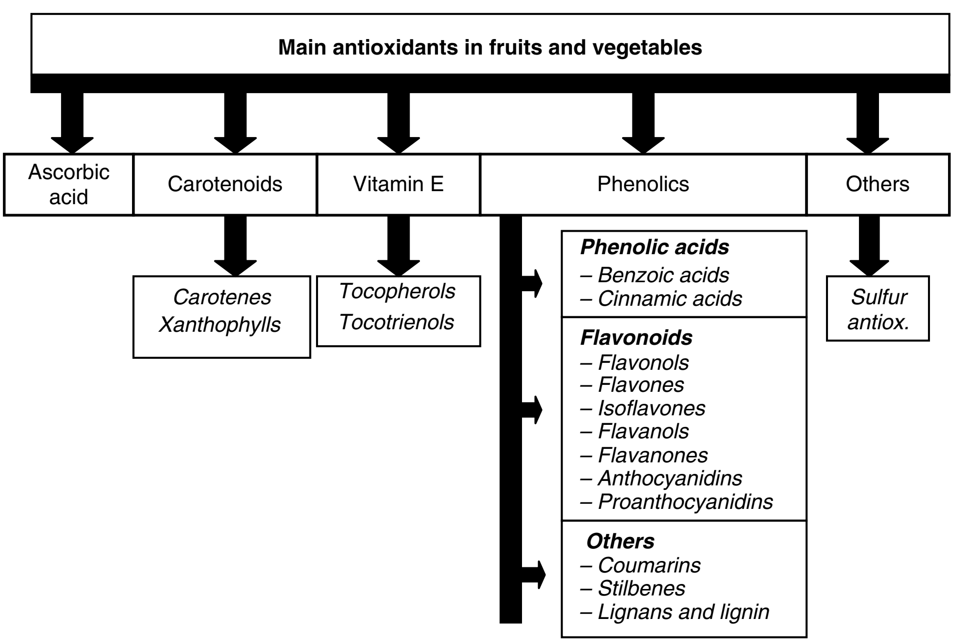

Figure 5.3 Main dietary antioxidants present in fruits, vegetables and legumes.

C. Carotenoids

Fruits and vegetables are the main sources of carotenoids in the diet (Rao and Rao, 2007). The presence of conjugated double bonds in carotenoids has a main role in determining their antioxidant properties (Sandmann, 2001). In the last few years, carotenoids have received great attention due to their antioxidant properties and potential to prevent some diseases. The general properties of these compounds were described in Section II.G.

D. Tocopherols and tocotrienols

These include the fat-soluble compounds grouped as vitamin E, characterized by a high antioxidant capacity. Their distribution in fruits and vegetables was previously described (see Section II.G).

E. Phenolic compounds

This group encompasses a great diversity of compounds derived from the aromatic amino acids phenylalanine and tyrosine. Their main functions are acting as deterrents of potential predators or antimicrobials, protecting against UV-radiation and contributing to the pigmentation of fruits and flowers. Phenolic compounds can contribute to the astringency and bitter taste of some products. They are generally present in low concentrations, but in certain cases, such as in blueberry, they can reach levels of more than 0.1%. In general, they also accumulate in the peel more than in the pulp of fruits. The general characteristic of the compounds within this group is to have aromatic rings with variable degrees of hydroxylation (Mattila et al., 2006). Phenolic compounds are easily oxidized to quinones. The beneficial properties of berry fruits on human health have been associated in part with the presence of relatively high levels of phenolic compounds (Seeram et al., 2006). There is *in vitro* evidence showing that these compounds could influence several cellular processes. Information regarding the metabolism and effect *in vivo* is much more limited (Duthie et al., 2003). A large number of phenolic compounds have been identified in plants (Tsao and Deng, 2004). They have been subdivided into different subclasses, such as phenolic acids, flavonoids and other compounds (e.g. lignans, stilbenes, tannins, coumarins and lignin).

Phenolic acids

Phenolic acids include derivatives of benzoic and cinnamic acid (Benbrook, 2005) (Figure 5.4). The most common benzoic acid derivatives are *p*-hydroxybenzoic, vanillic, syringic and gallic acid, while common cinnamic acid derivatives include *p*-coumaric, caffeic, ferulic and sinapic acid. The derivatives differ in the degree of hydroxylation and methoxylation of the aromatic ring. Caffeic acid is the most abundant phenolic acid in several fruits such as berries (Mattila et al., 2006), while coumaric acid is usually present in lower proportions (Rice-Evans et al., 1997). Ferulic acid represents 90% of total phenolic acids in cereals (Manach et al., 2004; Scalbert and Williamson, 2000). The contribution of each of the phenolic compounds to the

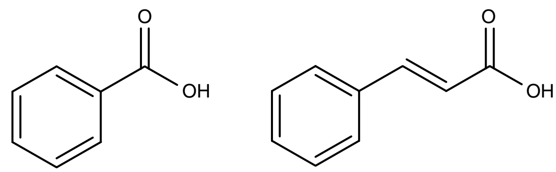

Figure 5.4 Structure of benzoic acid (left) and cinnamic acid (right), precursors of the two main classes of phenolic acids present in fruits and vegetables.

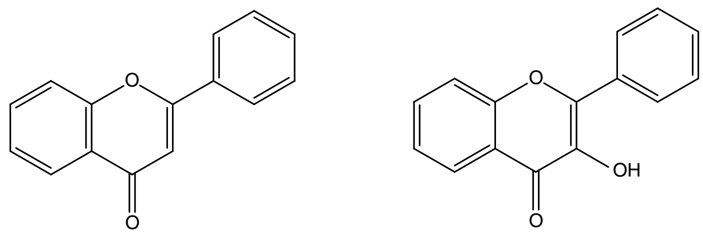

Figure 5.5 General structure of flavones (left) and flavonols (right).

antioxidant capacity depends on their structure. For instance, the number of hydroxyls present in the molecule can increase the antioxidant capacity.

Flavonoids

Flavonoids represent a large group of phenolic compounds with two aromatic rings in their structure that are associated together by a 3C-oxygenated heterocycle. Phenolic compounds are usually present as glycosides, which reduce their activity against free radicals and increase their solubility. At the cellular level, they are compartmentalized in the vacuoles (Rice-Evans et al., 1997). There are different classes of flavonoids (Le Marchand, 2002) such as:

a) flavones and flavanols;
b) flavanones, flavanols;
c) isoflavones;
d) proanthocyanidins; and
e) anthocyanidins.

Flavones and flavonols Flavonols have a central ring of 3-hydroxypyran-4-one (Rice-Evans et al., 1997). Flavones lack the OH in position 3 (Figure 5.5). Rutin, luteolin and apigenin are common among flavones, while the most abundant flavonols are quercetin and kampferol (Manach et al., 2004). Onions are rich in these compounds. Blueberries also have high levels, especially in the peel, because synthesis is stimulated by exposure to light. Celery is a good source of flavones. Flavones are also present in citrus, but they are associated mainly with the fruit peel.

Flavanones and flavanols Flavanones do not have the double bond in position 2,3 of the central ring, while flavanols lack the carbonyl group at position 4 (Figure 5.6). The genus *Citrus* is characterized by the accumulation of flavanone glycosides.

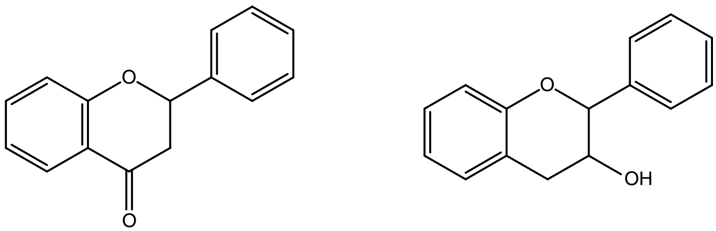

Figure 5.6 General structure of flavanones (left) and flavanols (right).

Orange juice is a source of the flavanone glycoside hesperidin (Tripoli et al., 2007). The flavanols catechin and epicatechin are common in grapes (Rice-Evans et al., 1997).

Isoflavones Isoflavones are phytoestrogens present in legumes. Soybean products are a good source of these compounds (Manach et al., 2004). The three most commonly found isoflavones are genistein, glycitein and daidzein.

Proanthocyanidins Proanthocyanidins are oligomeric flavonoids (usually dimers or oligomers of the flavanols catechin and epicatechin). They are common in the peel and seeds of grapes (Gu et al., 2004). Other sources of these compounds include apple, almond and blueberry.

Anthocyanidins Anthocyanidins are pigments giving several fruits their characteristic red or purple colors, although in some conditions they can be uncolored. Besides being pigments, anthocyanidins have great relevance due to their contribution to the antioxidant capacity of fruits and vegetables. The basic structure of anthocyanidins is derived from the flavilium cation (2-phenyl-benzopyril). There are six anthocyanidins more common in fruits and vegetables: pelargonidin, cyanidin, delphynidin, peonidyn, petunydin and malvidin. The differences between them are the OH, H and OCH_3 groups associated with the phenolic rings. The distribution of hydroxyls in the molecule influences the antioxidant capacity of the different anthocyanidins. These compounds are usually present as glycosides associated with different sugars, since anthocyanidin glycosylation reduces antioxidant capacity relative to the free aglycons.

Others

Lignans are diphenolic structures formed by the association of two derivatives of cinnamic acid (Liu, 2007). They are present mainly in linseeds, cereals and legumes, but their levels are low in fruits and vegetables. Stilbenes are also phenolic compounds described in fruits. The most studied compound in this group is resveratrol (Figure 5.7). This compound has been known for quite a while, and is commonly produced in response to pathogens and other stress conditions in grapes (Langcake and Pryce, 1976). It has also been identified in other fruits, such as blueberry. It has been suggested that it may have anticarcinogenic properties.

Finally, lignin is a phenolic polymer present in secondary cell walls of plant tissues. It is highly hydrophobic and is formed by three main monomeric precursors: coumarylic, sinapylic and coniferyl alcohols. It is associated with conduction tissues

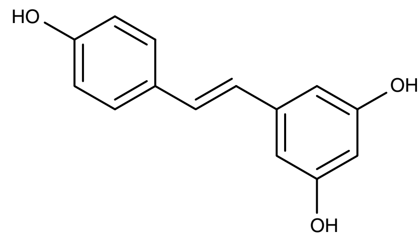

Figure 5.7 Resveratrol has been studied in detail in grapes. It has been suggested that this compound has anticarcinogenic properties.

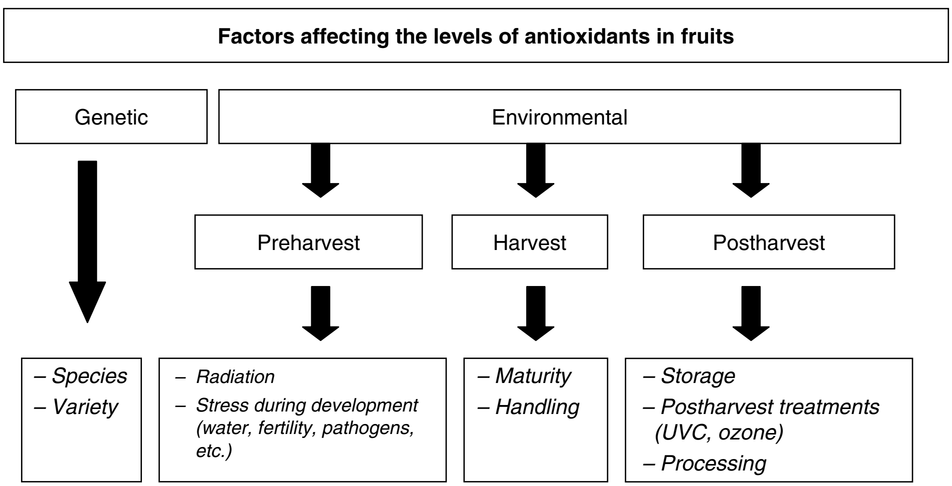

Figure 5.8 Main factors affecting the level of antioxidants in fruits.

(xylem vessels, sclereids, tracheids), and in general it is not abundant in fruits and vegetables. Its contribution, from the antioxidant point of view, is associated only with the products of its potential degradation that are very limited.

F. Factors affecting the levels of antioxidants in fruits and vegetables

Several factors influence the accumulation and degradation of antioxidant compounds in fruits. In general terms, these variables could be divided into genetic and environmental. Different factors are included within each of these groups (Figure 5.8).

Genetic factors

Species The species is the first factor determining the prevalence of different antioxidants. Although there are some exceptions, each group is characterized by the accumulation of certain types of antioxidants (Table 5.5). Berries are particularly rich in phenolic compounds (Zheng and Wang, 2003) and vitamin C (Kevers et al., 2007). The main antioxidants in this group seem to be phenolics because, in general, a good correlation between total antioxidant capacity and phenolic compounds has been

Table 5.5 Fruits and vegetables rich in the different groups of antioxidants

Ascorbic acid	Vitamin E	Carotenoids	Phenolics
Strawberry	Almond	Pineapple	Blueberry
Pepper	Corn	Plum	Plum
Kiwifruit	Broccoli	Peach	Raspberry
Orange	Spinach	Pepper	Strawberry
Pepper	Peanut	Mango	Apple
Broccoli	Avocado	Melon	Blackberry
Guava		Tomato	
Rosehip		Carrot	
Persimmon			

observed. In the case of ripe blueberry, ascorbic acid only contributes 0.4% to 9.0% to the total antioxidant capacity (Kalt et al., 1999).

Cultivar For a given species, the levels of antioxidants are also markedly affected by the cultivar considered. For instance, in strawberry, Nelson and co-workers (1972) found variations from 19 to 71 mg of ascorbic acid per 100 g FW in six varieties. Similar differences among varieties have been found for phenolic compounds (Wang and Lin, 2000). The identification of lines or mutants enriched in antioxidants might be useful in breeding programs aimed at improving the nutritional value of fruits and vegetables. The identification of the nature of the genes mutated in lines with altered accumulation of antioxidants might also be of great value. For instance, in the case of tomato the characterization of the high pigment (*hp*) mutants, which accumulate high levels of carotenoids, showed that the mutated gene is associated with plant light responses, and the over-expression of this gene resulted in increased accumulation of carotenoids (Liu et al., 2004). Also, in tomato the level of β-carotene and lycopene were raised by increasing the expression of phytoene synthase and lycopene cyclase, respectively (Fraser et al., 2002; D'Ambrosio et al., 2004). Similarly in carrot, the over-expression of a β-carotene ketolase isolated from *Haematococcus pluvialis* led to the accumulation of the ketocarotenoid astaxanthin (Jayaraj et al., 2008). The generation of transgenic plants has also been seen to increase the levels of other antioxidants such as phenolic compounds. Transformation of tomato with a *Petunia* gene for chalcone isomerase increased the concentration of flavonols in the peel almost 80 times, without altering other phenotypic characteristics (Muir et al., 2001). In the case of ascorbic acid, the elucidation of its biosynthetic pathway opened the way to manipulate ascorbate biosynthesis in plants (Smirnoff, 2000). However, while most of the genes proposed to be involved in these pathways have been cloned and expressed in various plant species, transformation strategies to increase AsA concentrations have had only limited success. Thus, there is a need for alternative approaches to identify the genetic determinants underlying whole plant AsA homeostasis.

Environmental factors

Radiation In many cases, modifications in the level of phenolic compounds, ascorbic acid and carotenoids have been associated with changes in the radiation interception in the field. Sun-exposed sides of fruits have higher levels of phenolics and vitamin C than shaded regions (Lee and Kader, 2000). In the case of leafy vegetables, the levels of flavonols are 10 times higher in the surface leaves than in the internal leaves. In tomato, the level of total phenolics increased twofold in plants exposed to higher irradiance. Similarly, these plants presented higher levels of carotenoids and ascorbic acid (Gautier et al., 2008). This illustrates that maximization of radiation interception is important to obtain products with higher accumulation of antioxidants. However, the optimal irradiance levels required to maximize accumulation of the different groups of antioxidants in fruits and vegetables are not well established.

Cultural practices There are several works analyzing the effect of cultural practices on the level of different groups of antioxidants. For instance, strawberry fruit grown with plastic mulch had higher antioxidant capacity than fruits from plants grown in beds without plastic mulch (Wang et al., 2002). High nitrogen fertilization has been associated with reduced levels of ascorbic acid (Lee and Kader, 2000), and compost as a soil supplement significantly enhanced levels of ascorbic acid (Wang and Lin, 2003). Vitamin C accumulation also has been inversely correlated with rainfall (Toivonen et al., 1994). Some authors have found evidence suggesting that organic products might accumulate higher levels of antioxidants and vitamins than those produced conventionally (Woese et al., 1997; Weibel et al., 2000; Asami et al., 2003; Chassy et al., 2006). However, there are also studies that show either results that are opposite, or results that show no difference (Barrett et al., 2007). Winter and Davis (2006) concluded that it is not possible to ensure that, from a nutritional point of view, organically grown products are superior to those obtained by conventional agricultural techniques.

Maturity at harvest The developmental stage might affect the antioxidant capacity of fruits (Prior et al., 1998). The nature of these changes depends on the product considered. For instance, in tomato and pepper total antioxidant capacity increases because of the accumulation of carotenoids and vitamin C. In the case of blueberry fruit the concentration of phenolic acids decreases during ripening, while anthocyanins are accumulated (Castrejón et al., 2008), resulting in a net reduction of total antioxidant capacity during development. Similar patterns have been observed in strawberry and blackberry (Wang and Lin, 2000). In the case of carotenoids, in some products (e.g. pepper, tomato, mango) the concentration increases during development (de Azevedo and Rodriguez-Amaya, 2005). In contrast, products in which color is mainly associated with the accumulation of anthocyanins or products that maintain their green color at harvest usually show a reduction in the level of carotenoids as development progresses (Rodriguez-Amaya, 2001).

Wounding Mechanical damage may cause alterations in the levels of antioxidants. In the case of AsA, cellular breakage causes an increase in the levels of the internal pressure of oxygen favoring oxidation. Carotenoid degradation is also accelerated by oxygen, but the stability of these compounds is higher than that of AsA. In the case of phenolic compounds, wounding could alter both their synthesis and degradation (Tomás-Barberán et al., 1997; Loaiza Velarde et al., 1997). In lettuce, wounding led to the accumulation of soluble phenolic compounds (e.g. chlorogenic acid) (Choi et al., 2005). From a molecular perspective, wounding has been shown to induce *de novo* synthesis of phenylalanine ammonia lyase, a key enzyme in phenylpropanoid metabolism (Choi et al., 2005). Besides its role on phenolic biosynthesis, wounding also affects degradation. First, also in response to wounding, an increase in enzymes associated with phenolics oxidation such as polyphenol oxidases (PPOs) and peroxidases (PODs) has been reported. In addition, cell disruption allows direct contact between pre-existing phenolic degrading enzymes. Finally, the production of hydrogen peroxide upon damage provides a secondary substrate of PODs and the reduction of barriers for oxygen diffusion might favor PPO activity. This might promote the oxidation of phenolics, which can then polymerize, leading to the formation of brown colored pigments that may ultimately reduce quality. Consequently, careful handling and minimization of physical damage is recommended.

Storage The effect of storage on antioxidants in many cases is related to the role of ethylene in the ripening process. Consequently, the final effect on antioxidant (AOX) levels will depend on the typical modifications observed during development of the species considered. In some cases, ethylene can induce specific antioxidants. For instance, in carrot, ethylene stimulated the accumulation of an isocoumarin (6-methoxymellein). In berries it has been observed that atmospheres with high levels of oxygen (60% and 100%) result in increased antioxidant capacity by favoring anthocyanins and other phenolics accumulation (Zheng et al., 2003). However, the oxidation of AsA might also be favored in these conditions. Besides the effect of any specific group of antioxidants in most fruits, it has been observed that the changes in total antioxidant capacity are not dramatic during postharvest storage. Excluding some products, such as broccoli and banana, fruits and vegetables, in general, lose their visual quality before marked losses in total antioxidants occur (Kevers et al., 2007). In some cases, an increase in total AOX capacity is observed, basically, associated with the accumulation of phenolics. In strawberry, storage at 5°C and 10°C increased the antiradical capacity (Ayala-Zavala et al., 2004). Further studies to evaluate the extent of this increased accumulation of antioxidants in some fruits might be done to determine the potential for increasing the functionality of fruits and vegetables through manipulation of the postharvest environment (Kalt et al., 1999).

Other treatments Some studies suggest that manipulation of the metabolism of products by the application of postharvest treatments could be useful to increase the antioxidant capacity, with consequent nutritional benefit (Kalt et al., 1999). Phenolic compounds' synthesis might be triggered in response to stress conditions, such as infection by microorganisms or wounding, ultraviolet (UV) irradiation or the exposure of the products to ozone-enriched atmospheres. In grapes, postharvest UV-C and ozone treatments increased the accumulation of resveratrol (Cantos et al., 2001; Versari et al., 2001; Gonzalez-Barrio et al., 2006). The elicitation of the accumulation of antioxidant compounds has also been observed in other fruits. In blueberry cv. Bluecrop, besides reducing decay, UV-C radiation exposure (2 or 4 kJ/m^2) resulted in increased accumulation of anthocyanins and higher levels of antioxidants (Perkins-Veazie et al., 2008). In the case of strawberry, UV-C treatments also increased the level of phenolic compounds and the antiradical capacity (Ayala-Zavala et al., 2004). These results, at a laboratory scale, show an interesting eliciting effect of some postharvest treatments on antioxidant accumulation. Further studies would be useful to determine the potential of these strategies on a commercial scale.

Processing The effect of processing on the level and bioavailability of antioxidants depends on the treatment intensity, as well as on the component considered (Bernhardt and Schlich, 2006). In some cases, processing could lead to higher availability of antioxidants, due to an increase in the ease of extractability. For instance, with carrot and spinach carotenoids vapor cooking increases assimilation, probably due to a disruption of carotenoid-protein complexes. Similarly, the bioavailability of lycopene increases in heat-treated tomato. However, cooking could cause the isomerization of β-carotene, leading to the formation of *cis* isomers with lower provitamin A activity (Deming et al., 2002a,b). For instance, in the case of fresh carrots, 100% of the β-carotene is present in the *trans* form, while canning results in a significant formation of *cis* isomers. Carotenoids are in general susceptible to oxidation. Heat, light and oxygen could accelerate their degradation (von Elbe and Schwartz, 1996). Minimizing the influence of these factors could reduce carotenoids loss. Ascorbic acid is one of the antioxidants more susceptible to degradation. Blanching or even freezing and thawing could cause losses up to 25%. More drastic treatments could lead to losses of up to 90% of AsA. Some of the factors affecting the loss of AsA include the degree of heating, the exposed surface (which affects lixiviation in the cooking media), oxygen levels and product pH (Eitenmiller and Landen, 1999). The stability of AsA could be increased at low pH, reduced oxygen pressure, darkness and presence of chelating agents. Consumption in the fresh state is the best way to minimize AsA losses. Finally, processing can also cause losses of phenolic antioxidants. For instance, peeling or cutting reduces quercetin levels by only 1%, but cooking in water may reduce the content of this component by 75%.

IV. Fruits and vegetables as direct sources of minerals

Dietary minerals raise concern for health specialists and consumers, due to the number of processes they are involved in and the continuous research highlighting the benefits of their adequate and balanced intake. Although there is no universally accepted definition or classification, the dietary focus on "minerals" derives from an interest in supporting the biosynthetic apparatus with required elemental components other than carbon, hydrogen and oxygen.

Total mineral content is determined by the ash value. Nevertheless, classification of many elements as essential minerals for human nutrition is not definitive, and there is still debate as to the natural biological role of vanadium, chromium, boron, aluminum and silicon in human health. Minerals are normally classified as macro- or micronutrients, based on the relative concentration of each nutrient when those concentrations are adequate for normal tissue function. Macronutrients include potassium (K), calcium (Ca), magnesium (Mg), nitrogen (N), and phosphorus (P), and their concentrations in plant tissues range from 1000 to 15 000 μg per gram of dry weight. In contrast, the concentrations of micronutrients usually found in plant tissues are 100- to 10 000-fold lower than those of macronutrients. Mineral micronutrients considered essential in human nutrition include manganese (Mn), copper (Cu), iron (Fe), zinc (Zn), cobalt (Co), sodium (Na), chlorine (Cl), iodine (I), fluorine (F), sulfur (S), and selenium (Se). Macronutrients can also be classified into those that maintain their identity as ions within plant tissues (e.g. K^+, Ca^{2+} and Mg^{2+}), and those that are assimilated into organic compounds (e.g. N and P).

In general, vegetables are a richer source of minerals than fruits, but both vegetables and fruits are considered "nutrient-dense foods" in that they provide substantial amounts of micronutrients, such as minerals and vitamins, but relatively few calories (Table 5.6).

Minerals have both direct and indirect effects on human health. The direct effects of minerals focus on the consequences of their consumption on human nutrition, while the indirect effects refer to their incidence in fruit and vegetable quality and subsequent consumer acceptance. From a direct nutrition standpoint, potassium has the biggest presence in both fruits and vegetables, but nitrogen and calcium show major impacts on horticultural crop quality.

Table 5.6 Fruit and vegetable sources of potassium, ranked by milligrams of potassium per standard amount, also showing calories in the standard amount*. The dietary reference intake (DRI) for potassium for adults and adolescents is 4700 mg/day.

Fruits and vegetables, standard amount	Potassium (mg)	Calories
Sweetpotato, baked, 1 potato (146 g)	694	131
Tomato paste, ¼ cup	664	54
Beet greens, cooked, ½ cup	655	19
Potato, baked, flesh, 1 potato (156 g)	610	145
White beans, canned, ½ cup	595	153
Tomato puree, ½ cup	549	48
Prune juice, ¾ cup	530	136
Carrot juice, ¾ cup	517	71
Lima beans, cooked, ½ cup	484	104
Winter squash, cooked, ½ cup	448	40
Banana, 1 medium	422	105
Spinach, cooked, ½ cup	419	21
Tomato juice, ¾ cup	417	31
Tomato sauce, ½ cup	405	39
Peaches, dried, uncooked, ¼ cup	398	96
Prunes, stewed, ½ cup	398	133
Apricots, dried, uncooked, ¼ cup	378	78
Cantaloupe, ¼ medium	368	47
Honeydew melon, ⅛ medium	365	58
Plantains, cooked, ½ cup slices	358	90
Kidney beans, cooked, ½ cup	358	112
Orange juice, ¾ cup	355	85
Split peas, cooked, ½ cup	355	116

*US Department of Health and Human Services and US Department of Agriculture, 2005.

Until recently, nutrition research focused on single-mineral impact on human health, generally with incongruent results. The recognition that minerals are not consumed individually, but as combined constituents of a varied diet, has shifted the efforts in this area to unraveling the role of the overall diet, or dietary patterns, in blood pressure and cardiovascular diseases, bone diseases and a range of chronic disorders. Epidemiological surveys suggest that the total diet has a greater influence on health than do specific components. From these dietary pattern studies, it has become increasingly clear that it is not merely the excess or deficiency of a single mineral, but also deficiencies of multiple nutrients in combination that have the greatest dietary effects on health. Adequate intake of minerals such as potassium – specifically derived from foods such as horticultural crops, where they coexist with other essential nutrients – contributes to overall health.

As described in previous sections, fruits and vegetables provide a milieu of phytochemicals, non-nutritive substances that possess health protective benefits. In contrast, fruits and vegetables may not usually be recognized as primary sources of mineral intakes from a nutritional point of view (Fairweather-Tait and Hurrell, 1996). Nevertheless, the Dietary Approaches to Stop Hypertension (DASH) emphasize fruit, vegetable and low-fat dairy product consumption as a source of minerals. In the DASH dietary pattern, vegetables contribute an average of 14.3%, 15.5%, 16.2% and 10.4% to the intakes of calcium, magnesium, potassium and zinc, respectively (Lin et al., 2003). Correspondingly, fruits and juices contribute an average of 5.8%, 17.3%, 33.0% and 6.6% (Lin et al., 2003).

There has been a natural trend towards lower mineral content in fruits and vegetables over the past decades (Mayer, 1997; Ekholm et al., 2007) which have not been fully compensated for by the increase in fruit and vegetable consumption. Vegetable contribution of potassium, phosphorus, magnesium, calcium, copper, iron and zinc to the US food supply significantly decreased during the last century, while fruit contribution of potassium, phosphorus, magnesium and copper increased (Table 5.7).

Table 5.7 Minerals (%) contributed from fruits and vegetables to the US food supply in selected years

Mineral	Fruit Year/s			Vegetables Year/s		
	1909–1919	1960–1969	2004	1909–1919	1960–1969	2004
Potassium	8.0	8.7	11.2	36.7	27.1	26.6
Calcium	2.6	2.2	2.6	8.7	6.0	7.0
Phosphorus	1.5	1.5	1.8	10.4	7.7	7.7
Magnesium	4.5	5.6	6.1	18.2	15.9	13.9
Copper	5.2	6.1	6.1	30.2	22.8	17.2
Iron	3.3	3.1	2.5	18.4	13.5	10.1
Zinc	1.2	1.3	1.2	9.1	7.4	6.4
Sodium	0.8	1.3	2.0	10.4	23.4	28.9
Selenium	0.5	0.6	0.4	1.2	2.4	2.3

Source: Hiza and Bente, 2007.

Nowadays different postharvest strategies for improving the mineral intake from fruits and vegetables are being implemented. These comprise increasing consumption of fruits and vegetables and increasing levels of essential nutrients through fortification methods. Alternative approaches include improving nutrient bioavailability and retention.

A. General considerations of selected minerals

Potassium (K)

A potassium-rich diet contributes to lower blood pressure, blunting the effects of salt (Salunkhe et al., 1991). Inadequate levels of potassium intake have long been associated with higher blood pressure (McCarron and Reusser, 2001). Potassium also regulates heartbeat, assists in muscle contraction and is needed to send nerve impulses and to release energy from fat, carbohydrates and protein. Different nutrients and phytochemicals in fruits and vegetables, including potassium, may be independently or jointly responsible for an apparent reduction in cardiovascular disease risk (Ignarro et al., 2007). Potassium is a systemic electrolyte and is essential in coregulating ATP with sodium. Potassium favorably affects acid–base metabolism, which may reduce the risk of developing kidney stones (Zerwekh et al., 2007), and possibly decrease bone loss with age. Although calcium intake is an important determinant in peak bone mass, and in retarding bone loss in postmenopausal women, findings of higher bone mass and lower bone resorption in women consuming high intakes of potassium, magnesium, zinc and vitamin C emphasizes the importance of considering the impact of variation in other nutrients when focusing on a particular mineral (Cohen and Roe, 2000). In fact, up to 11 different groups of compounds (vitamins, minerals, antioxidants and others) in fruits and vegetables could influence bone health (MacDonald, 2007).

Potassium is the most abundant individual mineral element in fruits and vegetables. It normally varies between 60 and 600 mg per 100 g^{-1} of fresh tissue. It plays a role in a myriad of cellular and whole plant functions: it serves as an osmoticum for cellular growth and stomatal function, balancing the charges of anions, activating almost 60 plant enzymes and participating in numerous metabolic processes, including protein synthesis, oxidative metabolism and photosynthesis.

In fruits and vegetables, potassium occurs mainly in combination with various organic acids. Examples of potassium-rich fruits and vegetables include bananas and plantains, leafy green vegetables, many dried fruits, oranges and orange juice, cantaloupes and honeydew melons, tomatoes and root vegetables (Table 5.7).

Calcium (Ca)

Calcium is essential for bone and tooth formation. Because of this, calcium requirements are higher during adolescence. Calcium is also very important during later adulthood, and of great consequence from a public health perspective, because inadequate intake of calcium may increase the risk of osteoporosis, a condition in which decreased bone mass weakens bone (Nordin, 1997; Cohen and Roe, 2000). With nearly half of all American women over 50 years of age demonstrating low mineral bone density or osteoporosis, and an estimated 1.3 million osteoporosis-related fractures occurring each year in the US, with a billion dollar estimated annual cost (DeBar et al., 2004), osteoporosis prevention is a major public health target. Calcium fluxes are important mediators of hormonal effects on target organs through the phosphoinositol system, and are closely linked with the cyclic AMP systems. There is also evidence linking hypertension with calcium deficiency (Appel et al., 1997; McCarron and Reusser, 2001).

In plants, calcium is primarily associated with the pectic materials. It is believed to have a major influence on the rheological properties of the cell wall and, consequently, on the texture and storage life of fruits and vegetables. Ca^{2+} can interact with the anionic pectic polysaccharides, coordinating with the oxygen functions of two adjacent pectin chains to form the so-called "eggbox structure," and cross-linking the chains (Rose et al., 2003). Intracellular Ca^{2+} also occupies a pivotal role in cell signal transduction (Sanders et al., 1999). The plant signals thought to be transduced through cytosolic Ca^{2+} include wounding, temperature stress, fungal elicitors, oxidative stress, anaerobiosis, abscisic acid, osmotic stress, red or blue light and mineral nutrition. Intracellular Ca^{2+} transient increases are often associated with initiation of responses. Thus, Ca^{2+} is a prominent second messenger, and it must be maintained in the cytoplasm at concentrations many orders of magnitude lower than the Ca^{2+} in the cell wall.

Horticultural crops are considered a secondary source of calcium in comparison to dairy products but, taken as a whole, fruits and vegetables account for almost 10% of the calcium in the US food supply (Table 7, Cook and Friday, 2003). Dark green leafy cabbage family vegetables and turnip greens are good calcium sources and most green leafy vegetables are potential calcium sources because of their absorbable calcium content (Jodral-Segado et al., 2003; Titchenal and Dobbs, 2007). Projects designed to test the efficacy of a health plan-based lifestyle intervention for increasing bone mineral density propose not only to increase the consumption of high calcium foods, but also of fruits and vegetables (DeBar et al., 2004).

Magnesium (Mg)

Magnesium is important in protein synthesis, release of energy from muscle storage and body temperature regulation. It is critical for proper heart function and plays a role in bone formation, as previously described. Magnesium activates over 100 enzymes.

In plants, magnesium is a constituent of the chlorophyll molecule: the porphyrin-like ring structure of chlorophylls contains a central magnesium atom coordinated to the four pyrrole rings. On the other hand, magnesium is involved in the energetic metabolism as a constituent of the Mg-ATP or Mg-ADP complex. Also, the Calvin cycle – the pathway that produces a three-carbon compound as the first stable product in the multistep conversion of CO_2 into carbohydrates – is partially regulated via stromal Mg^{2+} concentration. This nutrient also serves important biochemical functions in protein synthesis (Mengel and Kirkby, 1982).

In 2004, vegetable contribution to the total magnesium in the US food supply was an average of 14% (Table 5.7). Using current population standards, magnesium intake was found to be below adequate levels for both adults and children (Sigman-Grant et al., 2003). Mixed users, who are more likely to consume higher intakes of grains, fruit and milk products, were found to have higher magnesium densities than high-fat users, who consume significantly more servings of meat and higher levels of discretionary fat (Sigman-Grant et al., 2003). Generally, magnesium levels are significantly higher in vegetables than in fruits, but nuts are good sources of this nutrient. Dry fruits and legumes are the food groups that rank higher in magnesium content (Jodral-Segado et al., 2003).

Phosphorus (P)

Inorganic phosphate is essential for skeletal mineralization and for multiple cellular functions, including glycolysis, gluconeogenesis, DNA synthesis, RNA synthesis, cellular protein phosphorylation, phospholipid synthesis and intracellular regulatory roles (DiMeglio et al., 2000). Phosphorus is a primary bone-forming mineral. In western countries, isolated dietary phosphate deficiency is exceedingly rare, because most westerners eat high-phosphate diets, except for occasional metabolic disorders such as hyperphosphatemia (DiMeglio et al., 2000).

Phosphorus can exist in plants as both inorganic phosphate anions and organophosphate compounds (Raghothama, 1999). Unlike sulfate and nitrate, phosphate is not reduced in plants during assimilation, but remains in its oxidized state forming phosphate esters in a wide variety of organic compounds. Inorganic phosphorus constitutes a main structural component of nucleic acids and phospholipids, and plays a critical role in energy conversion in the form of high-energy phosphoester and diphosphate bonds. It is important both as a substrate and as a regulatory factor in oxidative metabolism and photosynthesis, it participates in signal transduction, and regulates the activities of an assortment of proteins by way of covalent phosphorylation/dephosphorylation reactions.

In 2004, the primary contributor of phosphorus to the food supply was the dairy group (31.3%), followed by the meat, poultry and fish group (24.9%) and grain products (19.4%) (Hiza and Bente, 2007). Fruit and vegetable contribution to the total phosphorus in the US food supply was an average of 9.5% (Table 5.7). Among tree fruits, nuts are natural sources of phosphorus.

Nitrogen (N)

The largest requirement for nitrogen in eukaryotic organisms is the biosynthesis of amino acids, building blocks of proteins and precursors of many other compounds. Proteins represent a large percentage of the human body and carry out many different cell functions. Therefore, protein synthesis is central to cell growth, differentiation, and reproduction.

Nitrogen is also an essential component of nucleic acids, cofactors and other metabolites. Several plant hormones (indole-3-acetic acid, zeatine, spermidine, etc.) contain nitrogen, or are derived from nitrogenous precursors. Alkaloids and other secondary compounds contain nitrogen, and various phenolics derive from phenylalanine and are therefore linked with amino acid metabolism. Moreover, nitrogen is a major constituent of chlorophyll. The characteristic preharvest yellow color of nitrogen-starved vegetables – a physiological disorder called chlorosis – reflects their inability to synthesize adequate amounts of green chlorophyll under nitrogen-limited conditions.

Sulfur (S)

Sulfur is an essential nutrient required for growth, primarily used to synthesize cysteine and methionine. The sulfur-containing amino acids play pivotal roles in the structural and catalytic functions of proteins. Cysteines are important because oxidizing the thiol groups of two cysteine residues can form disulfide bonds, important covalent linkages involved in establishing tertiary and, in some cases, quaternary protein structures. The dithiol↔disulfide interchange can be a regulatory mechanism, as well as a mediator of redox reactions. Sulfur is also a component of numerous essential and secondary metabolites derived from these amino acids.

Sulfur nutrition is important in the species within the order Brassicales (e.g. white cabbage, broccoli, cauliflower, capers) for the synthesis of anticarcinogenic glucosinolate compounds (reviewed in Sozzi, 2001). In caper (*Capparis spinosa* L.) flavor, 160 components were identified, including elemental sulfur (S_8) and more than 40 sulfur-containing compounds, among them thiocyanates and isothiocyanates.

Although of key importance in human and plant life, sulfur is a relatively minor component in comparison with nitrogen. Generally, it is not a growth-limiting nutrient, since sulfate, the oxidized anion, is relatively abundant in the environment.

Manganese (Mn)

Manganese is a key component of enzyme systems, including oxygen-handling enzymes. It supports brain function and reproduction and is required for blood sugar regulation. In addition, it is part of bone structure. Manganese is a cofactor in function of antioxidant enzymes, such as the mitochondrial superoxide dismutase.

In plants, manganese atoms appear to undergo successive oxidations to yield a strongly oxidizing complex that is capable of water oxidations during photosynthesis. Also like magnesium, manganese is required in enzyme reactions involving carbon assimilation. Chloroplasts are most sensitive to manganese deficiency. Among horticultural crops, spinach is a good source of manganese.

Copper (Cu)

Copper, a redox active metal, plays an important role in the oxidative defense system. In fact, oxidative stress is a characteristic of copper deficiency (Uriu-Adams and Keen, 2005). Copper is necessary for the formation of hemoglobin and is required for the function of over 30 proteins, including superoxide dismutase, ceruloplasmin, lysyl oxidase, cytochrome c oxidase, tyrosinase and dopamine-β-hydroxylase (Arredondo and Nuñez, 2005). During the past decade, there has been increasing interest in the concept that marginal deficits of this essential nutrient can contribute to the development and progression of a number of disease states, including cardiovascular disease and diabetes. Deficits of this nutrient during pregnancy can result in gross structural malformations in the fetus, and persistent neurological and immunological abnormalities in the offspring (Uriu-Adams and Keen, 2005).

In plants, copper is required for chlorophyll synthesis and in several copper-containing enzymes involved in the reduction of molecular oxygen. The availability of copper to plants, as with other trace minerals, markedly decreases as pH rises above seven. At high pH copper is strongly adsorbed to clays, iron and aluminum oxides, and organic matter. Of the micronutrients required by plants, copper often has the lowest total concentration in soil.

Between 1909 and 1919 in the US, the vegetable group was the leading source of copper (30%). In 2004, the grain group (21%) and the legumes, nuts and soy group (20%) replaced the vegetable group (17%) as the leading sources of copper (Table 7, Hiza and Bente, 2007).

Iron (Fe)

The metabolic fates of copper and iron are intimately related. The essentiality of iron, as well as that of copper, resides in its capacity to participate in one-electron exchange reactions. Systemic copper deficiency generates cellular iron deficiency that, in humans, results in diminished work capacity, reduced intellectual capacity, diminished growth, alterations in bone mineralization, and diminished immune response. Iron is required in numerous essential proteins, such as the heme-containing proteins, electron transport chain and microsomal electron transport proteins, and iron-sulfur proteins and enzymes such as ribonucleotide reductase, prolyl hydroxylase phenylalanine hydroxylase, tyrosine hydroxylase and aconitase (Arredondo and Nuñez, 2005).

Iron is a constituent of the haem complex, a naturally occurring plant chelate involved in electron transfer in a number of important plant enzymes (Mengel and Kirkby, 1982). The plant plastid stroma may contain deposits of phytoferritin, a storage form of iron similar to the ferritin of animal cells. Phytoferritin occurs almost exclusively in plastids and most abundantly in the plastids of storage organs (Briat and Lobreaux, 1997). In green vegetable leaves, there is a good correlation between iron supply and chlorophyll content. Inadequate iron nutrition results in abnormal chlorophyll development, so that deficiency begins as an interveinal chlorosis on younger leaves resulting in prominent green veins. The resultant reduction in photosynthetic capability also reduces the weight and area of affected leaves. Descriptions of causes of iron deficiency have been extensively reviewed for horticultural crops (Korcak, 1987).

Adult users of lower-fat foods consume more nutrient-dense diets, with higher intakes of iron (Kennedy et al., 2001; Sigman-Grant et al., 2003). The predominant source of iron in the American food supply is grain products, followed by the meat, poultry and fish group. Between 1909 and 1919, the vegetable group furnished an average of 18% of the iron in the food supply, but in 2004 that share dropped to an average of 10% (Table 5.7). This is partially due to a decrease in the use of white potatoes after 1920. Although potatoes are not a good source of iron, their contribution to the food supply increases when eaten in large quantities (Hiza and Bente, 2007), particularly if the skin is consumed (specifically, baked potato skin is 20-fold richer in iron than the flesh). Almonds, pistachio nuts, walnuts, pecans, etc., are very good sources of iron. Different vegetables (e.g. parsley, broccoli, kale, turnip greens and collards) and legumes (e.g. green peas and beans) are also considered good sources of iron.

Zinc (Zn)

Zinc is a pervasive microelement that plays a catalytic or a structural role in more than 200 enzymes (e.g. carboxypeptidase, liver alcohol dehydrogenase and carbonic anhydrase) involved in digestion, metabolism, reproduction, and wound healing. Zn^{2+} is a cation with various coordination possibilities and several potential geometries. Thus, it is easily adaptable for different ligands. The main role of structural Zn^{2+} in proteins is to stabilize tertiary structures. In addition, zinc has a critical role in immune response, and is an important antioxidant.

Zinc activates a number of plant cell enzymes (Romheld and Marschner, 1991), but only a few of them (i.e. alcohol dehydrogenase, superoxide dismutase, carbonic anhydrase, RNA polymerase) contain the micronutrient. Zinc can affect carbohydrate metabolism because different Zn-dependent enzymes participate in biochemical reactions involving sugars. Zinc also plays a role in the maintenance of cell membrane integrity, in the protection from $O_2^{-\bullet}$ damage, and the synthesis of RNA and tryptophan, a precursor of indole-3-acetic acid. A comprehensive review of soil, plant and management factors associated with zinc nutrition in horticultural crops has been developed by Swietlik (1999).

Fruits and vegetables account for only 1.2% and 6.4%, respectively, of the zinc in the American food supply (Hiza and Bente, 2007). As is the case for magnesium, zinc intakes may be below the adequate levels for both adults and children (Sigman-Grant et al., 2003). Fruits are poor in zinc, but pecans and walnuts are good sources of this essential mineral. Parsley is also a good source of zinc.

Sodium (Na)

Sodium is a systemic ion. It is important in electrolyte balance and essential in coregulating ATP with potassium. In addition, it has an important role in the regulation of blood pressure.

Sodium contributed from vegetables increased during the last decades (Table 5.7), due to the increased consumption of processed vegetables (largely tomatoes and white potatoes). With the exception of canned vegetables, sodium estimates in the food supply do not account for sodium added in processing. Thus, the relative contribution of vegetables to sodium reported in the food supply is likely overstated (Hiza and Bente, 2007). Table salt (NaCl) is by far the main dietary source for sodium. Olives and spinach are horticultural sources of sodium. In general, fruits are poor in sodium, and are recommended for low-sodium dietary patterns.

B. Factors influencing mineral content of fruits and vegetables

Influence of the species and the cultivar

Mineral composition varies widely in raw fruits (Table 5.8) and vegetables because of genetics. Leafy vegetables tend to have higher concentrations of nutrients that are less mobile in the plant (e.g. calcium) and depend on direct water flow rather than recycling from leaves. Tissues with higher transpiration rates generally have higher tissue calcium concentrations (Witney et al., 1990b). Concentrations of minerals may also vary widely with the cultivar. For example, both Dwarf Brazilian bananas

Table 5.8 Mineral composition of a range of fruit species. Results are in mg 100 g^{-1} fresh weight.

Fruit	Mineral									
	K	Ca	Mg	P	Mn	Cu	Fe	Zn	Na	Se
Apples, raw, with skin	107	6	5	11	0.035	0.027	0.12	0.04	1	0.0
Apricots, raw	259	13	10	23	0.077	0.078	0.39	0.2	1	0.1
Avocado, raw (California)	507	13	29	54	0.149	0.170	0.61	0.68	8	0.4
Avocado, raw (Florida)	351	10	24	40	0.095	0.311	0.17	0.4	2	–
Bananas, raw	358	5	27	22	0.270	0.078	0.26	0.15	1	1.0
Blackberries, raw	162	29	20	22	0.646	0.165	0.62	0.53	1	0.4
Blueberries, raw	77	6	6	12	0.336	0.057	0.28	0.16	1	0.1
Cherries, sweet, raw	222	13	11	21	0.070	0.060	0.36	0.07	0	0.0
Figs, raw	232	35	17	14	0.128	0.070	0.37	0.15	1	0.2
Grapefruit, raw, pink and red (California and Arizona)	147	11	9	12	0.020	0.032	0.08	0.07	1	–
Grapefruit, raw, pink and red (Florida)	127	15	8	9	0.010	0.044	0.12	0.07	0	1.4
Grapes, red or green (euro type, e.g. “Thompson seedless”), raw	191	10	7	20	0.071	0.127	0.36	0.07	2	0.1
Kiwifruit, fresh, raw	312	34	17	34	0.098	0.130	0.31	0.14	3	0.2
Lemons, raw, without peel	138	26	8	16	0.030	0.037	0.60	0.06	2	0.4
Mangos, raw	156	10	9	11	0.027	0.110	0.13	0.04	2	0.6
Melons, Cantaloupe, raw	267	9	12	15	0.041	0.041	0.21	0.18	16	0.4
Oranges, raw, California, “Valencia”	179	40	10	17	0.023	0.037	0.09	0.06	0	–
Papayas, raw	257	24	10	5	0.011	0.016	0.10	0.07	3	0.6
Peaches, raw	190	6	9	20	0.061	0.068	0.25	0.17	0	0.1
Pears, raw	119	9	7	11	0.049	0.082	0.17	0.10	1	0.1

(Continued)

Table 5.8 Continued

Fruit	Mineral									
	K	Ca	Mg	P	Mn	Cu	Fe	Zn	Na	Se
Pineapples, raw, all varieties	109	13	12	8	0.927	0.110	0.29	0.12	1	0.1
Plums, raw	157	6	7	16	0.052	0.057	0.17	0.10	0	0.0
Pomegranates, raw	259	3	3	8	–	0.070	0.30	0.12	3	0.6
Raspberries, raw	151	25	22	29	0.670	0.090	0.69	0.42	1	0.2
Strawberries, raw	153	16	13	24	0.386	0.048	0.41	0.14	1	0.4
Watermelon, raw	112	7	10	11	0.038	0.042	0.24	0.10	1	0.4

US Department of Agriculture, 2008.

(Santa Catarina Prata, *Musa* sp. AAB) and Williams (Cavendish subgroup, *Musa* sp. AAA) are considered as a good source of potassium. Nevertheless, Dwarf Brazilian bananas have higher P, Ca, Mg, Mn and Zn contents than Williams bananas (Wall, 2006). In contrast, no strawberry variety was statistically superior as a source of minerals (Hakala et al., 2003).

Because of the distribution of vascular tissue, sink characteristics and metabolic rates, higher mineral concentrations are usually found in the skin and seeds, with lower concentrations in the flesh of fruits. Tissues with higher metabolic rates (epicarp, core) may have higher requirements for nitrogen and phosphorus. Rapidly expanding or large-celled tissues are unlikely to have high calcium concentrations. In mature fruit, the calcium concentration is highest in the peel (Saure, 2005).

Influence of preharvest factors and practices

Orchard location has proved to have important effects on fruit and vegetable mineral content (Table 5.8). For example, potassium content in bananas markedly differs between different locations in Hawaii, from 288 mg $100\,g^{-1}$ in Kapaa to 485 mg $100\,g^{-1}$ in Waimanalo (Wall, 2006). Papaya cv. Rainbow is not very rich in potassium, but its content also varies between locations, from 113 mg $100\,g^{-1}$ on the island of Hawaii to 203 mg $100\,g^{-1}$ on the island of Maui (Wall, 2006).

Mineral composition fluctuates widely in raw fruits and vegetables, because of preharvest factors (soil fertility – including pH and availability of nutrients – moisture content of the soil, growth temperature) and cultural practices (amount and timing of fertilization and irrigation, application of plant growth regulators, pruning and thinning of tree fruit species, etc.). Most of these practices have been established primarily for productivity goals, and not as a medium to better human health, horticultural crop postharvest life or flavor quality (Crisosto and Mitchell, 2002). Usually, fertilizers are applied directly to the soil to raise nutrient levels, if they are inadequate for the successful growth of the crop, and to maintain soil fertility, which will decline if nutrient removal from the soil (via crop uptake, leaching, volatilization or denitrification) exceeds nutrients added via weathering of minerals and mineralization of organic matter. Nitrogen is the most frequently deficient and most commonly applied fertilizer in orchards, while addition to the soil of phosphorus and potassium is warranted when soil-test results, plant response or tissue analysis indicate a requirement. N-P-K addition with irrigation water (fertigation) has several advantages, including the ability to transport soluble nutrients directly to the root zone whenever the plant is watered. Thus, fertilizer amounts and timing can be precise and adjusted to coincide more closely with actual plant demand. Calcium additions can be large when lime is applied to increase soil pH. Most micronutrients are rarely applied via soil and can be directly supplied via spray application of dilute concentrations of minerals to the canopy. In the case of fruits, the quantity of nutrients capable of being absorbed through the waxy cuticle is often small relative to nutrient demand, but can ameliorate deficiency symptoms and improve fruit quality (Swietlik and Faust, 1984).

An excessive supply of nutrients relative to photosynthesis can develop when the rate of nutrient assimilation is high relative to net photosynthesis. In this case, an accumulation of nutrients in fruits and vegetables can reach levels that are toxic either to the plant or to consumers. For example, excessive nitrogen application can lead to potentially harmful accumulations of nitrate nitrogen, especially in leafy greens and potatoes (Eppendorfer, 1978; Blom-Zandstra, 1989). These nutrient imbalances also affect horticultural crop quality, as discussed above.

Many other factors influencing nutrient accumulation are related to nutrient transport and source-sink relations. For example, alterations in water economy affect calcium input. Since calcium is transported mainly in the transpiration stream (Grange and Hand, 1987), bagging fruit may result in lower calcium concentrations and higher calcium-related disorders (Witney et al., 1991; Hofman et al., 1997), due to increased relative humidity. Nevertheless, evidence is not conclusive (Saure, 2005). Canopy position and crop load also influence calcium input. Tree vigor is usually associated with lower calcium and magnesium content in fruits (Witney et al., 1990a,b). Fruit from upper parts of the canopy tend to show lower calcium contents (Ferguson and Triggs, 1990), and heavy cropping trees have fruit with higher calcium and lower potassium concentrations (Ferguson and Watkins, 1992). Nevertheless, calcium transport to fruit may be based on a hormonal control; gibberellins have been shown to inhibit calcium translocation (Saure, 2005).

Tree size, spacing, row orientation, canopy shape and training system influence light distribution within fruit trees, which in turn may affect mineral composition. In grapes, improvement of light penetration into the canopy enhanced anthocyanin and soluble phenol levels, but reduced potassium content (Prange and DeEll, 1997). In kiwifruit, light promoted calcium accumulation (Montanaro et al., 2006). The finding was not fully explained by fruit transpiration, a regulatory mechanism governed by phytohormones, which could play a role in determining calcium concentrations. Besides, the effect of sunlight does not seem to be universal: avocado fruit from the sunny side of trees did not contain significantly more calcium than fruit from the shaded side (Witney et al., 1990a).

The mineral content of some horticultural species seems to be affected under intensive culture systems (e.g. glasshouse) or organic conditions. Tomato fruit showed higher calcium and lower potassium, magnesium and sodium concentrations when grown on organic (compost/soil mix) versus hydroponic substrates (Premuzic et al., 1998). Smith (1993) reported higher mineral contents in organically cultivated apples, pears, potatoes and corn in comparison to conventionally cultivated ones. In contrast, Petersen and Pedersen (1991) did not find differences in mineral content between organically and conventionally cultivated vegetables. Hakala and co-workers (2003) reported that organic cultivation did not affect strawberry mineral contents consistently.

Postharvest practices influencing mineral content of fruits and vegetables

Postharvest treatments with minerals, primarily calcium, are used to improve the storage life and quality of different fruits and vegetables. In the last decade, the industry has been encouraged to fortify food and beverages with calcium. Increasing the calcium content of horticultural crops may give consumers new ways to enhance their calcium intake without resorting to supplements. In addition, the use of phosphorous-free sources of calcium can help to obtain a good balance of calcium and phosphorus in the diet (Martín-Diana et al., 2007).

Two major methods of postharvest application of calcium in horticultural crops are used: (1) dipping-washing and (2) impregnation processes (Martín-Diana et al., 2007). Dipping treatments are used for fresh, sensitive products, such as leafy vegetables. The delicate texture of berries prevents the use of vacuum infiltration, and dips in a solution of $CaCl_2$ are used (García et al., 1996), followed by the removal of excess washing solution. On the other hand, impregnation modifies the composition of food material through partial water removal and impregnation of solutes, with no impairment of the material integrity. The process-driven forces can be osmotic gradient between the sample and solution, application of vacuum followed by atmospheric condition restoration, or both. Calcium chloride has been widely used as firming agent and preservative for both whole and fresh-cut fruits and vegetables, as discussed above.

C. Effect of minerals on fruit and vegetable quality and consumer acceptance

Consumers buy certain items as good sources of specific minerals: potatoes and sweet potatoes for potassium, bananas for magnesium and potassium, spinach for iron, potassium, magnesium and as a non-dairy source of calcium. Mineral content of products is usually determined by ashing and atomic absorption (Pomeranz and Meloan, 1987). Without advanced analytical equipment, the consumer cannot detect differences in individual products at the point of purchase (Institute of Food Technologists, 1990). These attributes are considered credence attributes (see also Chapter 3), because they cannot be detected readily either by visual inspection or by consumption. Therefore, there is little or no incentive to measure mineral content in a quality control program, unless specific nutritional claims can be made.

Nevertheless, the consumer uses other criteria to judge quality. Quality attributes (see Chapter 3) include purchase attributes (i.e. size, color, firmness to the touch, aroma and absence of defects) and consumption attributes (i.e. flavor, mouth feel). Many of these quality characteristics are also affected by the mineral content and constitute part of a wider range of factors affecting fruit and vegetable acceptability. Acceptability, which is defined as "the level of continued purchase or consumption by a specific population" (Land, 1988), determines the consumption levels of many hidden essential nutrients: vitamins, antioxidants, fiber. Thus, the effect of minerals on horticultural crop quality attributes and consumer acceptance should be considered.

Effect of minerals on color

In apples and pears, both leaf and fruit nitrogen positively correlates with fruit green background color (Raese, 1977; Marsh et al., 1996), regardless of the rootstock used (Fallahi et al., 1985). Manganese has also been associated with green ground color in apples (Deckers et al., 1997). Excessive nitrogen application inhibits background color change from green to yellow and induces deficient reddish blush development and poor edible quality of peaches (Sistrunk, 1985; Crisosto et al., 1995; Crisosto et al., 1997). High nitrogen application also decreases fruit color in grapes (Kliewer, 1977). In *Citrus*, nitrogen is associated with an undesirable retardation of endogenous chlorophyll catabolism (Koo et al., 1974) and postharvest treatments with ethylene may be required to accelerate the loss of the green color (de-greening).

In apples, amelioration of potassium deficiencies can increase red fruit color, but such an effect is often not apparent when tree potassium status is adequate (Neilsen and Neilsen, 2003). In tomatoes, potassium deficiency is associated with lower levels of lycopene and higher levels of β-carotene (Trudel and Ozbun, 1971).

Effect of minerals on flavor

Nitrogen status negatively correlates with soluble solids, both in apples (Fallahi et al., 1985; Dris et al., 1999) and in pears (Raese, 1977). In contrast, soluble solid content increases with increasing fertilizer nitrogen levels in tomatoes (Barringer et al., 1999).

Apple calcium and phosphorus were both negatively correlated with fruit soluble solids at harvest, and after six months of 0°C storage, while fruit K/Ca ratio was positively correlated with titratable acidity (Fallahi et al., 1985). In mango, total soluble solids increased when zinc sulfate fertilizer was applied to the soil (Bahadur et al., 1998).

In "Fino 49" lemons, salinity reduces juice percentage and impairs juice quality by decreasing the total soluble solids and titratable acidity (García-Sánchez et al., 2003). Reduction of titratable acidity could be due to the greater accumulation of Cl^-, compared to Na^+, which could be compensated for by the degradation of organic acids for charge balance.

Minerals are also known to affect the production of several classes of volatile compounds in pome fruit (reviewed in Mattheis and Fellman, 1999). In fresh onions, increased sulfur availability enhances pungency and total sulfur flavor, but decreases the amounts of precursors for volatiles imparting "green" and "cabbage" notes (Randle, 1997).

Effect of minerals on firmness

Excess nitrogen fertilization can result in a decrease in firmness (Reeve, 1970; Prange and DeEll, 1997). Low phosphorus may also result in a loss of firmness in low-calcium content fruit (Sharples, 1980). The relationship between calcium and fruit firmness has been extensively studied and reviewed (Ferguson, 1984; Poovaiah et al., 1988; Harker et al., 1997; Sams, 1999). Higher firmness values and/or slower softening rates after harvest/storage have been associated with higher calcium concentrations, or with calcium applications in different fruit species, such as apples and pears (Fallahi et al., 1985; Raese and Drake, 1993, 2000a,b, 2002; Gerasopoulos and Richardson, 1999; Benavides et al., 2001); kiwifruit (Hopkirk et al., 1990; Gerasopoulos and Drogoudi, 2005); and strawberries (Chéour et al., 1990). Calcium foliar sprays on peaches and nectarines lead to a slight increase of calcium content (Manganaris et al., 2005a, 2006). Under Californian conditions, no consistent effect on fruit quality of mid- or late-season peach and nectarine varieties was found (reviewed in Crisosto et al., 1997).

Postharvest calcium treatments have been reported to retain fruit firmness in different horticultural products, among them, apples (Wang et al., 1993; Conway et al., 1994), peaches (Manganaris et al., 2005b, 2007), strawberries (Morris et al., 1985; García et al., 1996), lemons (Valero et al., 1998; Martínez-Romero et al., 1999), sliced pears and strawberries (Rosen and Kader, 1989). Calcium effects on fruit firmness are attributable to calcium's ability to cross-link with the pectic polysaccharide network by ionic association. Calcium binding may reduce the accessibility of cell wall degrading enzymes to their substrates.

Effect of minerals on rots, physiological disorders and nutritional value

In calcium-treated fruit, the association between firmness retention and reduced rot incidence suggests that calcium may affect both processes simultaneously through its cellular role in strengthening plant cell walls (García et al., 1996; Fallahi et al., 1997; Conway et al., 1999). On the other hand, high nitrogen fertilization increases susceptibility to decay caused by *Monilinia fructicola* (brown rot) in nectarines (Daane et al., 1995). Wounded and brown rot inoculated Fantasia and Flavortop nectarines from trees having more than 2.6% leaf nitrogen are more susceptible to *Monilinia fructicola* than fruit from trees with 2.6% or less leaf nitrogen (Michailides et al., 1993).

Consumers consider that fruits have less predictable eating quality than manufactured snacks. In fact, the effect of nutrients on the final quality of horticultural products may not become evident until harvest, distribution or consumption. The expression "latent damage" was coined by Peleg (1985) and later defined by Shewfelt (1986) as "damage incurred at one step but not apparent until a later step" to describe the result of non-visible quality loss. Physiological disorders may be a type of latent damage. Some physiological disorders relate to the imbalance between nutrients. Calcium is the nutrient most commonly associated with postharvest disorders. A calcium-deficient status is considered an important preharvest factor related to numerous physiological disorders of fruits and vegetables, such as bitter pit in pome fruit, blossom-end rot in tomato, blackheart in celery, cracking and cavity spot in carrot and tip burn in lettuce and cabbage (reviewed in Ferguson et al., 1999), although some authors have questioned the role of calcium in these disorders (Saure, 1998, 2001). Other calcium-related disorders are associated with long-term cold storage, such as chilling injury in muskmelon (Combrink et al., 1995) and avocado (Chaplin and Scott, 1980). Postharvest calcium applications limited the incidence of chilling injury in peach fruit, expressed as flesh browning, after four weeks cold storage at 5°C (Manganaris et al., 2007). Nevertheless, preharvest calcium applications showed no effect on the onset of chilling injury in peaches and nectarines (reviewed in Lurie and Crisosto, 2005).

Magnesium and potassium have been considered as part of an index to predict bitter pit (Bramlage et al., 1985; Autio et al., 1986). Fallahi and Righetti (1984) proposed the relation between nitrogen and calcium as an important component of a diagnosis and recommendation system (DRIS) for apple. High rates of nitrogen application exacerbate the incidence of many physiological disorders, such as apricot pit burn (Bussi and Amiot, 1998, 2003).

In addition, minerals can influence the concentrations of other nutrients in horticultural crops. Nitrogen fertilizers at high rates tend to decrease the concentration of vitamin C in fruits (citrus juices) and vegetables (potatoes, cauliflower, white cabbage, crisphead lettuce, etc.) while increased potassium fertilization increases ascorbic acid content (reviewed in Lee and Kader, 2000).

Bibliography

Agius, F., Gonzalez-Lamothe, R., Caballero, J.L., Muñoz-Blanco, J., Botella, M.A., Valpuesta, V. (2003). Engineering increased vitamin C levels in plants by overexpression of a D-galacturonic acid reductase. Nature Biotechnol., 21, 177–181.

Ames, B.M., Shigena, M.K., Hagen, T.M. (1993). Oxidants, antioxidants and the degenerative diseases of aging. Proc. Natl. Acad. Sci. U.S.A., 90, 7915–7922.

Anderson, J.S., Perryman, S., Young, L., Prior, S. (2007). Dietary fiber. Colorado State University Nutrition Resources. N 9333. http://www.ext.colostate.edu/PUBS/FOODNUT/09333.html Accessed April 2008.

Appel, L.J., Moore, T.J., Oberzanek, E., Vollmer, W.M., Svetkey, L.P., Sacks, F.M. (1997). A clinical trial of the effect of dietary patterns on blood pressure. N. E. J. Med., 336, 1117–1124.

Arredondo, M., Núñez, M.T. (2005). Iron and copper metabolism. Mol. Aspects Med., 26, 313–327.

Asada, K. (1999). The water–water cycle in chloroplasts: scavenging of active oxygen and dissipation of excess photons. Annu. Rev. Plant Physiol. Plant Mol. Biol., 50, 601–639.

Asami, D.K., Hong, Y.H., Barrett, D.M., Mitchell, A.E. (2003). A comparison of the total phenolic and ascorbic acid contents of freeze-dried and air-dried marionberry, strawberry and corn grown using conventional, organic and sustainable agricultural practices. J. Agric. Food Chem., 51, 1237–1241.

Asp, N.G. (1994). Nutritional classification of food carbohydrates. Am. J. Clin. Nutr., 59, S679–S681.

Autio, W.R., Bramlage, W.J., Weis, S.A. (1986). Predicting disorders of "Cox's Orange Pippin" and "Bramley's Seedling" apples by regression equations. J. Am. Soc. Hort. Sci., 111, 738–742.

Ayala-Zavala, J.F., Wang, S.Y., Wang, C.Y., Gonzalez-Aguilar, G.A. (2004). Effect of storage temperatures on antioxidant capacity and aroma compounds in strawberry fruit. Lebensm. Wiss. Technol., 37, 687–695.

Bahadur, L., Malhi, C.S., Singh, Z. (1998). Effect of foliar and soil applications of zinc sulphate on zinc uptake, tree size, yield, and fruit quality of mango. J. Plant Nutr., 21, 589–600.

Barrett, D.M., Weakley, C., Diaz, J.V., Watnik, M. (2007). Qualitative and nutritional differences in processing tomatoes grown under commercial organic and conventional production systems. J. Food Sci., 72, C441–C450.

Barringer, S.A., Bennett, M.A., Bash, W.D. (1999). Effect of fruit maturity and nitrogen fertilizer levels on tomato peeling efficiency. J. Veg. Crop Prod., 5, 3–11.

Benavides, A., Recasens, I., Casero, T., Puy, J. (2001). Chemometric analyses of "Golden Smoothee" apples treated with two preharvest calcium spray strategies in the growing season. J. Sci. Food Agric., 81, 943–952.

Benbrook, C.M. (2005). Elevating antioxidant levels in food through organic farming and food processing. An Organic Center state of science review, www.organic-center.org/reportfiles/Antioxidant_SSR.pdf Accessed April 2008.

Bernhardt, S., Schlich, E. (2006). Impact of different cooking methods on food quality: Retention of lipophilic vitamins in fresh and frozen vegetables. J. Food Eng., 77, 327–333.

Blom-Zandstra, M. (1989). Nitrate accumulation in vegetables and its relationship with quality. Annals Appl. Biol., 115, 533–561.

Boerjan, W., Ralph, J., Baucher, M. (2003). Lignin biosynthesis. Annu. Rev. Plant Biol., 54, 519–546.

Bramlage, W.J., Weis, S.A., Drake, M. (1985). Predicting poststorage disorders of "McIntosh" apples from preharvest mineral analyses. J. Am. Soc. Hort. Sci., 110, 493–498.

Brett, C.T., Waldron, K.W. (1996). Physiology and biochemistry of plant cell walls. In: 1. Topics in plant functional biology, M. Black, B. Charlwood (eds). Chapman and Hall, London, UK, p. 230.

Briat, J.-F., Lobreaux, S. (1997). Iron transport and storage. Trends Plant Sci., 2, 187–193.

Brummell, D.A. (2006). Cell wall disassembly in ripening fruit. Funct. Plant Biol., 33, 103–119.

Brummell, D.A., Harpster, M.H. (2001). Cell wall metabolism in fruit softening and quality and its manipulation in transgenic plants. Plant Mol. Biol., 47, 311–339.

Bussi, C., Amiot, M.J. (2003). Effects of fertilizer rates and dates of application on apricot (cv. Bergeron) cropping and pitburn. Sci. Hort., 98, 139–147.

Bussi, C., Amiot, M.J. (1998). Effects of nitrogen and potassium fertilization on the growth, yield and pitburn of apricot (cv. Bergeron). J. Hort. Sci. Biotechnol., 73, 387–392.

Cantos, E., Espín, J.C., Tomás-Barberán, F.A. (2001). Postharvest induction modeling method using UV irradiation pulses for obtaining resveratrol-enriched table grapes: a new "functional" fruit?. J. Agric. Food. Chem., 49, 5052–5058.

Cao, G., Sofic, E., Prior, R.L. (1996). Antioxidant capacity of tea and common vegetables. J. Agric. Food Chem., 44, 3426–3431.

Carpita, N., McCann, M. (2000). The plant cell wall. In: Biochemistry and Molecular Biology of Plants, B. Buchanan, W. Gruissem, R. Jones (eds). American Society of Plant Physiologists, pp. 52–109.

Carr, A.C., Frei, B. (1999). Toward a new recommended dietary allowance for vitamin C based on antioxidant and health effects in humans. Am. J. Clin. Nutr., 69, 1086–1107.

Castrejón, A.D., Eichholz, I., Rohn, S., Kroh, L.W., Huyskens-Keil, S. (2008). Phenolic profile and antioxidant activity of highbush blueberry (*Vaccinium corymbosum* L.) during fruit maturation and ripening. Food Chem., 109, 564–572.

Chaplin, G.R., Scott, K.C. (1980). Association of calcium in chilling injury susceptibility of stored avocados. HortScience, 15, 514–515.

Chassy, A., Bui, L., Renaud, E.N.C., Van Horn, M., Mitchell, A. (2006). Three-year comparison of the content of antioxidant microconstituents and several quality characteristics in organic and conventionally managed tomatoes and bell peppers. J. Agric. Food Chem., 54, 8244–8252.

Chatterjee, I.B. (1973). Evolution and the biosynthesis of ascorbic acid. Science, 182, 1271–1272.

Chéour, F., Willemot, C., Arul, J., Desjardins, Y., Makhlouf, I., Charest, P.M., Gosselin, A. (1990). Foliar application of calcium chloride delays postharvest ripening of strawberry. J. Am. Soc. Hort. Sci., 115, 789–792.

Choi, Y.J., Tomás-Barberán, F.A., Saltveit, M.E. (2005). Wound-induced phenolic accumulation and browning in lettuce (*Lactuca sativa* L.) leaf tissue is reduced by exposure to n-alcohols. Postharvest Biol. Technol., 37, 47–55.

Cohen, A.J., Roe, F.J.C. (2000). Review of risk factors for osteoporosis with particular reference to a possible aetiological role of dietary salt. Food Chem. Toxicol., 38, 237–253.

Combrink, N.J.J., Jacobs, G., Maree, P.C.J. (1995). The effect of calcium and boron on the quality of muskmelons. J. Southern African Soc. Hort. Sci., 5, 33–38.

Conway, W.S., Janisiewicz, W.J., Klein, J.D., Sams, C.E. (1999). Strategy for combining heat treatment, calcium infiltration, and biocontrol to reduce postharvest decay of "Gala" apples. HortScience, 34, 700–704.

Conway, W.S., Sams, C.E., Wang, C.Y., Abbott, J.A. (1994). Additive effects of postharvest calcium and heat treatment on reducing decay and maintaining quality in apples. J. Am. Soc. Hort. Sci., 119, 49–53.

Cook, A.J., Friday, J.E. (2003). Food mixture of ingredient sources for dietary calcium: Shifts in food group contributions using four grouping protocols. J. Am. Diet. Assoc., 103, 1513–1519.

Crisosto, C.H., Mitchell, J.P. (2002). Preharvest factors affecting fruit and vegetable quality. In: Postharvest technology of horticultural crops, A.A. Kader (ed.). Publication 3311. University of California, Agriculture and Natural Resources, CA, USA, pp. 49–54.

Crisosto, C.H., Johnson, R.S., DeJong, T., Day, K.R. (1997). Orchard factors affecting postharvest stone fruit quality. HortScience, 32, 820–823.

Crisosto, C.H., Mitchell, F.G., Johnson, R.S. (1995). Factors in fresh market stone fruit quality. Postharvest News and Information, 6, 17N–21N.

D'Ambrosio, C., Giorio, G., Marino, I., Merendino, A., Petrozza, A., Salfi, L., Stigliani, A.L., Francesco, L. (2004). Virtually complete conversion of lycopene into β-carotene in fruits of tomato plants transformed with the tomato *lycopene β-cyclase* (t*lcy-b*) cDNA. Plant Sci., 166, 207–214.

Daane, K.M., Johnson, R.S., Michailides, T.J., Crisosto, C.H., Dlott, J.W., Ramirez, H.T., Yokota, G.T., Morgan, D.P. (1995). Excess nitrogen raises nectarine susceptibility to disease and insects. California Agriculture, 49(4), 13–17.

de Ancos, B., Gonzalez, E.M., Cano, M.P. (2000). Ellagic acid, vitamin C, and total phenolic contents and radical scavenging capacity affected by freezing and frozen storage in raspberry fruit. J. Agric. Food Chem., 48, 4565–4570.

de Azevedo, C.H., Rodriguez-Amaya, D.B. (2005). Carotenoid composition of kale as influenced by maturity, season and minimal processing. J. Sci. Food Agric., 85, 591–597.

Debar, L.L., Rittenbaugh, C., Vuckovik, N., Stevens, V.J., Aickin, M., Elliot, D., Moe, E., Orwoll, E., Ernst, D., Irvin, L.M. (2004). YOUTH: decisions and challenges in designing an osteoporosis prevention intervention for teen girls. Prev. Med., 39, 1047–1055.

Deckers, T., Daemen, E., Lemmens, K., Missotten, C., Val, J. (1997). Influence of foliar applications on Mn during summer on the fruit quality of Jonagold. Acta Hort., 448, 467–473.

Deming, D.M., Baker, D.H., Erdman, J.W. (2002a). The relative vitamin A value of 9-cis β-carotene is less and that of 13-cis β-carotene may be greater than the accepted 50% that of all-trans β-carotene in gerbils. J. Nutr., 132, 2709–2712.

Deming, D.M., Teixeira, S.R., Erdman, J.W. (2002b). All-trans-β-carotene appears to be more bioavailable than 9-cis or 13-cis-β-carotene in gerbils given single oral doses of each isomer. J. Nutr., 132, 2700–2708.

Dimeglio, L.A., White, K.E., Econs, M.J. (2000). Disorders of phosphate metabolism. Endocrinology and Metabolism Clinics of North America, 29, 591–609.

Dragsted, L.O. (2003). Antioxidant actions of polyphenols in humans. Int. J. Vitam. Nutr. Res., 73, 112–119.

Dris, R., Bennett, M.A., Bash, E. (1999). Relationship between leaf and fruit minerals and fruit quality attributes of apples grown under northern conditions. J. Plant Nutr., 22, 1839–1851.

Duthie, G.G., Gardner, P.T., Kyle, J.A.M. (2003). Plant polyphenols: are they the new magic bullet?. Proc. Nutr. Soc., 62, 599–603.

Eitenmiller, R.R., Landen, W.O. (1999). Vitamin analysis for the health and food sciences. CRC Press, Boca Raton, London, New York, Washington, pp. 223–270.

Ekholm, P., Reinivuo, H., Mattila, P., Pakkala, H., Koponen, J., Happonen, A., Hellström, J., Ovaskainen, M.-L. (2007). Changes in the mineral and trace element contents of cereals, fruits and vegetables in Finland. J. Food Compos. Anal., 20, 487–495.

Eppendorfer, W.H. (1978). Effects of N-fertilisation on amino acid composition and nutritive value of spinach, kale, cauliflower, and potatoes. J. Sci. Food Agric., 29, 305–311.

Fairweather-Tait, S., Hurrell, R.F. (1996). Bioavailability of minerals and trace elements. Nutr. Res. Rev., 9, 295–324.

Fallahi, E., Righetti, T.L. (1984). Use of diagnosis and recommendation integrated system (DRIS) in apple. HortScience, 19, 54.

Fallahi, E., Conway, W.S., Hickey, K.D., Sams, C.E. (1997). The role of calcium and nitrogen in postharvest quality and disease resistance of apples. HortScience, 32, 831–835.

Fallahi, E., Richardson, D.G., Westwood, M.N., Chaplin, M.H. (1985). Relationships among mineral nutrition, ethylene and post-harvest physiology in apples on six rootstocks. Sci. Hort., 25, 163–175.

Ferguson, I.B. (1984). Calcium in plant senescence and fruit ripening. Plant Cell Environ., 7, 477–489.

Ferguson, I.B., Triggs, C.M. (1990). Sampling factors affecting the use of mineral analysis of apple fruit for prediction of bitter pit. N. Z. J. Crop Hort. Sci., 18, 147–152.

Ferguson, I.B., Watkins, C.B. (1992). Crop load affects mineral concentrations and incidence of bitter pit in "Cox's Orange Pippin" apple fruit. J. Am. Soc. Hort. Sci., 117, 373–376.

Ferguson, I., Volz, R., Woolf, A. (1999). Preharvest factors affecting physiological disorders of fruit. Postharvest Biol. Technol., 15, 255–262.

Fisher, R.L., Bennett, A.B. (1991). Role of cell wall hydrolases in fruit ripening. Annu. Rev. Plant Physiol. Plant Mol. Biol., 42, 675–703.

Fraser, P.D., Romer, S., Shipton, C.A., Mills, P.B., Kiano, J.W., Misawa, N., Drake, R.G., Schuch, W., Bramley, P.M. (2002). Evaluation of transgenic tomato plants expressing an additional phytoene synthase in a fruit-specific manner. Proc. Natl. Acad. Sci. U.S.A., 99, 1092–1097.

Frossard, E., Bucher, M., Machler, F., Mozafar, A., Hurrell, R. (2000). Potential for increasing the content and bioavailability of Fe, Zn and Ca in plants for human nutrition. J. Sci. Food Agric., 80, 861–879.

García, J.M., Herrera, S., Morilla, A. (1996). Effects of postharvest dips in calcium chloride on strawberry. J. Agric. Food Chem., 44, 30–33.

García-Sánchez, F., Carvajal, M., Porras, I., Botía, P., Martínez, V. (2003). Effects of salinity and rate of irrigation on yield, fruit quality and mineral composition of "Fino 49" lemon. Eur. J. Agron., 19, 427–437.

Gautier, H., Diakou-Verdin, V., Bernard, C., Reich, M., Buret, M., Bourgaud, R., Poessel, J.L., Caris-Veyrat, C., Genard, M. (2008). How does tomato quality (sugar, acid, and nutritional quality) vary with ripening stage, temperature, and irradiance?. J. Agric. Food. Chem., 56, 1241–1250.

Gerasopoulos, D., Drogoudi, P.D. (2005). Summer-pruning and preharvest calcium chloride sprays affect storability and low temperature breakdown incidence in kiwifruit. Postharvest Biol. Technol., 36, 303–308.

Gerasopoulos, D., Richardson, D.G. (1999). Storage temperature and fruit calcium alter the sequence of ripening events of "d'Anjou" pears. HortScience, 34, 316–318.

González-Barrio, R., Beltrán, D., Cantos, E., Gil, M.I., Espín, J.C., Tomás-Barberán, F.A. (2006). Comparison of ozone and UV-C treatments on the postharvest stilbenoid monomer, dimer, and trimer induction in var. "Superior" white table grapes. J. Agric. Food Chem., 54, 4222–4228.

Grange, R.I., Hand, D.W. (1987). A review of the effects of atmospheric humidity on the growth of horticultural crops. J. Hort. Sci., 62, 125–134.

Gross, K.C., Sams, C.E. (1984). Changes in cell wall neutral sugar composition during fruit ripening: a species survey. Phytochemistry, 23, 2457–2461.

Grusak, M.A., Della Penna, D. (1999). Improving the nutrient composition of plants to enhance human nutrition and health. Annu. Rev. Plant Physiol. Plant Mol. Biol., 50, 133–161.

Gu, L., Kelm, M., Hammerstone, J., Beecher, G., Holde, J., Haytowitz, D., Gebhardt, S., Prior, R. (2004). Concentrations of proanthocyanidins in common foods and estimations of normal consumption. J. Nutr., 134, 613–617.

Guillon, F., Champ, M. (2000). Structural and physical properties of dietary fibres, and consequences of processing on human physiology. Food Res. Int., 33, 233–245.

Hakala, M., Lapveteläinen, A., Huopalahti, R., Kallio, H., Tahvonen, R. (2003). Effects of varieties and cultivation conditions on the composition of strawberries. J. Food Compos. Anal., 16, 67–80.

Hancock, R.D., Viola, R. (2005). Improving the nutritional value of crops through enhancement of L-ascorbic acid (vitamin C) content: Rationale and biotechnological opportunities. J. Agric. Food Chem., 53, 5248–5257.

Harker, F.R., Redgwell, R.J., Hallett, I.C., Murray, S.H. (1997). Texture of fresh fruit. Hort. Rev., 20, 121–224.

Hiza, H.A.B., Bente, L. (2007). Nutrient content of the U.S. food supply, 1909–2004: A summary report. Home Economics Research Report Number 57. U.S. Department of Agriculture, Center for Nutrition Policy and Promotion, Washington, DC, USA.

Hofman, P.J., Smith, L.G., Joyce, D.C., Johnson, G.I., Meiburg, G.F. (1997). Bagging of mango (Mangifera indica cv. "Keitt") fruit influences fruit quality and mineral composition. Postharvest Biol. Technol., 12, 83–91.

Hopkirk, G., Harker, F.R., Harman, J.E. (1990). Calcium and firmness of kiwifruit. N. Z. J. Crop Hort. Sci., 18, 215–219.

Huber, D.J., O'Donoghue, E.M. (1993). Polyuronides in avocado (*Persea americana*) and tomato (*Lycopersicon esculentum*) fruits exhibit markedly different patterns of molecular weight downshifts during ripening. Plant Physiol., 102, 473–480.

Ignarro, L.J., Balestrieri, M.L., Napoli, C. (2007). Nutrition, physical activity, and cardiovascular disease: An update. Cardiovasc. Res., 73, 326–340.

Institute of Food Technologists (1990). Quality of fruits and vegetables. A scientific status summary by the Institute of Food Technologists' Expert Panel on Food Safety and Nutrition. Food Technol., 44, 99–106.

Institute of Medicine (2001). Dietary reference intakes proposed definition of dietary fiber. A report of the panel on the definition of dietary fiber and the Standing Committee on the scientific evaluation of dietary reference intakes. Food and Nutrition Board, National Academy Press, Washington, DC, USA.

Jayaraj, J., Devlin, R., Punja, Z. (2008). Metabolic engineering of novel ketocarotenoid production in carrot plants. Transgenic Res. 17, 489–501.

Jeremy, J.Y., Shukla, N., Muzaffar, S., Handley, A., Angelini, G.D. (2004). Reactive oxygen species, vascular disease and cardiovascular surgery. Curr. Vasc. Pharmacol., 2, 229–236.

Jodral-Segado, A.M., Navarro-Alarcón, M., López-G de la Serrana, H., López Martínez, M.C. (2003). Magnesium and calcium contents in foods from SE Spain: Influencing factors and estimation of daily dietary intakes. Sci. Total Environ., 312, 47–58.

Kalt, W., Forney, C.F., Martin, A., Prior, R.L. (1999). Antioxidant capacity, vitamin C, phenolics, and anthocyanins after fresh storage of small fruits. J. Agric. Food Chem., 47, 4638–4644.

Kays, S.J. (1997). Postharvest Physiology of Perishables Plant Products. Exon Press, Athens, GA, USA.

Kennedy, E., Bowman, S., Powell, R. (2001). Assessment of the effect of fat-modified foods on diet quality in adults, 19–50 years, using data from the Continuing Survey of Food Intake by Individuals. J. Am. Diet. Assoc., 101, 455–460.

Kevers, C., Falkowski, M., Tabart, J., Defraigne, J.O., Dommes, J., Pincemail, J. (2007). Evolution of antioxidant capacity during storage of selected fruits and vegetables. J. Agric. Food Chem., 55, 8596–8603.

Kliewer, W.M. (1977). Influence of temperature, solar radiation, and nitrogen on coloration and composition of "Emperor" grapes. Am. J. Enol. Vit., 28, 96–103.

Kobayashi, M., Matoh, T., Azuma, J. (1996). Two chains of rhamnogalacturonan II are cross-linked by borate-diol ester bonds in higher plant cell walls. Plant Physiol., 110, 1017–1020.

Koo, R.J.C., Young, T.W., Reese, R.L., Kesterson, J.W. (1974). Effect of nitrogen, potassium and irrigation on yield and quality of lemon. J. Am. Soc. Hort. Sci., 99, 289–291.

Kopsell, D.A., Kopsell, D.E. (2006). Accumulation and bioavailability of dietary carotenoids in vegetable crops. Trends Plant Sci., 11, 499–507.

Korcak, R.F. (1987). Iron deficiency chlorosis. Hort. Rev., 9, 133–186.

Land, D.G. (1988). Negative influences on acceptability and their control. In: Food Acceptability, D.M.H. Thomson (ed.). Elsevier, New York, NY, USA, pp. 475–483.

Langcake, P., Pryce, R.J. (1976). The production of resveratrol by *Vitis vinifera* and other members of the *Vitaceae* as a response to infection and injury. Physiol. Plant Pathol., 9, 77–86.

Larson, R.A. (1988). The antioxidants of higher plants. Phytochemistry, 27, 969–972.

Le Marchand, L. (2002). Cancer preventive effects of flavonoids – a review. Biomed. Pharmacother., 56, 296–301.

Lee, S.K., Kader, A.A. (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biol. Technol., 20, 207–220.

Levine, M., Wang, Y.H., Padayatty, S.J., Morrow, J. (2001). A new recommended dietary allowance of vitamin C for healthy young women. Proc. Natl. Acad. Sci. U.S.A., 98, 9842–9846.

Lin, P.-H., Aickin, M., Champagne, C., Craddick, S., Sacks, F.M., McCarron, P., Most-Windhauser, M.M., Rukenbrod, F., Haworth, L. (2003). Food group sources of nutrients in the dietary patterns of the DASH-Sodium trial. J. Am. Diet. Assoc., 103, 488–496.

Liu, R.H. (2007). Whole grain phytochemicals and health. J. Cereal Sci., 46, 207–219.

Liu, Y., Roof, S., Ye, Z., Barry, C., van Tuinen, A., Vrebalov, J., Bowler, C., Giovannoni, J. (2004). Manipulation of light signal transduction as a means of modifying fruit nutritional quality in tomato. Proc. Natl. Acad. Sci. U.S.A., 101, 9897–9902.

Loaiza-Velarde, J.G., Tomás-Barberán, F.A., Saltveit, M.E. (1997). Effect of intensity and duration of heat-shock treatments on wound-induced phenolic metabolism in Iceberg lettuce. J. Am. Soc. Hortic. Sci., 122, 873–877.

Lurie, S., Crisosto, C.H. (2005). Chilling injury in peach and nectarine. Postharvest Biol. Technol., 37, 195–208.

MacDonald, H.M. (2007). Influence of organic salts of potassium on bone health: Possible mechanisms of action for the role of fruit and vegetables. Int. Congr. Ser., 1297, 268–281.

Manach, C., Scalbert, A., Morand, C., Remesy, C., Jimenez, L. (2004). Polyphenols: Food sources and bioavailability. Am. J. Clin. Nutr., 79, 727–747.

Manganaris, G.A., Vasilakakis, M., Mignani, I., Diamantidis, G., Tzavella-Klonari, K. (2005a). The effect of preharvest calcium sprays on quality attributes, physicochemical aspects of cell wall components and susceptibility to brown rot of peach fruits (*Prunus persica* L. cv. Andross). Sci. Hort., 107, 43–50.

Manganaris, G.A., Vasilakakis, M., Diamantidis, G., Mignani, I. (2005b). Effect of post-harvest calcium treatments on the physicochemical properties of cell wall pectin in nectarine fruit during ripening after harvest or cold storage. J. Hort. Sci. Biotechnol., 80, 611–617.

Manganaris, G.A., Vasilakakis, M., Diamantidis, G., Mignani, I. (2006). Effect of in-season calcium applications on cell wall physicochemical properties of nectarine fruit (*Prunus persica* var. nectarina Ait. Maxim) after harvest or cold storage. J. Sci. Food Agric., 86, 2597–2602.

Manganaris, G.A., Vasilakakis, M., Diamantidis, G., Mignani, I. (2007). The effect of postharvest calcium application on tissue calcium concentration, quality attributes, incidence of flesh browning and cell wall physicochemical aspects of peach fruits. Food Chem., 100, 1385–1392.

Marlett, J.A. (1992). Content and composition of dietary fiber in 117 frequently consumed foods. J. Am. Diet. Assoc., 92, 175–186.

Marlett, J.A., Longacre, M.J. (1997). Comparisons of *in vitro* and *in vivo* measures of resistant starch in selected grain products. Cereal Chem., 73, 63–68.

Marlett, J.A., McBurney, M.I., Slavin, J.L. (2002). Position of the American Dietetic Association health implications of dietary fiber. J. Am. Diet. Assoc., 102, 993–1000.

Marlett, J.A., Slavin, J.L. (1997). Position of the American Dietetic Association health implications of dietary fiber. J. Am. Diet. Assoc., 97, 1157–1159.

Marsh, K.B., Volz, R.K., Cashmore, W., Reay, P. (1996). Fruit colour, leaf nitrogen level, and tree vigour in "Fuji" apples. N. Z. J. Crop Hort. Sci., 24, 393–399.

Martín-Diana, A.B., Rico, D., Frías, J.M., Barat, J.M., Henehan, G.T.M., Barry-Ryan, C. (2007). Calcium for extending the shelf life of fresh whole and minimally processed fruits and vegetables: A review. Trends Food Sci. Technol., 18, 210–218.

Martínez-Romero, D., Valero, D., Serrano, M., Riquelme, F. (1999). Effects of postharvest putrescine and calcium treatments on reducing mechanical damage and polyamine and ABA levels during lemon storage. J. Sci. Food Agric., 79, 1589–1595.

Mattheis, J.P., Fellman, J.K. (1999). Preharvest factors influencing flavor of fresh fruit and vegetables. Postharvest Biol. Technol., 15, 227–232.

Mattila, P., Hellstrom, J., Torronen, R. (2006). Phenolic acids in berries, fruits, and beverages. J. Agric. Food Chem., 54, 7193–7199.

Mayer, A.M. (1997). Historical changes in the mineral content of fruits and vegetables. British Food J., 99, 207–221.

McCarron, D.A., Reusser, M.E. (2001). Are low intakes of calcium and potassium important causes of cardiovascular disease?. Am. J. Hyp. 14, S206–S212.

Meléndez-Martínez, A.J., Vicario, I.M., Heredia, F.J. (2007). Provitamin A carotenoids and ascorbic acid contents of the different types of orange juices marketed in Spain. Food Chem., 101, 177–184.

Mengel, K., Kirkby, E.A. (1982). Principles of Plant Nutrition. International Potash Institute, Worblaufen-Bern, Switzerland.

Michailides, T.J., Ramirez, H.T., Morgan, D.P., Crisosto, C.H., Johnson, R.S. (1993). Effects of nitrogen fertilization on susceptibility of stone fruits (peach and nectarine) to brown rot. In: 1992 Research Reports for California Peaches and Nectarines. California Tree Fruit Agreement, Sacramento, CA, USA.

Mittler, R. (2002). Oxidative stress, antioxidants and stress tolerance. Trends Plant Sci., 7, 405–410.

Montanaro, G., Dichio, B., Xiloyannis, C., Celano, G. (2006). Light influences transpiration and calcium accumulation in fruit of kiwifruit plants (*Actinidia deliciosa* var. *deliciosa*). Plant Sci., 170, 520–527.

Morris, J.R., Sistrunk, W.A., Sims, C.A., Main, G.L. (1985). Effects of cultivar, postharvest storage, preprocessing dip treatments and style of pack on the processing quality of strawberries. J. Am. Soc. Hort. Sci., 110, 172–177.

Muir, S.R., Collins, G.J., Robinson, S., Hughes, S., Bovy, A., Ric De Vos, C.H., van Tunen, A.J., Verhoeyen, M.E. (2001). Overexpression of petunia chalcone isomerase in tomato results in fruit containing increased levels of flavonols. Nat. Biotechnol., 19, 470–474.

Murad, S., Grove, D., Lindberg, K.A., Reynolds, G., Sivarajah, A., Pinnell, S.R. (1981). Regulation of collagen synthesis by ascorbic acid. Proc. Natl. Acad. Sci. U.S.A., 78, 2879–2882.

Mussatto, S.I., Mancilha, I.M. (2007). Non-digestible oligosaccharides: A review. Carbohydr. Polym., 68, 587–597.

Neilsen, G.H., Neilsen, D. (2003). Nutritional requirements of apple. In: Apples: Botany, production and uses, D.C. Ferree, I.J. Warrington (eds). CABI Publishing, Wallingford, Oxon, UK, pp. 267–302.

Nelson, J.W., Barritt, B.H., Wolford, E.R. (1972). Influence of location and cultivar on color and chemical composition of strawberry fruit. Wash. Agric. Exp. Stn. Tech. Bull., 74, 1–7.

Nishiyama, I., Yamashita, Y., Yamanaka, M., Shimohashi, A., Fukuda, T., Oota, T. (2004). Varietal difference in vitamin C content in the fruit of kiwifruit and other *Actinidia* species. J. Agric. Food Chem., 52, 5472–5475.

Noctor, G., Foyer, C. (1998). Ascorbate and glutathione: Keeping active oxygen under control. Annu. Rev. Plant Physiol. Plant Mol. Biol., 49, 249–279.

Nordin, B.E.C. (1997). Calcium and osteoporosis. Nutrition, 13, 664–686.

O'Donoghue, E.M., Huber, D.J., Timpa, J.D., Erdos, G.W., Brecht, J.K. (1994). Influence of avocado (*Persea americana*) Cx-cellulase on the structural features of avocado cellulose. Planta, 194, 573–584.

O'Neill, M.A., Ishii, T., Albersheim, P., Darvill, A.G. (2004). Rhamnogalacturonan II: Structure and function of a borate cross-linked cell wall pectic polysaccharide. Annu. Rev. Plant Biol., 55, 109–139.

Pantelidis, G.E., Vasilakakis, M., Manganaris, G.A., Diamantidis, G. (2007). Antioxidant capacity, phenol, anthocyanin and ascorbic acid contents in raspberries, blackberries, red currants, gooseberries and cornelian cherries. Food Chem., 102, 777–783.

Peleg, K. (1985). Produce handling, packaging, and distribution. AVI/Van Nostrand Reinhold, New York, NY, USA.

Perkins-Veazie, P., Collins, J.K., Howard, L. (2008). Blueberry fruit response to postharvest application of ultraviolet radiation. Postharvest Biol. Technol., 47, 280–285.

Petersen, J., Pedersen, G. (1991). Sporelementer I økologisk dyrkede grønsaker. Levnedsmiddelstyrelsen. Rapport nr. F 91001 Levnedsmiddelstyrelsen, Copenhagen, Denmark (in Danish).

Pomeranz, Y., Meloan, C.E. (1987). Food Analysis Theory and Practice, 2nd edn. AVI/Van Nostrand Reinhold, New York, NY, USA.

Poovaiah, B.W., Glenn, G.M., Reddy, A.S.N. (1988). Calcium and fruit softening: physiology and biochemistry. Hort. Rev., 10, 107–152.

Prange, R., DeEll, J.R. (1997). Preharvest factors affecting quality of berry crops. HortScience, 32, 824–830.

Premuzic, Z., Bargiela, M., García, A., Rendina, A., Iorio, A. (1998). Calcium, iron, potassium, phosphorus, and vitamin C content of organic and hydroponic tomatoes. HortScience, 33, 255–257.

Prior, R.L., Cao, G., Martin, A., Sofic, E., McEwen, J., O'Brien, C., Lischner, N., Ehlenfeldt, M., Kalt, W., Krewer, G., Mainland, C.M. (1998). Antioxidant capacity as influenced by total phenolic and anthocyanin content, maturity, and variety of *Vaccinium* species. J. Agric. Food Chem., 46, 2686–2693.

Raese, J.T., Drake, S.R. (1993). Effects of preharvest calcium sprays on apple and pear quality. J. Plant Nutr., 16, 1807–1819.

Raese, J.T., Drake, S.R. (2000a). Effect of calcium sprays, time of harvest, cold storage, and ripeness on fruit quality of "Anjou" pears. J. Plant Nutr., 23, 843–853.

Raese, J.T., Drake, S.R. (2000b). Effect of calcium spray materials, rate, time of spray application, and rootstocks on fruit quality of "Red" and "Golden Delicious" apples. J. Plant Nutr., 23, 1435–1447.

Raese, J.T., Drake, S.R. (2002). Calcium spray materials and fruit calcium concentrations influence apple quality. J. Am. Pom. Soc., 56, 136–143.

Raese, J.T. (1977). Response of young "d'Anjou" pear trees to triazine and triazole herbicides and nitrogen. J. Am. Soc. Hort. Sci., 102, 215–218.

Raghothama, K.G. (1999). Phosphate acquisition. Annu. Rev. Plant Physiol. Plant Mol. Biol., 50, 665–693.

Ramalingam, K., Lee, K.M., Woodard, R.M., Bleecker, A.B., Kende, H. (1985). Stereochemical course of the reaction catalyzed by the pyridoxal phosphate-dependent enzyme 1-aminocyclopropane-1-carboxylate synthase. Proc. Natl. Acad. Sci. USA, 82, 7820–7824.

Randle, W. (1997). Onion flavor chemistry and factors influencing flavor intensity. In: Spices: Flavor Chemistry and Antioxidant Properties, S.J. Risch, C.T. Ho (eds). ACS Symposium Series 660. ACS Press, Washington, DC, USA, pp. 41–52.

Rao, A.V., Rao, L.G. (2007). Carotenoids and human health. Pharmacol. Res., 55, 207–216.

Reddy, M.S., Chen, F., Shadle, G., Jackson, L., Aljoe, H., Dixon, R.A. (2005). Targeted down-regulation of cytochrome P450 enzymes for forage quality improvement in alfalfa (*Medicago sativa* L.). Proc. Nat. Acad. Sci. USA, 102, 16573–16578.

Redgwell, R.J., MacRae, E., Hallett, I., Fisher, M., Perry, J., Harker, R. (1997). *In vivo* and *in vitro* swelling of cell walls during fruit ripening. Planta, 203, 162–173.

Reeve, R.M. (1970). Relationships of histological structure to texture of fresh and processed fruits and vegetables. J. Text. Stud., 1, 247–284.

Rice-Evans, C.A., Miller, N., Paganga, G. (1997). Antioxidant properties of phenolic compounds. Trends Plant Sci., 2, 152–159.

Ridley, B.L., O'Neill, M.A., Mohnen, D. (2001). Pectins, structure, biosynthesis, and oligogalacturonide-related signaling. Phytochemistry, 57, 929–967.

Rimm, E.B., Ascherio, A., Giovannucci, E., Spiegelman, D., Stampfer, M.J., Willett, W.C. (1996). Vegetable, fruit, and cereal fiber intake and risk of coronary heart disease among men. J. Am. Med. Assoc., 275, 447–451.

Rodriguez-Amaya, D.B. (2001). A Guide to Carotenoid Analysis in Foods. ILSI Press, International Life Sciences Institute, One Thomas Circle, N.W. Washington, DC, USA.

Romheld, V., Marschner, H. (1991). Function of micronutrients in plants. In: Micronutrients in agriculture, J.J. Mortvedt, F.R. Cox, L.M. Shuman, R.M. Welch (eds), 2nd edn. Soil Science Society of America, Madison, WI, USA, pp. 297–328.

Rose, J.K.C., Catalá, C., Gonzalez-Carranza, Z.H., Roberts, J.A. (2003). Cell wall disassembly. In: The Plant Cell Wall, J.K.C. Rose (ed.). Blackwell Publishing Ltd., Oxford, UK, pp. 264–324.

Rosen, J.C., Kader, A.A. (1989). Postharvest physiology and quality maintenance of sliced pear and strawberry fruit. J. Food Sci., 54, 656–659.

Sajilata, M.G., Singhal, R.S., Kulkarni, P.R. (2006). Resistant starch – A review. Compr. Rev. Food Sci. Food Safety, 5, 1–17.

Saltveit, M.E. (1988). Postharvest glyphosate application reduces toughening fiber content and lignification of stored asparagus spears. J. Am. Soc. Hort. Sci., 113, 569–572.

Salunkhe, D.K., Bolin, H.R., Reddy, N.R. (eds) (1991). Storage, processing, and nutritional quality of fruits and vegetables. Volume I. Fresh Fruits and Vegetables. CRC Press, Boston, MA, USA.

Sams, C.E. (1999). Preharvest factors affecting postharvest texture. Postharvest Biol. Technol., 15, 49–254.

Sanders, D., Brownlee, C., Harper, J.F. (1999). Communicating with calcium. Plant Cell, 11, 691–706.

Sandmann, G. (2001). Genetic manipulation of carotenoid biosynthesis, strategies, problems and achievements. Trends Plant Sci., 6, 14–17.

Sanmartin, M., Pateraki, I., Chatzopoulou, F., Kanellis, A.K. (2007). Differential expression of the ascorbate oxidase multigene family during fruit development and in response to stress. Planta, 225, 873–885.

Saure, M.C. (1998). Causes of the tipburn disorder in leaves of vegetables. Sci. Hort., 76, 131–147.

Saure, M.C. (2001). Blossom-end rot of tomato (*Lycopersicon esculentum* Mill.) – a calcium or stress-related disorder?. Sci. Hort., 90, 193–208.

Saure, M.C. (2005). Calcium translocation to fleshy fruit: Its mechanism and endogenous control. Sci. Hort., 105, 65–89.

Scalbert, A., Williamson, G. (2000). Dietary intake and bioavailability of polyphenols. J. Nutr., 130, 20735–20855.

Seeram, N.P., Adams, L.S., Zhang, Y., Lee, R., Sand, D., Scheuller, H.S., Heberg, D. (2006). Raspberry, blueberry, cranberry, red raspberry, and strawberry extracts inhibit growth and stimulate apoptosis of human cancer cells *in vitro*. J. Agric. Food Chem., 54, 9329–9339.

Sharples, R.O. (1980). The influence of orchard nutrition on the storage quality of apples and pears grown in the United Kingdom. In: Mineral Nutrition of Fruit Trees, D. Atkinson, J.E. Jackson, R.O. Sharples, W.M. Waller (eds). Butterworths, London, UK, pp. 17–28.

Shewfelt, R.L. (1986). Postharvest treatment for extending the shelf life of fruits and vegetables. Food Technol., 40, 70–89.

Sigman-Grant, M., Warland, R., Hsieh, G. (2003). Selected lower-fat foods positively impact nutrient quality in diets of free-living Americans. J. Am. Diet. Assoc., 103, 570–576.

Sistrunk, W.A. (1985). Peach quality assessment, fresh and processed. In: Evaluation of Quality of Fruits and Vegetables, H.E. Patee (ed.) AVI, Westport, pp. 1–42.

Slavin, J.L. (2005). Dietary fiber and body weight. Nutrition, 21, 411–418.

Smirnoff, N. (2000). Ascorbic acid, metabolism and functions of a multifaceted molecule. Curr. Opin. Plant Biol., 3, 229–235.

Smirnoff, N., Wheeler, G.L. (2000). Ascorbic acid in plants, Biosynthesis and function. Crit. Rev. Biochem. Mol. Biol., 35, 291–314.

Smith, B. (1993). Organic food vs. supermarket food, Element levels. J. Appl. Nutr., 45, 35–39.

Sozzi, G.O. (2001). Caper bush, botany and horticulture. Hort. Rev., 27, 125–188.

Swietlik, D., Faust, M. (1984). Foliar nutrition of fruit crops. Hort. Rev., 6, 287–355.

Swietlik, D. (1999). Zinc nutrition in horticultural crops. Hort. Rev., 23, 109–178.

Terry, P., Giovannucci, E., Michels, K.B., Bergkvist, L., Hansen, H., Holmberg, L., Wolk, A. (2001). Fruit, vegetables, dietary fiber, and risk of colorectal cancer. J. Nat. Canc. Instit., 93, 525–533.

Titchenal, C.A., Dobbs, J. (2007). A system to assess the quality of food sources of calcium. J. Food Compos. Anal., 20, 717–724.

Toivonen, P.M.A., Zebarth, B.J., Bowen, P.A. (1994). Effect of nitrogen fertilization on head size, vitamin C content and storage life of broccoli (*Brassica oleracea* var. italica). Can. J. Plant Sci., 74, 607–610.

Tomás-Barberán, F.A., Loaiza-Velarde, J., Bonfanti, A., Saltveit, M.E. (1997). Early wound- and ethylene-induced changes in phenylpropanoid metabolism in harvested lettuce. J. Am. Soc. Hort. Sci., 122, 399–404.

Tripoli, E., La Guardia, M., Giammanco, S., Di Majo, D., Giammanco, M. (2007). Citrus flavonoids, molecular structure, biological activity and nutritional properties, a review. Food Chem., 104, 466–479.

Trudel, M.J., Ozbun, J.L. (1971). Influence of potassium on carotenoid content of tomato fruit. J. Am. Soc. Hort. Sci., 96, 763–765.

Tsao, R., Deng, Z. (2004). Separation procedures for naturally occurring antioxidant phytochemicals. J. Chromatogr. B., 812, 85–99.

Uriu-Adams, J.Y., Keen, C.L. (2005). Copper, oxidative stress, and human health. Mol. Aspects Med., 26, 268–298.

U.S. Department of Agriculture (2008). Composition of foods, raw, processed, prepared. USDA national nutrient database for standard reference, release 20. USDA-ARS, Beltsville Human Nutrition Research Center, Nutrient Data Laboratory, Beltsville, Maryland. http://www.ars.usda.gov/nutrientdata Accessed April 2008.

U.S. Department of Health and Human Services and U.S. Department of Agriculture (2005). Dietary Guidelines for Americans, 2005, 6th edn. U.S. Government Printing Office, Washington, DC, USA.

Valero, D., Martínez-Romero, D., Serrano, M., Riquelme, F. (1998). Influence of postharvest treatment with putrescine and calcium on endogenous polyamines, firmness, and abscisic acid in lemon (*Citrus limon* L. Burn cv. Verna). J. Agric. Food Chem., 46, 2102–2109.

Valpuesta, V., Botella, M.A. (2004). Biosynthesis of L-ascorbic acid in plants, new pathways for an old antioxidant. Trends Plant Sci., 9, 573–577.

Versari, A., Parpinello, G.P., Tornielli, G.B., Ferrarini, R., Giulivo, C. (2001). Stilbene compounds and stilbene synthase expression during ripening, wilting, and UV treatment in grape cv. Corvina. J. Agric. Food. Chem., 49, 5531–5536.

Vicente, A.R., Ortugno, C., Rosli, H., Powell, A.L.T., Greve, C., Labavitch, J.M.L. (2007a). Temporal sequence of cell wall disassembly events in developing fruits. 2. Analysis of blueberry (*Vaccinium* Species). J. Agric. Food Chem., 55, 4125–4130.

Vicente, A.R., Saladié, M., Rose, J.C.K., Labavitch, J.M. (2007b). The linkage between cell wall metabolism and fruit softening, looking to the future. J. Sci. Food Agric., 87, 1435–1448.

von Elbe, J.H., Schwartz, S.J. (1996). Colorants. In: Food Chemistry, O.R. Fennema (ed.) 3rd edn. Marcel Dekker, New York, NY, USA.

Wall, M.M. (2006). Ascorbic acid, vitamin A, and mineral composition of banana (*Musa* sp.) and papaya (*Carica papaya*) cultivars grown in Hawaii. J. Food Compos. Anal., 19, 434–445.

Wang, C.Y., Conway, W.S., Abbott, J.A., Kramer, G.F., Sams, C.E. (1993). Postharvest infiltration of polyamines and calcium influences ethylene production and texture changes in "Golden Delicious" apples. J. Am. Soc. Hort. Sci., 118, 801–806.

Wang, H., Cao, G., Prior, R.L. (1996). Total antioxidant capacity of fruits. J. Agric. Food Chem., 44, 701–705.

Wang, S.Y., Lin, H.S. (2000). Antioxidant activity in fruits and leaves of blackberry, raspberry, and strawberry varies with cultivar and developmental stage. J. Agric. Food Chem., 48, 140–146.

Wang, S.Y., Lin, H.S. (2003). Compost as a soil supplement increases the level of antioxidant compounds and oxygen radical absorbance capacity in strawberries. J. Agric. Food Chem., 51, 6844–6850.

Wang, S.Y., Zheng, W., Galletta, G.J. (2002). Cultural system affects fruit quality and antioxidant capacity in strawberries. J. Agric. Food Chem., 50, 6534–6542.

Waris, G., Ahsan, H. (2006). Reactive oxygen species, role in the development of cancer and various chronic conditions. J. Carcinog., 6, 14–21.

Weibel, F., Bickel, R., Leuthold, S., Alfoldi, T. (2000). Are organically grown apples tastier and healthier? A comparative field study using conventional and alternative methods to measure fruit quality. Acta Hort., 57, 417–426.

Willats, W.G.T., McCartney, L., Mackie, W., Knox, J.P. (2001). Pectin, cell biology and prospects for functional analysis. Plant Mol. Biol., 47, 9–27.

Winter, C.K., Davis, C.F. (2006). Organic foods. J. Food Sci., 71, R117–R124.

Witney, G.W., Hofman, P.M., Wolstenholme, B.N. (1990a). Effect of cultivar, tree vigour and fruit position on calcium accumulation in avocado fruits. Sci. Hort., 44, 269–278.

Witney, G.W., Hofman, P.J., Wolstenholme, B.N. (1990b). Mineral distribution in avocado trees with reference to calcium cycling and fruit quality. Sci. Hort., 44, 279–291.

Witney, G.W., Kushad, M.M., Barden, J.A. (1991). Induction of bitter pit in apple. Sci. Hort., 47, 173–176.

Woese, K., Lange, D., Boess, C., Bogel, K.W. (1997). A comparison of organically and conventionally grown foods – results of a review of the relevant literature. J. Sci. Food Agric., 74, 281–293.

Wolk, A., Manson, J.A.E., Stampfer, M.J., Colditz, G.A., Hu, F.B., Speizer, F.E., Hennekens, C.H., Willett, W.C. (1999). Long-term intake of dietary fiber and decreased risk of coronary heart disease among women. J. Am. Med. Assoc., 281, 1998–2004.

Zerwekh, J.E., Odvina, C.V., Wuermser, L.-A., Pak, C.Y.C. (2007). Reduction of renal stone risk by potassium-magnesium citrate during 5 weeks of bed rest. J. Urol., 177, 2179–2184.

Zheng, W., Wang, S.W. (2003). Oxygen radical absorbing capacity of phenolics in blueberries, cranberries, chokeberries, and lingonberries. J. Agric. Food Chem., 51, 502–509.

Zheng, Y., Wang, C.Y., Wang, S.Y., Zheng, W. (2003). Effect of high-oxygen atmospheres on blueberry phenolics, anthocyanins, and antioxidant capacity. J. Agric. Food Chem., 51, 7162–7169.

Zyren, J., Elkins, R., Dudek, J.A., Hagen, R.E. (1983). Fiber contents of selected raw and processed vegetables, fruits and fruit juices as served. J. Food Sci., 48, 600–603.

6

Value Chain Management and Postharvest Handling: Partners in Competitiveness

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I. Introduction

A. Firms, competitiveness and supply chains

The traditional economic view is that a firm's competitiveness is determined by how efficiently and effectively its management is able to organize the firm's internal processes, structures, resources and people so as to maximize profits. This allows firms

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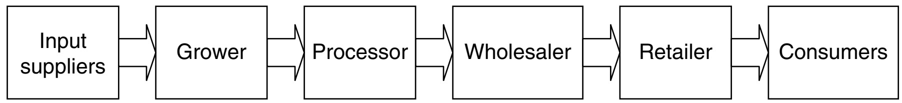

Figure 6.1 Simplified supply chain showing flow of product from input suppliers to consumers.

to compete against each other for a share of a particular market or market segment, based on their ability to keep prices low and/or to differentiate their product from competitors' products (Williamson, 1971; Porter, 1980; Wernerfelt, 1984).

To some extent this model still applies. Firms do have to be price competitive and firms do have to differentiate their products and services from those of their competitors. However, over the last 20 years the traditional view of how firms become and remain competitive has been challenged by an alternative view that sees a firm as part of a chain that links the production of goods and services with the consumers of those goods and services, a chain referred to as the supply chain (Figure 6.1).

In this alternative view, the competitiveness of a firm is influenced by how it interacts with other firms in the supply chains to which it belongs. As van Roekel (in Gifford et al., 1998, p. 4) pointed out:

> "it is becoming increasingly evident that achievement of the desired market position cannot be achieved solely through the company's own efforts. Because each company is just one link in the production chain, with upstream and downstream links, it has to cooperate. The more effectively it does this, the stronger its competitive position in the market."

Van Roekel's statement captures the essence of this alternative view of competitiveness, that cooperation among firms in a supply chain can positively improve their competitiveness. This view is in sharp contrast to the idea of a competitive firm being independent, and internally efficient and effective.

Among traditionally competitive firms, linkages in supply chains are usually at arms length and adversarial. Typically, firms attempt to buy inputs at the cheapest possible price from their suppliers, and sell outputs at the highest possible price to their customers. These transactions are at the expense of the buyers or suppliers in the chain, i.e. actions between chain members are self-optimizing, and tend to shift costs to other firms in the chain and ultimately to the consumer. Many authors have pointed out the shortcomings of this way of operating, most noting that it does not necessarily improve the efficiency of the chain, does not lead to the best prices for consumers, and does not make the individual firms more competitive (Bowersox, 1990; Mentzer et al., 2001). Under adversarial conditions, independent, efficient firms do not lead to the most efficient supply chains.

B. Supply chain management

When firms belonging to a supply chain work together to address inter-firm efficiencies and take more notice of what consumers want, a different picture of competitiveness emerges. Here, there is an opportunity for collaboration to replace adversarial behavior, and for the focus to move away from price and onto customers' needs. This business model, called supply chain management (SCM), is built on the proposition that there are gains from cooperation and coordination between firms in a supply chain that are simply not available to firms operating independently of each other. Thus, a firm's ability to collaborate becomes intimately linked with its ability to compete, a proposition that is well-supported in the literature (O'Keeffe, 1998; van Roekel et al., 2002; Gunasekaran et al., 2001; Halldorsson et al., 2007).

It has been suggested that the practices of SCM have existed for hundreds of years (Hugos, 2000), but supply chain management as a modern business strategy has its origins in manufacturing industries in the 1960s (Mentzer et al., 2001). More recently it has taken hold in agri-food industries, including horticulture (Fearne and Hughes, 1999). Originally, SCM referred to approaches that ensured the logistical and distributional efficiency of flows of materials along a supply chain (Cooper and Ellram, 1990). Over time however, the focus of SCM became less tactical and less focused on achieving logistical efficiency alone. It evolved to encompass what Spekman et al. (2002, p. 41) called a "competitive reality," where "firms compete as constellations of collaborating partners." More than any other factor, this change in orientation away from just the logistical aspects of the supply chain was driven by the increasing attention being paid to two factors:

- the importance of relationships in achieving inter-firm coordination; and
- the importance of identifying and satisfying the end consumer as the "target" of the supply chain.

Today, a widely accepted view is that SCM is:

> "an integrated approach that aims to satisfy the expectations of consumers through continual improvement of processes and relationships that support the efficient development and flow of products and services from the producer to the consumer."
>
> *(Gifford et al., 1997, p. 2)*

The key elements of this definition are:

- the need for integration between firms;
- a focus on consumers;
- the importance of relationships;
- a whole-of-supply-chain perspective.

Integration of business systems and processes between firms is necessary to achieve operational efficiencies, and to improve the flow and transparency of information (Beers et al., 1998). A focus on consumers acknowledges the need for the supply chain to have information about consumers' needs and wants, including feedback as to how these are being met. Effective relationships drive successful SCM, because they are the antecedents of information exchange, conflict resolution and co-innovation between supply chain partners (Morgan and Hunt, 1994). Finally, the view of the supply chain as a dynamic, complex, system linking input suppliers and producers through to consumers reinforces the idea that the whole is more than an aggregation of parts that can be improved independently of each other, and that performance of the whole system fundamentally depends on the interactions among its parts (Jackson, 2003).

II. Value chain management

In spite of what seems to be an all-embracing concept, SCM has been criticized as being too supply-oriented, having an upstream focus and not attaching enough importance to the role of consumers in the chain. For example, Mudimigh et al. (2004, p. 309) argue that:

> "SCM does not extend far enough to capture customers' (end user) future needs and how these get addressed and, furthermore, it does not encompass the post-delivery, post-evaluation and relationship building aspects."

These authors, and others, argue that a focus on value rather than supply is more appropriate. As a result, the term value chain management (VCM) is frequently used in preference to SCM (Martinez and Bititci, 2006), even though the terms are sometimes used interchangeably in the literature.

A. The concept of value

In the context of VCM, value is usually defined in terms of the customer (the next firm downstream) or the consumer (the final purchaser of the finished goods). Mudimigh et al. (2004, p. 311) list three themes that run through definitions of value:

1. customer value is linked to the use of a product or service;
2. value is perceived by the customer, not determined by the seller; and
3. customer value typically involves a trade-off between what the customer wants and what must be given up in order to acquire and use a product or service.

Sources of value have been shown to lie in features of products and services, such as price, convenience, appearance, nutrition, safety and reliability. Thus, the concept of value is framed by the perspective of the user or consumer looking back to the chain that produced and delivered the product or service. Having a focus on the consumer as the ultimate "target" of the activities of a chain is a distinguishing feature of VCM (Collins, 2006). Explanations of VCM, such as that given by the Agriculture and Food Council of Alberta (2002, p. 3), highlight this orientation: "a value chain begins and ends with the market. Interaction with the marketplace provides information to decision makers for every link in the chain."

B. Sources and drivers of value

In the context of food in general, and horticultural produce in particular, the sources and drivers of value have some special features. Because food is "consumed," attributes associated with safety, nutrition, well-being, freshness and the overall sensory experience of food each play a role in determining how individual consumers attach value to the product as part of their purchase decision-making. If these attributes are loosely bundled together under the general banner of "quality" then, as Collins (2006) points out, it is the interaction of price and quality that results in what buyers regard as "value for money." The challenge for the chain is, therefore, to understand and deliver this value in ways that profitably meet consumers' needs.

The ability of an agri-food chain to deliver consumer value is driven by a combination of its ability to be as efficient as possible, and its ability to innovate (Taylor, 2005). Lean manufacturing principles, originally devised by the Toyota Corporation to reduce waste and maximize value-adding activities in car manufacturing, have been adapted to value chains in the food industry (Simons et al., 2002). A lean agri-food value chain achieves efficiency through operating with minimal waste and clearly focusing on only undertaking those activities that are necessary and that add value in the eyes of the consumer. Being lean however, does not necessarily mean being innovative. Innovation occurs when a chain discovers and captures new sources of value, either for the individual firms in the chain or for the consumer. New sources of value are a critical source of competitive advantage in rapidly changing environments, such as the food sector. Firms seek these sources of value through process innovation (new ways to manufacture products) or product innovation (new product development), and in a value chain they may do so in association with a chain partner. The process of pairs or groups of firms innovating with a common purpose is referred to as co-innovation, and has been described as a powerful driver of value in chains (Collins et al., 2002).

C. Value orientation in fresh produce chains

It has already been argued that the value chain needs to be viewed as a system. Food value chains are systems driven by the interaction of their technical (production, processing, transport, etc.), economic (profitability), information-related (communication) and governance (human relationships) subsystems. Evaluating their performance is, therefore, a multidisciplinary task that may combine measures drawn from fields as diverse as engineering, biology, economics and psychology. A review of literature on the performance of food supply/value chains carried out by Collins (2006) revealed the following indicators of performance:

1. The balance of focus between price and value;
2. The amount and type of information shared;
3. The time orientation of chain participants;
4. The nature of the business-to-business relationships;
5. The basis of the interactions between chain members;
6. Dependence in the chain;
7. Use of power in the chain;
8. Orientation of chain members to self or chain.

Collins used each of these criteria to evaluate the performance of fresh produce value chains (Table 6.1).

Table 6.1 Fresh produce value chain orientation matrix

Evaluative criterion	Characteristics of chain activities Least value orientation ←→ Greatest value orientation			
Balance between price and value	Always price	Usually price	Usually value	Almost always value
Amount and type of information shared	No significant information shared	Little information shared	Some information shared	Extensive information shared
Time orientation	Short term, transaction to transaction	Short term, periodic	Short to medium term	Medium to long term
The nature of relationships	Adversarial	Occasionally cooperative	Mostly cooperative	Collaborative
Interactions between chain members	Transaction based	Mostly transaction based	More relationship based	Always relationship based
Dependence in the chain	Independence	Occasionally relies on others	Usually relies on others	Interdependence
Power in the chain	The individual has the power	The individual has the power	Some recognition of the consumer	The consumer has the power
Orientation of chain members	Always self maximizing	Self first, chain second	Chain first, self second	Always chain optimizing

The balance of focus between price and value

On one end of the scale, the members of a fresh produce value chain may focus entirely on price. The goal of buyers in the chain is always to achieve the lowest possible price. At the other end of the scale, chain members may focus entirely on value creation through strategies such as product and process innovation, extensive market research and the adoption of lean manufacturing principles.

The amount and type of information shared

In traditional, price-oriented chains, individual members can wield power by withholding critical information, such as price signals from buyers, or supply signals from providers. Such information is usually used as a bargaining tool to maximize returns to one chain member at the expense of another but, as previously noted, this behavior does not result in the greatest value being delivered to the consumer. In contrast, in value-based chains it is regarded as important by chain members to share information freely, so that the needs of chain participants can be fully understood and met, and so that signals from the marketplace can be transmitted undistorted back down the chain to where they are needed, so as to evaluate how well the chain is creating value for its consumers.

The time orientation

A short-term orientation does not allow chain members to properly understand each other's needs, or to build stronger relationships. Short-term thinking is associated with a singular orientation to price rather than value.

The nature of business-to-business relationships

Relationships may be adversarial, as in the case of bargaining to get the lowest price, or collaborative, as in the case of trying to achieve a better understanding of chain members' needs. Value chains cannot deliver superior value to consumers in the absence of collaborative relationships among chain members.

The basis of interactions between chain members

Interactions may be on a transaction-by-transaction basis, or on the basis of ongoing relationships. Transaction-based interactions are typical where relationships are adversarial and the focus is on price.

Dependence in the chain

Members of a chain may operate totally independently of each other, typically in a price-based environment, or more interdependently, for example when collaborating to establish and deliver value to consumers.

Use of power in the chain

Power in a chain may lie in the hands of some individuals. Alternatively, the chain as a whole may acknowledge that the consumer exercises the ultimate power in the act of making the decision to purchase or not to purchase, and that the chain as a competitive unit can orientate itself towards meeting the needs of the consumer.

Orientation of chain members

Chain members may orient themselves towards maximizing gains for themselves, at the expense of other chain members, or optimizing returns for the whole chain in which they share.

Using the eight performance-related criteria, it is possible to map a range of characteristics of a fresh produce chain's orientation, activities, and behavior from the least value-conscious to the most highly value oriented (Collins, 2006). Such a mapping exercise can identify the "value orientation" of a particular fresh produce chain, as shown in the examples in Tables 6.2, 6.3 and 6.4.

Using this approach, it is possible to plot the value-orientation profile of traditional, price-based, adversarial chains where product flows through centralized wholesale marketing channels. These types of chains are still common around the world, especially in developing countries. Their typical profile is shown in Table 6.2. Features of this profile are that chain members only cooperate when absolutely necessary, meaning that very occasionally they have to rely on each other, but otherwise the chain is driven by negotiations around price.

A second type of value profile is that of "category managed" chains. Category management firms are becoming more common, taking on the role of bridging between suppliers and retailers, especially large supermarket operators. Upstream in the chain, the category manager organizes and manages supply of product to clear specifications that include parameters of quality, quantity, safety, delivery and price. Downstream they manage supply of product to retailers, may plan marketing strategies with them, or may undertake market research upon which to base these strategies. In fresh produce,

Table 6.2 Traditional fresh produce chains

Evaluative criterion	Characteristics of chain activities Least value orientation ←→ Greatest value orientation			
Balance between price and value	Almost always price	Usually price	Usually value	Almost always value
Amount and type of information shared	No significant information shared	Little information shared	Some information shared	Extensive information shared
Time orientation	Short term, transaction to transaction	Short term, periodic	Short to medium term	Medium to long term
The nature of relationships	Adversarial	Occasionally cooperative	Mostly cooperative	Collaborative
Interactions between chain members	Transaction based	Mostly transaction based	More relationship based	Always relationship based
Dependence in the chain	Independence	Occasionally relies on others	Usually relies on others	Interdependence
Power in the chain	The individual has the power	The individual has the power	Some recognition of the consumer	The consumer has the power
Orientation of chain members	Always self maximizing	Self first, chain second	Chain first, self second	Always chain optimizing

category managers typically ameliorate problems faced by retailers as a result of the impacts of seasonality, environmental conditions and wholesale price fluctuations. They are also increasingly involved in innovation related to new product development. They achieve these outcomes through their relationships with both suppliers and retailers, and their ability to focus the chain on reliably delivering value for money, as opposed to price alone. Table 6.3 shows a typical value orientation profile for a "category managed" fresh produce value chain.

There are very few examples of best practice value chain management in fresh produce, but the trends are pointing in that direction. A small number of value chains have gone beyond the profile of category managers shown in Table 6.3, and have embraced a strategy of total focus on the consumer, absolute transparency of information and full collaboration among chain members. Their typical profile is shown in Table 6.4.

It is also possible to compare the performance of the three types of fresh produce chains described above using criteria that are associated with competitiveness. These criteria, shown in Table 6.5, focus on attributes such as agility (speed and flexibility), the ability to innovate and not easily be copied by competitors, and the ability to guarantee product integrity.

It is interesting to note from Table 6.5 that the overall competitiveness of each of the three models can be high. At their best, each business model is capable of delivering high returns to the managers of the firms involved. But as the environment in

Table 6.3 Contemporary, category-managed fresh produce value chain

Evaluative criterion	Characteristics of chain activities Least value orientation ←→ Greatest value orientation			
Balance between price and value	Almost always price	Usually price	Usually value	Almost always value
Amount and type of information shared	No significant information shared	Little information shared	Some information shared	Extensive information shared
Time orientation	Short term, transaction to transaction	Short term, periodic	Short to medium term	Medium to long term
The nature of relationships	Adversarial	Occasionally cooperative	Mostly cooperative	Collaborative
Interactions between chain members	Transaction based	Mostly transaction based	More relationship based	Always relationship based
Dependence in the chain	Independence	Occasionally relies on others	Usually relies on others	Interdependence
Power in the chain	The individual has the power	The individual has the power	Some recognition of the consumer	The consumer has the power
Orientation of chain members	Always self maximizing	Self first, chain second	Chain first, self second	Always chain optimizing

Table 6.4 Best current examples of fresh produce value chains

Evaluative criterion	Characteristics of chain activities Least value orientation ←→ Greatest value orientation			
Balance between price and value	Almost always price	Usually price	Usually value	Almost always value
Amount and type of information shared	No significant information shared	Little information shared	Some information shared	Extensive information shared
Time orientation	Short term, transaction to transaction	Short term, periodic	Short to medium term	Medium to long term
The nature of relationships	Adversarial	Occasionally cooperative	Mostly cooperative	Collaborative
Interactions between chain members	Transaction based	Mostly transaction based	More relationship based	Always relationship based
Dependence in the chain	Independence	Occasionally relies on others	Usually relies on others	Interdependence
Power in the chain	The individual has the power	The individual has the power	Some recognition of the consumer	The consumer has the power
Orientation of chain members	Always self maximizing	Self first, chain second	Chain first, self second	Always chain optimizing

Table 6.5 Comparison of competitiveness performance of different types of chains

	Traditional chain	Category managed chain	Best current practice value chain
Speed of response	High	Medium	Medium
Flexibility	High	High	High
Innovation potential	Low	Medium	High
Ease of copying by competitors	Easy	Moderate	Difficult
Traceability of product	Low	High	High
Overall competitiveness	Can be high	Can be high	Can be high

which fresh produce chains are operating continues to change, firms using traditional adversarial business models will come under increasing pressure as they are forced to compete with more closely aligned value chains whose primary focus is on meeting consumers' needs. This pressure will become particularly disabling for traditional operators in fresh produce retail environments that demand a combination of innovation, traceability, differentiation and responsiveness.

III. Value chain management and postharvest systems

A. The changing environment of value chain management in the food industry

To understand how VCM and postharvest horticulture are interrelated, it is necessary first to examine the factors that have driven the adoption of more collaborative whole-of-chain business models. Three broad forces are at work here, the forces of globalization, technology and consumerism (Figure 6.2), and they are shaping the macro environment, the competitive environment and the internal business environment of every horticultural firm.

Globalization

Over the last few decades the barriers to trade in food between most countries in the world have gradually fallen away, spearheaded by the efforts of the World Trade Organization (WTO) to achieve freer global trade. Under these initiatives, many governments have agreed to reduce tariffs that had been used mainly to protect domestic food producers. At the same time, new technologies for storage and transport have allowed food products to access distant markets. The physical location of food production and processing facilities is no longer a guarantee of market access, and it is now possible for food companies to see the world as their marketplace, as they have both the access and the technology to reach distant markets.

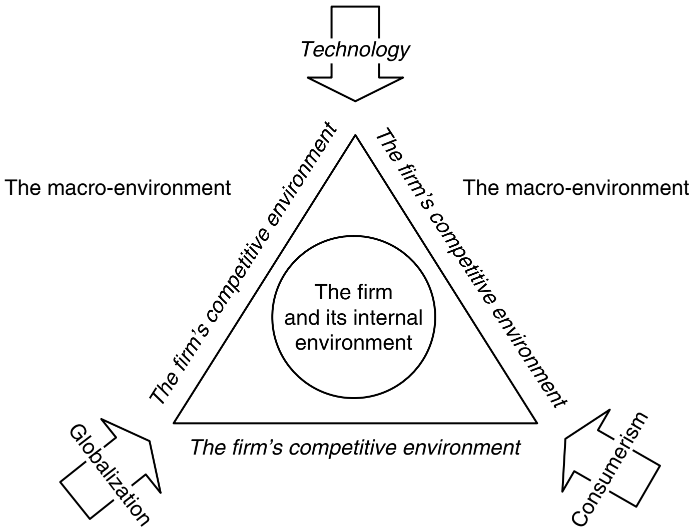

Figure 6.2 Three forces of change impacting on business. Aapted from: Dunne, A., Collins, R. (2004). The marketing of food and fibre products: evolution and revolution. In: Emerging Challenges for Farming Systems, K. Rickert (ed.). Rural Industries Research and Development Corporation, Canberra, Australia, pp. 39–52.

The opening up of trade has changed the face of global competition. No longer are firms competing against other local firms for a share of their own domestic market. Many are competing in distant markets against firms from other countries who are also not local to that market, or they are competing in their own domestic markets against firms from overseas. This global marketplace for food has, quite understandably, attracted the biggest processors (e.g. Nestlé) and retailers (e.g. Wal-Mart) but small firms have not been shut out. There are many examples of small food companies that have identified profitable opportunities in distant markets. It has been shown that the ability of a firm to profit from globalization of markets is not a function of its size, but of how well the firm understands that it is the "total competitiveness along the value chain which determines whether they can export successfully" (Instate, 2000, p. 3).

The opening of global markets has also resulted in increasing concentration of supermarket and food service operators. A small number of large food retailers have expanded operations across the globe, and they have been especially active in countries where they can introduce more highly-developed retail systems that streamline logistics and distribution, widen the choice of products to consumers, and provide new shopping experiences. Firms such as Wal-Mart and Carrefour, for example, have been predicted as becoming the major players in Asian retail markets by the end of this decade (IGD, 2002).

In extending their reach to new and distant markets, one of the biggest challenges for global food retailers has been to take their supply chains with them, so that they can guarantee a supply of products that reliably meet quality specifications at competitive prices. What was already a complex, and at times difficult, process in their own domestic markets becomes far more complex and difficult in markets that are far away, and whose consumers are not as well understood. Retailers have realized that sourcing the right products, and having a supply chain that is capable of delivering those products often from one hemisphere to another, is a major challenge in the global marketplace for food (see also Chapter 8).

Technological advances

It is not difficult to see how advances in science and technology have radically shaped the food business environment at every stage, from production through to processing, storage, transport and retail. Hewett (2006, p. 39) refers to genetic technology (see Chapter 21), nanotechnology and information technology as a "triad of technologies driving change in supply chains worldwide." These technologies have spawned innovations in products (genetically modified products, bioactives), as well as processes (radio frequency identification, irradiation, active packaging). At the same time, the technology that allows firms to gather, store, manipulate and communicate information is developing exponentially.

In combination, technological advances of all kinds have opened up new possibilities for firms to deliver new food products more efficiently to more distant consumers, and to send and receive information in real-time along the complete chain from production to consumption. Not surprisingly, a food industry firm's ability to capture and use newly emerging technologies has been shown to be associated with its ability to compete (Collins, 2004; Hewett, 2006).

Consumerism: the power of consumers

Consumers have more power than ever before, and they are prepared to exercise that power. As many more suppliers achieve the capacity to target many more markets, some markets become "saturated," giving retailers and consumers the ability to exert considerable power in choosing between the many offers from would-be suppliers (Gifford et al., 1998). The food industry is quoted as one example where markets are saturated with product offers, and suppliers are having to become more sophisticated in developing new products to attract and retain customers, a process that has been described as "mass individualization" (Linnemann et al., 2006).

Broadly speaking, consumers of food products exert their influence in two different ways. On the one hand, they influence the outputs of food production systems (the kind of food produced), and on the other hand, they influence the systems themselves (how food is produced).

Food and lifestyle are inextricably linked. Consumers want food that is nutritious, safe and healthy, but they also want it in a convenient form, they want variety and new experiences, and they want to be able to find food that fits all these needs without having to work too hard to find it (see Chapter 3). Milstein (2007) identified the mega trends that consumers are responding to as including products and services made "just for me," a growing interest in health and well-being, and an increasing belief that quality is better than quantity. Milstein also notes that debate will continue to revolve around issues such as obesity, nutrition labeling, absolute traceability along the food chain, and the role of "authenticity" in food production. Consumers are expressing a well-developed understanding of the relationships between food and quality of life in their consumption habits and buying behavior.

How food is produced is an increasing concern for consumers worldwide. Of particular interest is how food production systems affect the environment and here, too, consumers are expressing their concerns through their purchasing decisions. This has given rise to foods certified as being produced in environmentally responsible ways, food that has been produced by systems with a low carbon footprint, or food that has traveled a low number of "food miles." Companies are responding to these consumer-driven concerns by adopting more sustainable business practices, such as sourcing products locally, using less water or power in production, producing less waste, or reducing unnecessary packaging. In the developed world, every food company, whether they be farmers, packers, processors, transport operators or wholesalers, could point to some part of its business that is a direct response to increasing consumer concern for the impact of food production systems on the environment.

In an increasingly crowded global marketplace for food products, the ability of firms to make profits by responding to what consumers need is related to their ability to differentiate themselves from one another. Differentiation is virtually impossible unless firms engage with the chains that create and deliver what consumers need. In a global marketplace, independent firms, even with the world's best new product development ideas and technologies, simply cannot guarantee consumers that their products are safe, healthy, environmentally responsible, available all-year-round and represent value for money, unless they collaborate with the other firms that make up the chain from production to consumption of those products.

B. Value chain management as a setting for postharvest horticulture

VCM has been described as a business model in the previous section, and the changing environment in which it applies to food products has been examined. This provides the background for exploring how VCM and postharvest horticulture are linked. In this section it is argued that postharvest practices are value-adding activities, and that VCM can enhance a firm's ability to deliver postharvest outcomes and outputs to those parts of the chain where they represent value. When another firm in the chain, for example a retailer, recognizes the value created through postharvest practices, incentive is created to continue these practices. Ultimately, consumer purchase behavior determines financial returns from the value it creates, and the members of the chain determine how those returns are shared.

Why horticultural firms become involved in value chain management

Boehlje et al. (1998) note that firms collaborate to form value chains for three reasons:

- to be able to respond better to consumers;
- to improve efficiency; and
- to reduce risks.

As mentioned above, consumers are becoming more discerning about the food they consume, and they tend to direct their business towards those chains that can anticipate and service these needs. The value created through postharvest activities such as grading, processing, packaging, storage and transport is targeted at meeting specific consumer requirements. By meeting these requirements more precisely, reliably and economically, more value can be created. When a chain of collaborating firms is able to create value in this way, it not only strengthens the relationships among the collaborating firms, but it also builds relationships between the chain and its consumers. This is VCM at work, and chains of firms operating in this way become extremely difficult for competitors to emulate, because they have to compete against not only the technical value-creating abilities of the chain, but also against the strength of the relationships that have been formed through meeting consumers' needs.

The second motivator behind value chain formation relates to efficiency. Chains must deliver food products to particular specifications, including conformance with mandatory requirements, such as food safety standards. Collaboration among firms in a value chain not only ensures that specifications have been met at every point in the chain, but also allows efficiencies and cost savings to be identified within firms, as well as between firms. Examples include the ability to hold lower inventory through made-to-order systems, sharing of infrastructure, such as storage and transport between firms, integrating IT systems between firms, and the adoption of technologies and systems that are unavailable or uneconomic for single firms. The ability to reduce costs through improved efficiency represents value created through collaboration. This value may be kept by the firm(s) responsible, or passed along the chain so that it becomes value for other chain members, and ultimately the consumer.

Finally, firms form value chains to reduce risks. Individual firms can lower their exposure to influences, such as the unavailability or rising price of inputs, the impact of seasonal variation on product quality and availability, or the need to ensure that a whole chain can guarantee food safety through the adoption of a certified food safety management system. On their own, most firms would be far more exposed to these risks, and could make few guarantees beyond their own boundaries.

All three examples demonstrate how postharvest systems and practices can create value for collaborating firms along a chain. Put another way, those same postharvest systems and practices, in the hands of independent horticultural firms aiming to maximize their individual profitability are far less able to:

1. monitor, respond to and influence consumer needs;
2. ensure that product is delivered to the retailer as cost efficiently as possible; and
3. guarantee the safety of the product delivered to consumers.

How horticultural firms become involved in value chain management

The most common pathway to VCM begins when two firms decide to collaborate, and then based on positive results extend their reach to other chain members (Collins and Dunne, 2002). A value chain is formed when firms involved in an alliance share a common objective of targeting a specific market or market segment. The more successful they are, the more difficult it becomes for competitors to copy their value chain, as shown in the example below.

An example (based on an actual case)

A large vegetable grower successfully negotiates with a processor to supply higher quality inputs at a slightly higher price. Customers of the processor respond to the higher quality output, and business expands until more inputs are required than can be supplied by the original grower. With the support of the processor, the original grower invites a small group of new growers to become high-quality suppliers to the processor. These new growers are in different regions, and therefore can extend supply over a much longer season. Growing across more regions also spreads environmental risks. These growers are trained to meet the same higher standards, and they prove to be reliable and committed. Business continues to expand. Now the supplier group investigates genetics as a source of even higher quality, and they form an alliance with a supplier of superior genetics. The genetics supplier sees enough business, and has enough trust, to give exclusive rights to the grower alliance for certain of its seed products. The seed supplier's company name also appears on the packaged product that consumers buy. Business continues to expand; retailers are happy with the results and ask for a wider range of products. This represents an opportunity for both the growers and the processor to diversify and spread their risks. Collaboratively, a small number of new products are identified for which high-quality genetics are available, that require only minimal investment in new processing and growing capacity. These products are also successful and a small portfolio of products under a common brand becomes established. The genetics–grower–processor value chain adopts a strategy of reinvesting a share of each partner's returns into consumer research. The objective is to stay in touch with how consumers are responding to their products so the value chain can assist retailers to promote and merchandise their brand. Over time, and based on consumer feedback, the group is able to incorporate world class environmental standards into its production and processing systems. At this point, with exclusive genetics, dedicated and capable growers across a number of regions, an innovative processor and satisfied retailers and consumers, the value chain has put itself in a position where competitors were struggling to keep up.

It is important to note, from the example above, that it is not necessary for every firm in a value chain to collaborate. Retailers and wholesalers, for example, may not be directly involved, but may be willing to cooperate as customers of the main value chain partners. In fact, in practice, it is rare to find a value chain that is able to achieve high levels of collaboration and value creation that involve every member of the chain (Bollen, 2004). What is always needed, however, is a chain champion who initiates value chain formation, and oversees the early stages of formation. These principles, and those illustrated in the example above, have been discussed by van Roekel et al. (2002).

In horticulture, as individual producers are relatively small in relation to their ability to service a market segment, it is common for producers to form alliances among themselves, sometimes referred to as horizontal alliances (Agriculture and Food Council, 2002). It is also common for horizontal alliances of producers to initiate the formation of value chains in horticultural industries. Collins (2004) describes the type of activities that firms become capable of once a successful alliance has been formed. They include:

- co-investing in research to better understand consumers' needs;
- seeking to actively influence consumers;
- exploring new products, technologies or markets; and
- providing proof of authenticity, such as country of origin or environmental credentials.

These are the kinds of activities that confer competitive advantage on a whole value chain, because each of them is difficult to achieve by individual producers or other chain members acting alone.

C. Postharvest horticulture as a value creation domain

Defining the domain

Postharvest horticulture can be defined at various scales and in various ways. At its widest scale it begins when the product is separated from the plant or growing medium and ends with consumption by the final consumer. More narrowly, it might be defined as extending from harvest up until the product is in the form in which it will be retailed. By any definition, postharvest horticulture involves transformation of product from its state at harvest into its ready-to-consume state. This may be a simple transformation, e.g. for a fresh whole lettuce that will be retailed in that form within a few days, or a complex transformation, e.g. for a potato processed into frozen French fries sold many months later in another country. The chain along which the product flows may be very short and involve none or few other firms, e.g. product sold at the farm gate, or it may be long and involve many other firms, e.g. potatoes in the frozen French fries example given above. Regardless of their scale or complexity, postharvest activities have two features in common: they add value and they involve members of the supply chain.

The ways in which postharvest activities can involve other chain members have been addressed earlier in this chapter. At sophisticated levels of involvement, these activities are elements of a business model known as VCM. At minimal levels of involvement, they may simply represent the various stages at which product changes hands from one firm to another along a supply chain, for example from a grower to a packer, a packer to a wholesaler, or a wholesaler to a retailer. This chapter concentrates on the higher levels of involvement that are associated with VCM, because they have been shown to improve the competitiveness of businesses at all stages of the horticultural supply chain.

Adding value through postharvest science and technology

Postharvest horticulture has been defined as having the potential to add value through four interconnected areas of activity. They are food safety, traceability, information systems and consumer response to quality (Bollen, 2004). Each of these is discussed below.

Food safety

The need for food safety is beyond question (see also Chapters 10, 13 and 18). Research has shown that general consumer confidence in the motives of food producers and retailers has decreased (Frewer, 2003), fueled by publicity surrounding outbreaks such as BSE, bird flu and foot and mouth disease. While horticulture has not been subject to this same level of public concern about its systems and their outputs, there is still enough publicity to keep food safety issues squarely in the minds of consumers, such as reports of deaths from agricultural chemical contamination of vegetables in China.

Hurst (2004) reports that the incidence of human food-borne illnesses related to horticultural produce is low, but increasing. He suggests that this may be because of better microbial detection methods, increasing per capita consumption of fruit and vegetables, global sourcing, and the evolution of more virulent strains of pathogens. Hurst goes on to argue that every horticultural supply chain needs a food safety plan, and in many countries this is a mandatory requirement.

Postharvest practices that ensure food safety add value through the confidence that they instill in the consumer. When consumers believe that a horticultural product is "risky" they engage in the following behaviors, all of which directly impact on the profitability of the chains that delivered the product to the consumer (Frewer, 2003):

- they move to another product category, e.g. from fresh-cut product to fresh product;
- they change to another brand or origin of the product, e.g. away from product produced in a particular country;
- they move to another retailer or type of retailer, e.g. away from supermarkets or away from local markets;
- they move towards product produced in a particular way, e.g. towards low chemical usage produce; or
- they reduce consumption altogether, e.g. they stop consuming products in that broad category.

In summary, one objective of postharvest horticulture is to create value, based on its ability to ensure food safety. Ultimately this is achieved through building trust with consumers that a particular product, brand, retailer and production method is safe, time after time. From a technical point of view, food safety means avoiding microbiological contamination that exceeds defined limits. From a management point of view, it means implementing and enforcing food safety standards and management systems that deliver value 100% of the time. While individual firms can, and must, carry responsibility for their part of the chain, integrated value chains can give much higher level food safety assurances to consumers, because the whole chain is managed as a system whose responsibility is to deliver food safety.

Traceability

Bollen (2004) lists four functions of traceability in a supply chain (see also Chapter 12). They are:

- so that product can be traced back as part of a food safety system;
- tracking ability of product from farm to market to give evidence of good agricultural practice or good manufacturing practice;
- ability to trace and track shipments by air or sea, especially given current international security concerns; and
- the improvement of product segregation so that specific market segments may be targeted.

Each of these functions involves postharvest activities and technologies, and each adds value for one or more members of a value chain. Because all of them rely on documentation produced as part of a codified management system, it is therefore impossible to achieve traceability without at least some cooperation from every chain member. At one end of the spectrum is the minimum acceptable functional level of traceability, or base-level traceability. At the other end of the spectrum, when chain members make a collective decision to invest in traceability systems as part of a VCM business strategy, very high levels of performance become possible. This may be because of improved inventory management, higher levels of security, guaranteed best practice, or more highly differentiated offers to consumers. In each of these cases, postharvest systems and technologies have a critical role to play in adding value.

Information systems

The globalization of horticultural markets has brought with it a manifold increase in logistical complexity. Because of the perishability of horticultural products, supply chains have time-critical dimensions, thus any improvements to the ability to store and transport horticultural products have significant commercial value. At the same time, the storage and transport of products is meaningless without information exchange and the timing and quality of information exchanged often determines the value that can be created by the storage and transport functions themselves. Poor information exchange is directly linked with lower profitability in horticultural supply chains (Collins and Dunne, 2002).

Information systems may not always be thought of as part of the postharvest system. However, without them the flow of product within and between firms is impossible. Information is needed to capture the characteristics of the product, its location in the value chain at any time, the state of the processes that transform the product, and the value of the product at each stage of the chain. Postharvest activities not only directly add value to the product along the chain, but they can also create the information that is needed to inform decisions about the product as it flows along the chain. The integration of postharvest technologies with information management systems has received relatively little research attention. However, in the VCM business model, the value added by improved postharvest technologies is only translated into profits when information about that value is communicated to those to whom it is commercially significant. Bollen (2004, p. 48) has suggested that information systems are “the major opportunity for the logistics supply chain to progress to become a value chain.”

Consumers and quality

The role of postharvest research and development in ensuring that consumers get the quality they demand has been the central orientation of the discipline. A review by the author of 180 published papers in the field of postharvest science since 2003 revealed 155 that made direct reference to consumer satisfaction or meeting the needs of markets as the rationale for the research. The significance of this orientation is captured by Shewfelt (2006, p. 31) in stating “the success or failure of any food is determined by the consumer.”

In defining quality using simple and practical terms, Prussia (2004) defined low quality as not meeting consumer expectations; acceptable quality as satisfying consumer expectations; and high quality as exceeding consumer expectations. This definition is consistent with Shewfelt's (2006) view of the primacy of the consumer in determining what constitutes quality. Prussia (2004) also separated purchase quality from consumption quality. Purchase quality related to those attributes that could be assessed at the time of purchase, such as size, color, blemish, firmness and aroma. Consumption quality related to attributes that could only be assessed destructively, such as flavor, texture, flesh color, juiciness and mouth-feel.

Understanding what constitutes quality for a product, and being able to deliver that quality, is the main business of a horticultural value chain. The capacity to deliver purchase quality attracts consumers to make purchases, but being able to deliver consumption quality drives repeat purchases and builds consumer loyalty – and these are the drivers of sustained profitability for a value chain.

While some quality attributes are determined preharvest, many are determined after harvest. For fresh produce, ripening and storage conditions after harvest, for example, have direct effects on quality attributes such as flavor, texture, color, blemish and perceptions of freshness. For processed horticultural products, every aspect of the postharvest system creates value in the finished product, for example by grading, slicing, mixing ingredients, sanitation treatments, packaging and labeling. Collectively, these activities create value through flavor, color and texture profiles, portion or pack size, and attractiveness for the consumer.

The goal of VCM is to deliver value to consumers at an acceptable price, i.e. to deliver value for money. Quality, as perceived by the consumer, is central in determining what represents value for money. The orientation of postharvest R&D towards quality for the consumer is in fact an orientation towards value creation, which is the basis of VCM.

IV. The future

The future for VCM and its interaction with postharvest horticultural systems will be shaped by the three forces of change discussed earlier: globalization, technology and consumerism.

Globalization will continue to give access to new markets, and will bring more competition to domestic markets. Both large players and small will stand to benefit, but whatever the scale, the ability to capture new markets will be determined by the quality of the whole value chain, not the quality of any individual firm. At the same time, food security will be a counterbalancing force. Nations will not want to become wholly reliant on imported foods, and local production to ensure food security will be a strategic issue for some nations. Horticultural industries will figure prominently in these strategies for their ability to produce large volumes of fresh, nutritious food quickly and flexibly to local communities.

Advances in postharvest technologies will be used to create new food products, new processes and new ways of managing information. Only those that represent value, either to members of value chains or to consumers, will survive. New technologies associated with the intersection of food, health and well-being will be especially valued, as will those that help to ensure the security of supply chains.

Consumers in the future will be even more discerning than they are now. The ability to anticipate, understand and influence consumers will confer competitive advantage on value chains, the members of which will invest more and more in consumer research. Shewfelt and Henderson (2003) list six consumer trends related to horticultural produce relevant to this chapter. They are:

1. More emphasis on quality: fruits and vegetables will become more of a high value specialty item; safety may be associated with total absence of pesticides;
2. More emphasis on local production: more incentive to produce horticultural food locally to avoid dependence on imported produce;
3. Less emphasis on shelf life and more emphasis on consumption quality: long shelf life will be considered a negative attribute; a true appreciation of flavor will supersede the importance of purchase quality attributes such as size and color;
4. Less concern about price and more emphasis on value: consumers will pay higher prices for fruit and vegetables as a specialty item; consumers will be less forgiving for unreliability of quality and will demand more information;
5. More emphasis on technological solutions: campaigns against technologies such as irradiation and genetic modification will be less effective; technologies that can deliver consumption quality, especially those that maximize flavor, will be accepted;
6. More emphasis on sustainable production: governments will require accounting for environmental impacts; inputs such as power and water will become more expensive; higher costs will be passed on to the consumer.

Broadly speaking, the forces of globalization, changing technology and consumerism will exert their influence on postharvest horticulture in two ways. They will define what constitutes consumer value; and they will, therefore, influence R&D priorities in the domain of postharvest R&D. Perhaps most importantly, more firms will adopt VCM strategies that are based on delivering value to consumers based on these R&D outputs.

Key words

Supply chain management, value chain management, competitiveness, postharvest horticulture, collaboration, value.

Bibliography

Agriculture and Food Council (2002). Value Chain Handbook. Alberta Agriculture, Food and Rural Development, Alberta, Canada.

Beers, G., Beulens, A., van Dalen, J. (1998). Chain science as an emerging discipline. Proceedings of the Third International Conference on Chain Management in

Agribusiness and the Food Industry. Wageningen Agricultural University, The Netherlands, pp. 295–308.

Boehlje, M., Schrader, L., Akridge, J. (1998). Observations on the formation of chains. Proceedings of the Third International Conference on Chain Management in Agribusiness and the Food Industry, G. Ziggers, G. Trienekens, J. Zuurbier (eds). Wageningen Agricultural University, The Netherlands, pp. 393–403.

Bollen, F. (2004). Logistics in supply chains for fresh produce. Proceedings of the APEC Symposium on Quality Management in Postharvest Systems. King Mongkut's University of Technology, Thailand, pp. 47–56.

Bowersox, D. (1990). The strategic benefits of logistics alliances. Harvard Bus. Rev., 68, 36–43.

Collins, R. (2006). The functions and consequences of alternative fresh produce supply chain models. Acta Hort., 712, 67–73.

Collins, R. (2004). Whole-of-chain quality management: an emerging perspective for post-harvest science. Proceedings of the APEC Symposium on Quality Management in Postharvest Systems. King Mongkut's University of Technology, Thailand, pp. 15–23.

Collins, R., Dunne, A. (2002). Forming and Managing Agribusiness Supply Chains: Learning From Others. CD. Department of Agriculture Fisheries and Forestry, Australia, Canberra.

Collins, R., Dunne, A., O'Keeffe, M. (2002). The locus of value: a hallmark of chains that learn. Supply Chain Manage. Int. J., 7, 318–321.

Cooper, M., Ellram, L. (1990). Supply chain management, partnerships, and the shipper-third party relationship. Int. J. Logistics Manag., 1, 1–10.

Dunne, A., Collins, R. (2004). The marketing of food and fibre products: evolution and revolution. In: Emerging Challenges for Farming Systems, K. Rickert (ed.). Rural Industries Research and Development Corporation, p. 40.

Fearne, A., Hughes, D. (1999). Success factors in the fresh produce supply chain: insights from the UK. Supply Chain Manage., 4, 120–128.

Frewer, L. (2003). Quality in chains: consumers and risk. Acta Horticulturae, 604, 233–237.

Gifford, D., Hall, E., Collins, R. (eds) (1997) Competitive Performance. Australian Government Publishing Service, Canberra.

Gifford, D., Hall, E., Ryan, W. (eds) (1998) Chains of Success. Commonwealth Department of Primary Industries and Energy, Canberra.

Gunasekaran, A., Patel, C., Tirtiroglou, E. (2001). Performance measures and metrics in a supply chain environment. Int. J. Operations and Prod. Manage., 21, 71–87.

Halldorsson, A., Kotzab, H., Mikkola, J., Skjott-Larsen, T. (2007). Complementary theories to supply chain management. Supply Chain Management, 12, 284–296.

Hewett, E. (2006). Progressive challenges in horticultural supply chains: some future challenges. Acta Hort., 712, 39–49.

Hugos, M. (2003). Essentials of Supply Chain Management. John Wiley & Sons Ltd, New York, NJ, USA.

Hurst, W. (2004). GAPs/GMPs/HACCP: Food Safety Systems for Handling Fresh Produce. Proceedings of the APEC Symposium on Quality Management in Postharvest Systems. King Mongkut's University of Technology, Thailand, pp. 129–136.

IGD (2002). The True Picture of Global Retailing. Conference Report, 4th Annual Global Retailing Conference. QEII Centre, London, UK.

Instate Pty Ltd. (2000). Exporting Australian Processed Foods: Are We Competitive? Agriculture, Fisheries and Forestry, Australia, Canberra.

Jackson, M. (2003). Systems Thinking. Creative Holism for Managers. John Wiley & Sons Ltd., West Sussex, UK.

Linnemann, A., Benner, M., Verkerk, R., van Boekel, M. (2006). Consumer driven food product development. Trends in Food Sci. and Tech., 17, 184–190.

Martinez, V., Bititci, U. (2006). Aligning value propositions in supply chains. Int. J. Value Chain Manage., 1, 6–18.

Mentzer, J., DeWitt, W., Keebler, J., Min, S., Nix, N., Smith, C., Zacharia, Z. (2001). Defining supply chain management. J. Bus. Logistics, 22, 1–25.

Milstein, D. (2007). What's Hot in Food? 6th edn update. David Milstein and Associates, Brisbane, Australia.

Morgan, R., Hunt, S. (1994). The commitment-trust theory of relationship marketing. J. Market., 58, 41–55.

Mudimigh, A., Zairi, M., Ahmed, A. (2004). Extending the concept of supply chain: The effective management of value chains. Int. J. Prod. Econ., 87, 309–320.

O'Keeffe, M. (1998). Establishing supply chain partnerships. Supply Chain Manage., 3, 5–9.

Porter, M. (1980). Competitive Strategy. The Free Press, New York, NY, USA.

Prussia, S. (2004). Systems thinking for improving modern quality management systems. Proceedings of the APEC Symposium on Quality Management in Postharvest Systems. King Mongkut's University of Technology, Thailand, pp. 39–46.

Shewfelt, R., Henderson, J. (2003). The future of quality. Acta Horticulturae, 604, 49–59.

Shewfelt, R. (2006). Defining and meeting consumer requirements. Acta Hort., 712, 31–37.

Simons, D., Francis, M., Jones, D. (2002). Food value chain analysis. In: Consumer Driven Electronic Transformation, G. Doukidis, A. Vrechopolous (eds). Springer, Berlin, Germany, pp. 179–192.

Spekman, R., Spear, J., Kamauff, J. (2002). Supply chain competency: learning as a key component. Supply Chain Manage., 7, 41–55.

Taylor, D. (2005). Supply Chain Analysis: an approach to value chain improvement in agri-food chains. Int. J. Phys. Dist. and Logistics Manage., 35, 744–761.

van Roekel, J., Kopicki, C., Broekmans, C., Boselie, D. (2002). Building Agri Supply Chains: Issues and Guidelines. World Bank, Washington, DC, USA.

Wernerfelt, B. (1984). The resource-based view of the firm. Strategic Management Journal, 14, 415–423.

Williamson, O. (1971). The integration of production: market failure considerations. Am. Econ. Rev., 23, 335–345.

7

A Functional Evaluation of Business Models in Fresh Produce in the United States

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I. A functional evaluation of business models of fresh produce in the United States

A functional approach to a supply chain identifies the activities or actions that are carried out at each stage. Some firms could decide to incorporate some or all of the functions. Other firms may specialize in just one, and coordinate with other members of the chain through various agreements. Marketing in the food system has at least three broad categories (physical functions, exchange functions, and facilitating functions) each with three or four sub-functions (Table 7.1).

II. Physical functions

Physical functions include those activities that alter the form or place utility of produce. Form utility refers to the appearance the produce will have. Manufacturing, processing, and packaging create additional value for the consumer that prefers the product in an altered state. Place utility refers to the time and location at which the produce is consumed. Some degree of physical transportation and storage is used in selling fresh produce.

A. Manufacturing, processing and packaging

One way that firms can add value in the supply chain is to identify how consumers will use the product. Firms can then modify the product in such a way that will make

Table 7.1 Functions in the food marketing system

Functions	Sub-functions
Physical function	• Manufacturing, processing, and packaging • Transportation • Storage
Exchange function	• Buying and selling • Price determination • Risk bearing
Facilitating function	• Standardization, grading • Financing • Market intelligence • Communication, advertising, promotion, public relation

Source: Kohls, R.L., Uhl, J.N. (1998); Schaffner, D.J., Schroder, W.R., Earle, M.D. (1998).

its use more convenient. For example, firms sell heads of lettuce, but also began selling packaged, pre-cut bags of lettuce (form utility). Thus, firms that are able to rinse, cut and package salads save a consumer time, have been rewarded for adding that value in terms of market share and/or price premiums. Several types of processing and packaging occur in the produce supply chain including canned fruits, individual serving-sized packaged fruit salads, frozen fruits, fruit juices, and dried fruits. It should be noted however, that fresh produce has often been offered with minimal amounts of processing and packaging, either through farmers' markets or even in grocery retail. Providing fresh orange slices for athletes competing in a triathlon is an example of place utility.

For a given geographic area, crops typically mature at the same time, leading to peak demands for handling and processing at harvest time. These spikes in demand for processing create the need for large-scale processing facilities and/or well-coordinated delivery of harvested products to processing facilities. Unfortunately, large-scale processing facilities require large amounts of financial capital that is idle for much of the rest of the year. In the absence of well-coordinated delivery, every grower also has an incentive to be the first to market, and seeks to pre-empt other producers. Hence, processors have incentives to smooth out supplies that avoid dumping too much product on the market during the harvest season, and a need to carry supplies past the harvest season to help pay for storage and plant facilities (see Chapter 1). Growers generally do not have storage capabilities, and therefore want to move their product quickly, leading to excess supply. Market alliances and contracts have been used successfully to address these coordination challenges.

One interesting example of a successful marketing alliance is the Pink Lady™ apple. Pink Lady™ is grown under a strictly controlled license, and marketed through a limited number of resellers to the supermarkets. The purpose of this arrangement is to keep quality and prices high, portraying a premium product. In order to maintain the differentiated appeal of Pink Lady™, about 65% of the production which does not meet the standards required for Pink Lady™ is sold as Cripps Pink instead. The main difference between Pink Lady™ and Cripps Pink is the color intensity and the sugar/acid balance. Pink Lady™ apples are targeted towards young women, and have been cross-marketed with Barbie dolls. Pink Lady™ even has its own website, www.pinkladyapples.co.uk (Orange Pippin, 2008).

Another example of producers working together to offset the effects of selling perishable products during harvest is in the potato industry in the northern half of the US. It is quite common for small potato producers to sell their crop through packing sheds which store the fall harvest, and pack to order as needed from October until June. These smaller growers tend to have little if any storage or ability to access the large regional grocery and food service buyers. These packing sheds often use pool pricing, where the high and the low prices of the marketing season are distributed across all growers in the pool. Pooling helps all growers in the pool reap the benefits of the high-priced markets, and affords some protection when prices are lower. Without pooling, individual growers would want the packing sheds to sell their potatoes first during the high markets, but not all the product in storage can be sold at the same time or the market would be flooded and all producers would receive a lower price. Packing sheds, through economies of scale and scope, are able to invest in storage, packaging and marketing facilities that individual producers could not afford.

Processors such as Frito Lay have long ago moved processing facilities away from the production areas, and moved them nearer to metropolitan areas. It is considerably less expensive to ship bulk potatoes than it is to ship potato chips. This movement has also changed the way Frito Lay purchases their raw potatoes. Fifteen years ago, it would not be uncommon for Frito Lay to contract with 20–30 producers in a given production area. Today, Frito Lay uses one or two large potato producer/shippers that have the responsibility of ensuring the quality standards and product availability needed to keep these plants running as efficiently as possible. These preferred suppliers will sub-contract with other local producers, but Frito Lay only deals directly with the preferred suppliers.

B. Transportation

An important part of produce marketing is transportation. This is particularly important because consumers now demand access to their favorite fruits and vegetables year-round, in spite of a local climate that might not permit year-round production (Govindasamy and Thornsbury, 2006; Agricultural and Resource Economics Department, 2007). In an effort to satisfy year-round consumer demand, grocery retailers source produce globally. As a result, produce is often transported northward during winter months, sometimes crossing international borders. Transportation can occur by semi-trailer, rail, boat and even air. The perishable nature of fresh produce requires controlled-climate environments (see also Chapter 19), which add additional costs related to cooling. "U-pick" operations, that allow consumers to pick produce out of the field or orchard, move the transportation function to the consumer, while large grocery chains might pay for fresh produce to be transported from nearly half-way around the globe.

In the US, California, Florida and Texas are the major production areas for many types of fruits and vegetables. The comparative advantage for these areas is based, in part, on climatic and topographical conditions. Major production areas that are located in California, Florida and Texas result in the need for transport across vast distances. During the peak produce shipping months of summer in California, the demand for semi-trailers often exceeds supply, significantly driving up the cost of shipping produce. It is no surprise that the cost of produce will continue to rise given the distances shipped, increasing demand and increasing energy costs. Diesel prices are expected to average about $3.62 per gallon in 2008, with higher prices predicted for the future (Energy Information Administration, 2008). These rising energy costs will continue to impact consumer prices for food, including produce.

An emerging issue related to transportation is the notion of food miles. "Food miles" is a term coined in the 1990s by Dr Tim Lang, professor of food policy at London's City University. Measuring food miles is an attempt to quantify the impact that food has on the environment. Initially, food miles took into account the distance food travels from field to fork, but it has been expanded to include the environmental impacts of growing, shipping, processing and transportation. For countries like the United Kingdom, half the vegetables and 95% of the fruit eaten are imported, resulting in significant food miles. Retailers, such as Tesco and Marks & Spencer, have begun labeling food that is flown in with stickers depicting airplanes (Stacey, 2008).

Increasing energy prices and global warming concerns will continue to fuel the food miles discussion. Food miles are just one of the many factors that produce supply chains must contend with. Even in Europe, where the food miles discussion is the most developed, UK retailers are being urged by the British government not to make food miles the only reason for choosing food suppliers. Retailers are encouraged to ignore food miles when it comes to supporting farmers in the developing world (Patton, 2008).

C. Storage

Storage of fresh produce is difficult, because the product is highly perishable. Therefore, the supply chain requires several climate-controlled environments for storage (see also Chapter 19). Investments in cold storage facilities are quite expensive, and require substantial outlays for energy to cool the environment.

Common types of storage for produce include cold storage and controlled-atmosphere storage. Cold storage generally refers to a refrigerated storage space that maintains temperatures under 45°F (7°C). These temperatures slow the rate of decay, and prolong the shelf life of produce. Selected produce, such as potatoes and bananas, require slightly warmer temperatures during the final stages of storage for optimal consumer acceptance. For example, russet potatoes are harvested between September and October in northern states, such as Idaho and Wisconsin, and then placed into large cold storage warehouses with holding temperatures around 40°F (4°C). These potatoes can maintain their quality in storage until June (i.e. up to seven months). When it is time to pack the potatoes for human consumption they are gradually warmed to a temperature between 50°F and 65°F (10°C and 18°C).

Controlled-atmosphere (CA) storage is accomplished by keeping the level of oxygen at about 5%, and carbon dioxide at 1% to 3%, while temperature is held at a level best suited to the particular fruit. CA storage is common today for apples and pears, and is being adapted to other fruits. Controlled atmosphere and refrigeration, in conjunction with the removal of ethylene gas (which emanates from fruits and speeds ripening) helps slow the ripening process considerably. Golden Delicious apples and some pears are shipped in polyethylene containers in which a desirable, modified atmosphere is created by the respiration of the fruit (Fruit Farming, 2008).

The length of time produce is stored varies by produce variety and seasonal demand as indicated earlier. Strawberries, for example, are highly perishable and can only be stored for short periods of time (e.g. days) while other produce, such as onions and potatoes, can be stored for months under the proper conditions. The ability to store selected produce allows producers to avoid some of the price risk associated with increased supplies at harvest time and to take advantage later of shorter supplies in the months after harvest in their growing region, before the next harvest season in a competing growing region.

So far, the discussion of storage has been limited to the packer–shipper. Storage at various intermittent points in the produce cold chain is extremely important. For example, head lettuce storage occurs within a matter of hours after harvest, with hydro-cooling to remove the "field heat" from the heads of lettuce. Lettuce is placed in cold storage until it is ready to be shipped. The storage length is usually a matter of hours, but may take as long as a few days. If the lettuce is to be shipped to the east coast of the US, it will spend an average of three to four days in a refrigerated semi-trailer or seven days in a refrigerated rail car. Once the lettuce arrives at the distributor, in this case a grocery retailer, it will be transferred to the retailer's produce distribution warehouse, where it is likely to spend on average another one to two days before being shipped to a grocery store. At the grocery store, the lettuce is unloaded from refrigerated trailers into refrigerated rooms, and then placed into refrigerated produce cases in the store. The lettuce may only stay in the display case for a few hours before being purchased by the consumer. The storage cool chain ends when consumer places the lettuce in a household refrigerator until it is consumed. This is usually within one to seven days for most consumers.

III. Exchange functions

Exchange functions are activities related to the possession utility of a product. Individuals or firms with knowledge of buyers and sellers can facilitate exchange between these two groups. Buyers and sellers must agree on setting a price for the product and ownership transfer. As supply and demand fluctuates and the governing rules change, so too do prices. Fluctuation risks are borne by the owner. Therefore, one of the key functions in a food supply chain is the ability to bear the risk associated with these changes.

A. Buying and selling

Many opportunities exist for the ownership of fresh produce to change in getting the product from the producer to the final consumer. Brokers and agents, assemblers, processors, wholesalers and retailers may all take possession of produce under certain circumstances. Alternatively, a farmers' market may bring together buyers and sellers, and serve as the facilitating agent without ever taking possession of the produce. Often, a broker or agent will only take possession of produce if an arbitrage opportunity exists. That is, there is a profit opportunity by moving plentiful goods at low prices to plentiful demand areas at higher prices. There are at least four key outlets available to the final consumer: grocery retail, farmers' markets, restaurants and other food service providers. Each of these outlets presents a different experience for the consumer.

B. Price determination

Price is determined by negotiation between a buyer and seller. A seller at a farmers' market might even enter into bartering with buyers to determine the price charged.

Alternatively, a farmer might negotiate a contract that sets a price for a specified quantity and/or length of time a given price will remain constant (e.g. one year). Often in grocery retail, the grocer sets a non-negotiable price for consumers. Price determination in the fresh produce industry is much less transparent than in many other agricultural supply chains. Many other commodities have products traded on exchanges, for example the New York and Chicago Boards of Trade. While contracts for frozen-concentrated and not-from-concentrate orange juice markets do trade, currently, no fresh produce futures contracts exchanges exist.

Traditionally produce was priced on spot markets and delivered to restaurants or local grocery retailers via local independent produce distributors. Terminal markets, based primarily in major metropolitan areas such as New York City, Chicago, Philadelphia and Los Angeles, were the primary hubs connecting packer–shippers to produce-based distributors and brokers at these markets. Today, the volume of produce through these terminal markets has been reduced significantly, because the remaining produce-based distributors are big enough to buy direct from packer–shippers in the major growing areas, viz., California, Florida and Texas (USDA-ERS, 2001).Terminal markets, although different in size and scope than they once were, still exist and serve a need, especially in large metropolitan areas. With the increasing emphasis on buying local, terminal markets could experience a renewal.

Due in part to the emergence of pre-cut produce (see also Chapter 10), and also to the continuing expansion of regional and national multi-unit restaurant chains, contract pricing in the produce industry is used extensively in selected produce markets. It is not uncommon for these chains to seek out year-long contract prices for potato products and pre-cut produce, such as lettuce, salad mix and cabbage. Price risk has certainly shifted to the producer, in exchange for a guaranteed volume of business. Most, if not all, long-term produce contracts include an "act of God" clause in case of weather-related events that make honoring a particular contract unrealistic. These clauses allow for price adjustments for the packer–shipper, and allow the restaurant buyers to seek alternative sources of supply during these volatile events (e.g. frost, whitefly).

On the grocery retail side of the produce system, packer–shippers are large enough to work directly with the national grocery chains. While there have been efforts to contract more products between packer–shippers and grocery retailers, the incentives to deviate from a contract remain strong. For example, in a time of product shortage the producer has incentives to renegotiate the contract, so that they can sell on the open market in an effort to maximize returns. In times of product gluts, the retailer has incentives to break the contract, and to purchase product at lower cost on the open market to remain competitive with other retailers who have not contracted at the higher price. The volatility of the produce market affects competitiveness and contributes to the decreased use of contracting between packer–shippers and grocery retailers, compared to contracting between packer–shippers and food service operators.

The consumer price index (CPI) for all food is projected to increase by 3.5% to 4.5% in 2008. Food-at-home prices are forecast to increase by 4.0% to 5.0%, while food-away-from-home prices are forecast to increase by 3.0% to 4.0%. The all-food CPI increased 4.0% between 2006 and 2007, the highest annual increase since 1990 (USDA-ERS, 2008a).

C. Risk bearing

Many risks exist in the production and marketing of fresh produce. Changes in rainfall and temperature, catastrophic weather events and shifts in demand all represent risks that are faced in the fresh produce supply chain. There has been substantial government programs intended to reduce the volatility of prices for many other agricultural commodity producers in the US. Furthermore, major row crop commodities generally have well-functioning futures markets that allow for the transfer of risk from producers to speculators. Fresh produce, however, has limited channels to reduce risk in prices and production. Futures markets for frozen, concentrated orange juice (FCOJ) and not-from-concentrate orange juice (NFC) can provide an opportunity to mitigate some risk, but are not tied directly to fresh produce production. Historically, fruits and vegetables have not received the generous government subsidies seen in other commodity products. As a result, much risk remains throughout the fresh produce supply chain that is borne by producers, processors and retailers.

There are a number of methods used in the produce supply chain to reduce risk. The use of contract pricing is discussed as a risk management tool. Building long-term storage is a form of risk reduction. Effective storage smoothes out the peaks in supply and helps to maintain product quality. The diversification across produce varieties, types of customers (e.g. selling to both grocery retailers and food service operations) and spreading the business across multiple buyers, are all risk reduction strategies implemented in the produce supply chain (see also Chapter 11).

IV. Facilitating functions

In the case of fresh produce, facilitating functions can be thought of as the actions that allow the system to function at peak efficiency. Such types of actions provide conduits for information and capital flows in the produce supply chain. Private firms, government and industry groups have all historically served in facilitating roles for fresh produce. Standards and grades can ensure the flow of uniform products, financing provides the capital needed to operate the system, market intelligence can drive competition and communication efforts serve to inform the final consumer.

A. Standardization and grading

Standards and grades can lower costs in the supply chain, by creating uniform products that flow through the system, regardless of the channel. Standards are set to identify minimum hurdles for appearance; nutritional value and information that ensure a minimum level of quality for consumers (see also Chapters 8, 9 and 12). Federal legislation allows the United State Department of Agriculture (USDA) and state marketing boards to play a large role in establishing and enforcing marketing standards. Grades are a specific form of standards (see also Chapter 9). USDA grading of beef is one of the most widely recognized grading standards in the food system. Grades are simply different levels of standards among the same product. Grading helps consumers gauge the additional value of higher quality standards.

Grades and standards for fresh produce facilitate the marketing of these products. Specifically, negotiations about prices and delivery of products can be based on mutually understood descriptions of the product, thus lowering the need for physical inspection of all shipments. Without grades and standards, costly inspections are needed because the biological nature and perishability of these commodities make product consistency difficult to specify on an *ad hoc* basis. Grades and standards can improve information flows and lower transaction costs. Commodity-specific marketing alliances, such as marketing orders and trade associations, have often taken on the responsibility for specifying and enforcing industry grades and standards.

Although grades provide the minimum standards, an increasing number of grocery retail and food service buyers are requiring product specifications that exceed USDA standards. It is imperative for growers, packers, shippers and distributors to understand the product specifications of the buyers to whom they are selling.

Like grades and standards for products, uniform packaging and shipping practices facilitate the marketing of fresh produce. Growers are often widely dispersed, and buyers must source from many different producers because no single grower has sufficient volume to meet their demands. Each grower could conceivably develop individualized packaging and shipping practices best suited for their own situation, which could create significant costs for buyers. The misalignment of incentives within the marketing channel adds costs and generates aggregate welfare losses, if generally accepted industry practices are not adopted. Once again, marketing alliances have been used to overcome these challenges by imposing uniform packaging and shipping standards. Another option is to develop an industry standard performance scorecard, as is underway at the Brussels-based Trading Partner Performance Management (Supermarket News, 2008a). This scorecard will be used by both retailers and suppliers to rank performance in meeting supply chain tasks. As produce supply chains become more global in nature, the need for performance standards across supply chain participants and products will continue to increase (see also Chapters 6 and 8).

B. Financing

Access to low-cost financial capital is the lifeblood of business. Debt and equity provide the necessary funds to buy real assets and serve as the basis of production. Much of the financial capital in fresh produce production comes from the equity of the producers. Likewise, produce marketing firms can be cooperatives that rely on the equity of its member producers, or private firms that rely on equity from stockholders. The other source of funding, debt, is often provided by commercial banks and input suppliers. The US government has also played a role in this important facilitating function by creating and backing the Farm Credit System (FCS). The cooperative associations of the FCS provide additional competition in lending funds to agricultural producers. The associations are also authorized to fund agribusinesses that are related to marketing agricultural products.

C. Market intelligence

Collecting information on the state of the industry facilitates the spread of contemporary production and marketing processes. By collecting this information it is also easy to communicate the relative importance of the industry to entities outside the industry. Typically, industry associations and producer groups have served this critical role. The groups often host producer meetings that encourage the spread of efficient production and marketing practices. They also can communicate to legislators, media, and others the economic impact of their particular sector.

As the produce industry continues to move toward fewer and larger producers, and fewer and larger buyers, the market for information is becoming increasingly thin. Market intelligence is not shared freely with the USDA-Agricultural Marketing Service or competitors, until a given sector is under financial pressure. For example, potato growers are reluctant to hold out for a better contract price for an upcoming season, even if these same growers discussed a pricing strategy at an earlier growers' meeting. The growers know the processor needs a limited quantity of contracted potatoes, they are afraid that if they refuse a contract price a neighbor may accept the price and, if enough producers accept a given contract price, they may find themselves without a contract. It usually takes a few years of contracts priced at a break-even or at a loss for enough producers who are willing to understand their true costs of production and to use this information to work together to raise the contract price for all producers.

Electronic data systems (EDS) or electronic data interchange (EDI) is the use of technology to reduce transactions costs. Food manufacturers and retailers are increasingly looking at ways to cut the cost of logistics (ElAmin, 2007). One example of an EDI system is the accounting, billing and tracking system requirement Wal-Mart places on its suppliers. Suppliers are not only required to meet the quantity and quality specifications for Wal-Mart, they must also be able to communicate electronically with the stores and distribution facilities to carry out "just-in-time" inventory measures. These EDI systems require a significant investment on the part of the supplier, and act as barrier to dealing with retailers the size of Wal-Mart. EDI requirements can offset some of the gains made in logistics, because the number of suppliers a retailer the size of Wal-Mart can purchase from is often limited to a select few who have EDI systems compatible with Wal-Mart's EDI system.

D. Communication, advertising, promotion and public relations

Communicating to consumers the value of goods can represent a challenge for producers and marketers alike. If producers fail to advertise and communicate with consumers, then consumers will be unaware of the benefits of fresh produce. To avoid such situations, some producers and marketers invest in advertising to promote the benefits of fresh produce. Those who do not invest, however, still benefit from the overall expansion of the market. This challenge has been mitigated by an act of the federal government. The USDA facilitates generic promotional boards that collect funds from producers based on production, and then coordinate the promotional message. Boards serve an important role in expanding the generic market for fresh produce. Alternatively, some fresh produce is marketed under brands; Dole, Del Monte, and Chiquita are well-known examples. Brands might be distinguished based on quality. Currently, additional efforts focus on communicating the location of origin of fresh produce.

Public relations and other communication bureaus have traditionally played a strong role in advocating for producers in the US. In addition, these groups sometimes publish their own periodicals and maintain websites to communicate within and outside the group.

V. Market participants and their functions

There are five sets of key participants in the fresh produce marketing chain: growers, packers, shippers, retailers and foodservice operators (Figure 7.1). These members of the chain carry out the production, processing and selling of fresh produce, while other participants, such as the government and lenders, provide capital and market coordination resources. The key participants operate under an industry structure governed by functioning markets that use the unique aspects of agricultural goods and services.

A. Growers

Growing fresh produce is a capital intensive process that requires growers to deal with seasonality with regards to weather, market demand, labor and other inputs. Growers face increasing competitive pressures as free trade is promoted and borders are increasingly open to foreign goods and services. Growers have responded to these pressures by adopting mechanization, differentiating their product, or marketing directly to the end consumer.

Vegetable and melon farms are largely individually owned and relatively small, with nearly 75% harvesting fewer than 25 acres. However, relatively few farms

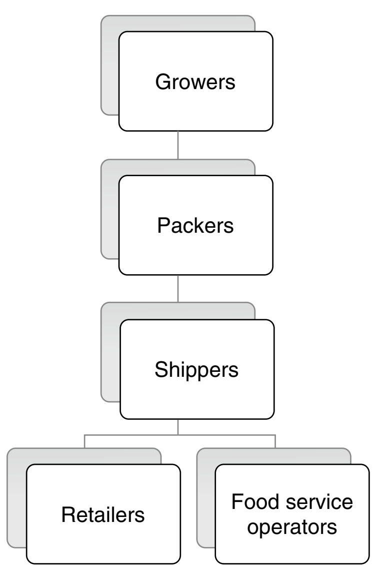

Figure 7.1 Basic structure of the produce industry. Adapted from: Prevor (2006).

account for most of the commercial sales of vegetables and melons. In 2006, about 12% of vegetable and melon farms had sales in excess of $500 000, yet these farms accounted for 87% of the vegetables and melons sold by growers. Production of vegetables and melons in the US continues to increase, with output this decade running about 12% above that of a decade earlier. While total vegetable output has continued to rise over the past decade, acreage has declined slightly, indicating increasing productivity per acre (USDA-ERS, 2008c).

Vegetable and melon production (including potatoes and sweet potatoes) occurs throughout the US, with the largest acreage in California, North Dakota (primarily potatoes and pulse crops), Idaho, Michigan, Minnesota, Washington and Wisconsin. More than half of all vegetable production occurs on irrigated acreage. The Upper Midwest (Wisconsin, Minnesota and Michigan) and the Pacific States (California, Washington and Oregon) report the largest vegetable acreage for processing, while California, Florida, Georgia, Arizona and Texas harvest the largest acreage for the fresh market. California and Florida produce the largest selection and quantity of fresh vegetables. California also produces vegetables for processing (especially tomatoes); while the Upper Midwest States (Michigan, Wisconsin and Minnesota) grow a large portion of the peas, snap beans and sweet corn used in canning. Northwestern States (Washington, Oregon and Idaho), along with New York, supply the lion's share of frozen vegetables and more than half the potatoes. Significant potato production also takes place in Wisconsin, Colorado and North Dakota. North Carolina, Louisiana and California produce 75% of the sweet potato crop. Pennsylvania and California raise the majority of the nation's mushrooms (USDA-ERS, 2008c).

The US is among the top producers and consumers of fruit and tree nuts in the world. Each year, fruit and tree nut production generates about 13% of US farm cash receipts for all agricultural crops. Annual US per capita consumption of fruit and tree nuts totals nearly 300 pounds fresh-weight equivalent. Oranges, apples, grapes and bananas are the most popular fruit while almonds, pecans and walnuts are the most preferred tree nuts (USDA-ERS, 2008b).

B. Packers

If growers do not sell directly to the end market, then they typically sell to a packer. Packers transform loose product into a saleable product by packing it into cartons, boxes, or bags as appropriate. They also perform the key functions of sorting, washing and packing the produce.

The application of new technologies occurs at ever-increasing rates in the produce industry. Ultra-sound and X-ray technology are used to detect hollow-heart spots inside potatoes (see also Chapter 15). The ability to detect defects of this nature allows the packer–shipper to guarantee a more uniform product, and therefore to secure a higher price. Technology has allowed packers to reduce their reliance on human labor in the sorting, grading and packaging process. The family of one of the authors used to employ over 50 people in a potato packing warehouse. Today this operation relies on approximately 30 people, who pack five times the output of the crew of 50.

Participants in the produce supply chain are constantly looking for new and innovative packaging. Paper bags and cardboard trays have given way to complex polymer containers. Consumers buy with their eyes, and expect to be treated to bold, crisp colors in packaging. It is common to pack produce in packaging that complements the product. For example, carrots will usually be packed in plastic bags with orange and green colors, while strawberries are packed in clear clam-shells with red labels and a moisture pad on the bottom to soak up any condensation that may form during transit.

Produce packaging commonly takes advantage of highly specialized designs that allow the produce to breath in the package. Some packaging is geared toward reducing preparation and cooking time. For example, baking potatoes can be wrapped in a specialized plastic wrap that allows the end-user to microwave the potato in five minutes, in essence, steaming the potato. In addition, many produce offerings are being packaged as "fresh-cut." Fresh-cut refers to pre-cut, pre-packaged produce, such as salads that include cut lettuce, shredded carrots and sliced onions (see also Chapter 10). In fact, the value of fresh-cut sales has increased by more than four times since 1994 (Rabobank, 2004). This particular segment of the value chain is innovative and capturing additional profits. As a result, many participants have considered serving this role in the value chain.

Consumers are increasingly demanding packaging that is "earth friendly." The produce industry is seeking ways to reduce the amount of packaging required, while maintaining the integrity of the product during transit. Wal-Mart has led the push to use reusable product containers (RPCs). These could be used not only to pack and ship produce, but also to display produce directly in the store with these containers. At the time of writing, RPCs have not gained wide acceptance because of issues of ownership of these reusable containers as they change hands through the produce supply chain.

C. Shippers

The term shipper understates the role of these members of the fresh produce marketing chain. This group is responsible for bringing together buyers and sellers. In the past, they have relied on a transactional approach, but recently have switched to using intermediate and long-term contracts with buyers. Shippers can be very large, vertically-integrated growers, a cooperative of growers, or independent businesses.

A cooperative is a type of corporation that usually has multiple owners, offers goods and services to customers, utilizes sound business practices and operates under state-granted articles of incorporation. Three principals distinguish cooperatives from general corporations. These are: user-owned, user-controlled and user-benefits. The people who use the cooperative own and finance the business. "User-controlled" means a majority of the customers are members who select their boards of directors. "User-benefits" explain the cooperative's primary purpose is to provide and distribute benefits to members (USDA-RBCDS Cooperative Services, 1995). Fruit and vegetable-based cooperatives are still important in the produce supply chain today.

Of the 2675 registered cooperatives in the US in 2006, there were 167 fruit and vegetable cooperatives. These 167 cooperatives were comprised of 28 700 members with sales of $5.8 billion. It is not surprising that California and Florida had the largest number of fruit and vegetable-related cooperatives, 45 and 18, respectively (USDA-Rural Development, 2008).

D. Retailers

Grocery stores are the first group that comes to mind when thinking of retailers but fresh produce can also be purchased in convenience stores, malls, by mail order and even on the Internet.

The top 75 North American food-based retailers (e.g. grocery stores, supercenters, wholesale clubs, convenience stores) accounted for $830.19 billion in sales in 2007 (Supermarket News, 2008b). The top five North American retailers include:

1. Wal-Mart Stores: $240.8 billion in sales;
2. Kroger Co.: $69.0 billion in sales;
3. Costco Wholesale Corporation: $63.1 billion in sales;
4. Supervalu: $43.9 billion in sales; and
5. Safeway: $42.3 billion in sales.

The top five retailers accounted for 55% of the sales volume.

Internet-based retailers have been around since the 1980s. Internet grocery retailers have come and gone (mostly gone), with one exception, Peapod. Founded in 1986, it takes orders from customers online and then someone from Peapod physically goes to the retailer to pick the items requested by the customer. The minimum order size is $75. Next, Peapod delivers the grocery items to a customer at retailer cost plus a delivery charge. Before 1996, it provided an online grocery shopping service in partnership with Jewel in Chicago and surrounding towns, Safeway in San Francisco, California, Randall's in Houston, Texas and Kroger in Columbus, Ohio. Peapod was one of the earliest Internet start-ups; the company made the Inc. 500 list of fast-growing privately held US companies. Between 1997 and 2000, Peapod expanded into Boston and Watertown, Massachusetts, Long Island, New York and Norwalk, Connecticut in partnership with Stop & Shop. In late 2000, they entered Washington DC and surrounding towns, cooperating with the Giant Food supermarket chain.

Royal Ahold bought 51% of Peapod's shares in June 2000, and in August 2001 they bought out the entire company. As a result, Peapod's only remaining retailer contracts are with Royal Ahold's two primary American chains, Stop & Shop and Giant Food (Peapod, 2008). One of the reasons for the success of Peapod has been their ability to take care of a primary need for time-starved consumers – convenience. While the idea of using this type of service has a certain appeal, many consumers are wary of turning over the selection of perishable items, such as produce, to a stranger. For other consumers, there is value in spontaneously shopping for items that answer the question: "what's for dinner?" The other reason there have not been more companies entering into the e-commerce grocery retail business is that no one has been able to overcome effectively all the transaction costs of buying in bulk and selling by the piece to consumers distributed over large areas. Peapod has chosen its marketing to coincide with densely populated areas to drive up sales to cover costs.

In an annual survey of grocery shoppers, when asked to rank the importance of quality fruits and vegetables among top factors in selecting the primary grocery store, 77% of respondents named produce a very important factor, and 7% ranked it as the overriding factor. In another survey by *Progressive Grocer*, consumers were asked how they spent their money in a grocery store. In 2006, the average consumer spent $10.23 on produce out of every $100 spent on groceries (The American Institute of Food Distribution, Inc., 2007).

Grocery retailing is comprised of the following formats (Food Marketing Institute, 2008), with produce sold in each format:

- Conventional supermarket: the original supermarket format offering a full line of groceries, meat and produce, with at least $2 million in annual sales; a typical store carries approximately 15 000 items, offers a service delicatessen and frequently a service bakery;
- Superstore: larger version of the conventional supermarket with at least 40 000 square feet in total selling area and 25 000 items;
- Food/drug combo: combination of superstore and drug store under a single roof, with common checkouts; these stores also have a pharmacy;
- Warehouse store: low-margin grocery store offering reduced variety, lower service levels, minimal decor and a streamlined merchandising presentation, along with aggressive pricing; in general, warehouse stores do not offer specialty departments, e.g. Xtra;
- Super warehouse: high-volume, hybrid format of a superstore and a warehouse store; super warehouse stores typically offer a full range of service departments, quality perishables and reduced prices, e.g. Cub Foods;
- Limited-assortment store: “bare-bones,” low-priced grocery store that provides very limited services and carries fewer than 2000 items with limited, if any, perishables, e.g. Aldi and Sav-A-Lot;
- Convenience store (traditional): small, higher-margin store that offers an edited selection of staple groceries, non-foods and other convenience food items, i.e. ready-to-heat and ready-to-eat foods; the traditional format includes stores that started out as strictly convenience stores, but might also sell gasoline;
- Convenience store (petroleum-based): the petroleum-based stores are primarily gas stations with a convenience store;
- Hypermarket: a very large food and general merchandise store with approximately 180 000 square feet of selling space. While these stores typically devote as much as 75% of the selling area to general merchandise, the food-to-general merchandise sales ratio is typically 60:40, e.g. Bigg’s;
- Wholesale club: membership retail/wholesale hybrid with a varied selection and limited variety of products presented in a warehouse-type environment. These 120 000 square foot stores have a grocery line dedicated to large sizes and bulk sales. Memberships include both business accounts and consumer groups, e.g. Sam’s Club, Costco and BJ’s;
- Mini-club: a scaled-down version of the wholesale club. The mini-club is approximately 25% of the size of a typical wholesale club, and carries about

60% of the SKUs, including all of the major food and laundry departments and a limited line of merchandise (soft goods, office supplies and opportunistic, one-time buys), e.g. Smart & Final. Some of these stores do not have membership fees and often operate as a "cash & carry;"

- Supercenters: a large food/drug combination store and mass merchandiser under a single roof. The supercenters offer a wide variety of food, as well as non-food merchandise. These stores average more than 170 000 square feet, and typically devote as much as 40% of the space to grocery items, e.g. Wal-Mart, Kmart, Super Target, Meijer and Fred Meyer;
- Deep-discount drug store: a low-margin, GM/HBC store with approximately 28 000 square feet of selling space and 25 000 SKUs. Food accounts for 20% of store sales, e.g. Phar-Mor and Drug Emporium;
- Internet: an Internet-based grocery distribution operator; included in this format are all Internet operators who use the Internet as the primary means of accepting grocery orders for home delivery or pick-up. Also included are major food retailers that generate a portion of their sales through Internet-based sales. Internet suppliers typically offer 12 000 SKUs or more for home delivery, e.g. Peapod.

E. Food service operators

Restaurants are key outlets for fresh produce (see also Chapter 11). In addition, fresh produce can be found at hotels, cruise ships, corporate and school cafeterias, college and university dining halls, arenas, theme parks, hospitals, nursing homes and prisons, among other places. Many of these outlets rely on food service distributors to deliver fresh produce to each location.

Restaurant sales reached $537 billion in 2007. This is an increase of almost 5% over 2006. This marked the sixteenth consecutive year of real growth. Total food service sales account for approximately 4% of the US gross domestic product (GDP). The nation's 935 000 restaurant and food service outlets have a total economic impact that exceeds $1.3 trillion (The American Institute of Food Distribution, Inc., 2007).

The restaurant industry's share of the consumer's food dollar is 47.9%. While the share is much higher than the 25% in 1955 (The American Institute of Food Distribution, Inc., 2007), the split between consumer food dollars spent away from home (food service operations) and food dollars spent at home (grocery stores) has remained relatively constant over the past ten years, in part due to an increasing emphasis on home meal replacement by grocery store operators.

A major challenge for produce in the food service system is the role convenience continues to play in consumer eating habits. Consumers are 17% more likely to purchase fast food when convenience is the main factor, while consumers seeking more healthful foods are 19% more likely to patronize full service restaurants over fast food restaurants, because they perceive that full service restaurants serve healthier food (The American Institute of Food Distribution, Inc., 2007). The issue for produce providers is to find new ways to get additional produce offerings on these menus.

Food service, once the home of specialists in produce, meat, dry goods and equipment, is now dominated by large broad line distributors that position themselves as a one-stop shop for restaurants and other food service operations. Sales of the largest broad line distributors continue to grow each year. In 2007, sales from the top 50 broad line distributors exceeded $95 billion. The top 50 broad line distributors accounted for nearly 39% of all food service distribution sales in 2007. Total food service distribution sales were $215 billion in 2007. The largest food service distributors are:

1. Sysco Corporation, $36.6 billion in sales;
2. U.S. Foodservice, $19.2 billion in sales;
3. Performance Food Group, $5.8 billion in sales;
4. Gordon Food Service, $5.2 billion in sales; and
5. Reinhart Foodservice, $2.6 billion in sales (Dlaboha, 2008).

Produce has become a point of differentiation for Sysco, the largest of the top 50 breadline food service distributors. In the early part of this century, Sysco purchased FreshPoint, Inc., the largest produce specialist in the nation (http://www.freshpoint.com). Sysco acquired four produce specialists in 2005 and three more in 2006: Incredible Fresh Produce (Florida), City Produce Inc. (Texas), and Thomas Brothers Produce (Oklahoma), respectively (The American Institute of Food Distribution, Inc., 2007). Although owned by Sysco, Fresh Point is operated separately, and in fact competes against local Sysco distribution centers. Sysco has used the acquisitions of produce specialists to drive sales growth and to gain competitive advantage in the marketplace.

VI. Structural issues impacting market functions

There are several contemporary issues that impact the relationships among key market participants. Among the issues are changes in labor, capital and institutional design. There are also concerns with respect to the environment, government regulation and sustainability. The current issues have the potential to alter significantly the way that the produce marketing system functions. For example, marketing alliances in fresh produce exist because fresh produce markets are imperfect, dynamic institutions that are quite dissimilar from the abstract models of economic theory. At least three general sources of these imperfections provide economic incentives and rewards for creating alliances: industry structure, the under-provision of “goods and services” needed for well-functioning markets, and the inherent characteristics of fresh produce itself (Sterns, 2008).

A. Industry structure

Produce markets typically are characterized by conditions of uneven distribution of market power that disadvantage small producers and initial handlers. As a consequence, those whose preferences count in determining terms of trade are often down-stream market participants, such as repackers, processors, distributors, retailers and other market intermediaries. Often, these terms of trade are more than just the specification of price and "quality" of products. Market structure can also have a significant effect on what products are actually bought and sold, and who actually gets to buy and sell them. For example, large European and American retailers like Carrefour and Wal-Mart can dictate quality standards and minimum shipping volumes from their suppliers. When retail giants enter markets in developing countries, local producers may not have access to markets because they cannot meet the demands of the retailers.

B. A functioning market

Markets are not abstract ideals that magically emerge from chaos to order. Rather, choices and actions, both individual and collective, purposefully create markets, and drive their dynamic evolution as social institutions. Some choices facilitate the functioning of markets, while others impede them. When functioning well, markets can generate clear benefits and lower transaction costs for many, if not all, market participants. For example, benefits arise from clear market signals regarding quality. Consumers are supplied with sufficient quantities at satisfactory quality levels, and producers are rewarded in the form of profits. Transaction costs are minimized when quality is standardized, reducing the need for negotiating price levels.

However, benefits and lower costs often go unrealized, because individual incentives are difficult to align in the absence of some form of collective action and cooperation among market agents. One reason is that many benefits associated with improving the functioning of markets have high exclusion costs associated with them, hence if one market agent takes actions (and, thereby, incurs the costs) to create a better functioning market, others have strong incentives to free ride. For example, if one market agent pays for promotions that create consumer awareness and demand for a particular agricultural commodity, others in the market benefit from the action without incurring the cost of the promotion.

Another characteristic that complicates incentives for providing the necessary setting for well-functioning markets is that many of the benefits for doing so can be captured simultaneously by multiple agents. For example, if one market agent "consumes" (i.e. uses) market information, other market agents can still use that same information. This jointness-in-use creates an academically interesting, though in practice confounding, interdependency; the marginal cost of adding one more user of market information approaches (or is equal to) zero. From a practical standpoint, if marginal costs in use are zero, what price should the marginal user pay?

To a grower or market intermediary wanting to buy or sell fruits and vegetables, what matters is not the "economics" of why markets do or do not function well (i.e. the conditions noted in the previous section), but rather the actual "orderly marketing" of products and services is what matters. The phrase "orderly marketing" is frequently used in the legislation and regulatory statues of the US government, and it refers to a set of actions, authorized by law, which can directly facilitate the exchange of agricultural products.

"Orderly marketing," by definition, dictates the creation and free flow of information, low barriers to the adoption of innovations, the effective coordination of market transactions and the adoption of generally accepted practices for all industry participants. Orderly marketing results in economic gains, cost savings and an alignment of economic incentives that sustain these gains and cost savings. Hence, "orderly marketing" is the legal rationale written into US government policies that specify classes of marketing alliances that are allowable under law in the US. Examples of these alliances common in fresh produce industries include marketing orders, marketing commissions, promotional boards and cooperatives.

These various alliances are authorized to take actions that will improve the orderly marketing of fresh produce. For example, these alliances invest in research and development, establish grades and standards for agricultural commodities, mandate uniform packaging and shipping standards and coordinate the harvesting and preliminary processing of raw commodities. Each of these actions can and does contribute to the orderly marketing of agricultural products.

C. Characteristics of agricultural goods and services

Transaction costs in agricultural markets are particularly high. Following Williamson's (1985) general analytic framework, it is readily evident that individual growers are very susceptible to opportunism, simply because of inherent characteristics common to most fresh produce. For example, because fresh produce is perishable, buyers know that it must be sold quickly. Buyers can use this fact to leverage more favorable terms of trade, especially since buyers also have the advantage of being able to source relatively homogeneous products from multiple suppliers. Further, assets deployed in the production of fresh produce are typically very specific and, as Williamson (1985) noted, high levels of asset specificity increase the potential for others to act in an opportunistic way. Lastly, information flows in agricultural marketing channels are often imperfect, adding yet another incentive for downstream market agents to act opportunistically.

Therefore, basic economic conditions help substantiate the need for market alliances, and explain why alliances can provide economic benefits to those who form them. They also provide the intellectual rationale for government policies that facilitate the formation of market alliances, especially among fresh produce growers and first handlers.

With an understanding of the functions of the fresh produce marketing chain, one can begin to identify the functions members of the chain have taken on historically, presently, and might take on in the future. Many forces drive the decision to vertically integrate or coordinate. Consolidation among retailers, efforts to eliminate the "middleman," information technology, enhanced inventory management techniques, globalization, growth of organic consumption and increasing energy prices are just a few changes that are likely to bring changes in coordination along the fresh produce marketing chain.

D. Competing land use issues

There are a number of issues that produce supply chain participants face at the rural–urban interface, especially in states like California and Florida. From a grower perspective in fast-growth population states like Florida, rising land values are strong incentives to producers to sell their land for housing developments. Another issue is the potential for pesticide drift from farms affecting nearby housing communities and schools. This is a significant issue in parts of Florida. For example, the proximity of farms to urban areas is often beneficial for those that sell at local farmers' markets, and produce is obviously important for local markets.

The protection and preservation of farmland discussion is often driven by the rationale that farms generate ecosystem services. However, farmers that produce row crops, fruits and vegetables typically generate fewer ecosystem services than others, such as cattle ranchers, but, on the other side, there are ecosystem services produced through row crop farms that are not well understood (e.g. habitat for beneficial insects, pollination, erosion control).

E. Farmers' markets

Farmers' markets are a fundamental part of the urban–rural interface, they have continued to grow in popularity, mostly due to the growing consumer interest in obtaining fresh products, especially produce directly from the farm (see also Chapter 11). Farmers' markets allow consumers to have access to locally grown, farm-fresh produce, enable farmers to develop personal relationships with their customers, and cultivate consumer loyalty with the farmers who grow the produce. Direct marketing of farm products through farmers' markets continues to be a significant sales outlet for agricultural producers nationwide. In 2006, there were 4385 farmers' markets operating throughout the nation. The number was an increase of 18% from the number reported in 2004. The growth demonstrates that farmers' markets are meeting the needs of an increasing number of small- to medium-sized operations (USDA-AMS, 2008).

F. Labor issues

The production of fresh fruit and vegetables requires a significant amount of manual labor. University of Florida enterprise budgets (Hewitt, 2006) estimate that at least 200 hours of manual labor are required to plant, grow and harvest one acre of fresh market tomatoes. At least 50 hours are required to hand-harvest one acre of citrus. The bulk of labor is supplied by seasonal and migrant farm workers. The workers are hired by the day and, typically, are paid a piece rate wage, which rewards workers for their productivity and speed to complete the assigned task.

Between 50% and 70% of farm workers are undocumented, meaning they are working in the US illegally (Mehta et al., 2000). The latest Natural Agricultural Worker Survey results indicate that more than 50% of farm workers self-reported that they were working in the US without legal documentation. Data from the Social Security Administration reveal that more than 70% of social security numbers listed on W-2 forms from agricultural employers are "mismatched." The problem of illegal immigration in farm work is not new. The issue of illegal immigration rose to such importance that the US congress enacted the Immigration Reform and Control Act (IRCA) of 1986. At that time, the illegal immigration issue was viewed as an "agricultural" problem that involved between one and two million workers. IRCA was supposed to "fix" the problem by granting amnesty to undocumented farm workers, in exchange for tougher sanctions on employers who hired undocumented workers in the future.

Unfortunately, IRCA did not anticipate the rapid and sophisticated development of the forged document industry. A set of employment papers, including a social security number, could be purchased at a cost between $100 and $500 depending on the quality of the documents (Grassi, 2006). Employers were not able, nor allowed out of fear of discrimination lawsuits, to distinguish between legal and forged documentation. The problem of illegal immigration continued to grow through the 1990s, and into the twenty-first century. The difference between 2005 and 1986, however, is that illegal immigration ceased to be exclusively an agricultural problem. Over the last 20 years, the booming US economy has attracted more than 12 million undocumented workers, fewer than 2 million of whom work in agriculture.

G. Sustainability and the produce supply chain

Issues of sustainability have become increasingly important to the produce supply chain. As energy prices continue to increase and social issues, such as global warming, continue to gain the attention of consumers, produce supply chain participants must be ready to act. At the time of writing, the authors know of at least two major sustainability efforts in Florida. One is a sustainability effort at the University of Florida where Aramark, the food service management company, in conjunction with their approved suppliers, is actively seeking out local produce farmers to provide as much fresh produce as possible to the university. The second effort involves the Breakers Hotel in West Palm Beach, Florida. The Breakers is actively seeking local providers of, possibly, all food and other goods it uses in its operations. The Breakers has gone so far to promote the idea as to form a limited liability corporation with interested local suppliers to achieve these sustainability goals.

Sustainability initiatives are springing up all around the world. For example, the leading UK food retailer, Tesco, announced recently that it would show products' carbon footprints on its food labels. Tesco is one of the first grocery retailers to track and publicly display the total carbon footprint.

VII. Concluding remarks

Participants can determine the functions they are best suited to accomplish by viewing the produce marketing system as a set of tasks that must be accomplished, i.e. through the application of the functional view of the market. Indeed, over time, the system has seen changes that have encouraged participants to add or discontinue activities that they had previously accomplished. It is notable that, increasingly, producers have returned to direct marketing of products through buy local and farmers' markets campaigns.

At the time of writing there were a number of emerging issues facing the produce food system. The increasing cost of energy, the increasing popularity of "buying local" and the increasing demand of biofuels is likely to drive the growth of pockets of fruit and vegetable production to meet local needs. It will be interesting to see what happens when these trends meet the urban sprawl in California, Texas and Florida, the states expected to grow by the greatest amount between 1993 and 2020 (Campbell, 2008).

Consumers will continue to demand a wide variety of produce that is convenient and accessible year-round. The health attributes of produce will continue to drive consumer demand, especially in countries like the US where child and adult obesity issues continue to mount. Although some of these emerging issues are likely to result in increasing consumer prices for produce, others are likely to result in an increased willingness on the part of consumers to pay for products that deliver value.

The fresh produce marketing system continues to evolve. Many pending challenges cause system participants to reconsider their functions seriously. Competing land use, labor issues and sustainability issues will force changes in the system that seem likely to force consumers to rely increasingly on locally grown produce. These issues have implications for producers, transporters and assemblers. Although the participants accomplishing each of the functions may change, the functions themselves will remain.

Key words

Exchange functions, facilitating functions, physical functions, price determination, produce supply chain, storage, transportation.

Bibliography

Agricultural and Resource Economics Department (2007). Fresh produce: meeting year-round consumer demand. Department of Agricultural and Resource Economics at the University of Arizona. Available online at http://ag.arizona.edu/arec/dept/flyers/produce.html. Accessed 6 May 2008.

The American Institute of Food Distribution, Inc. (2007). The Food Institute's Food Industry Review, 2007 edn. The Food Institute, Elmwood Park, NJ.

Campbell, P.R. (2008). State Population Projections: States in the south and west are expected to show big gains between 1993 and 2020. U.S. Census Bureau. Available online at http://www.census.gov/population/www/pop-profile/stproj.html

Dlaboha, I. (2008). 2007 ID Top 50 report. Available online at http://www.myidaccess.com/. Accessed 15 April 2008.

ElAmin, A. (2007). Logistics study highlights use of technology in food sector. Food Navigator.com – Europe. Available online at http://www.foodnavigator.com/news/ng.asp?id=73794 Accessed 7 May 2008.

Energy Information Administration (2008). April 8. Short term energy and summer fuels outlook. Department of Energy. Available online at http://www.eia.doe.gov/emeu/steo/pub/contents.html Accessed 16 April 2008.

Food Marketing Institute (2008). Supermarket facts: store definitions. Available online at http://www.fmi.org/facts_figs/?fuseaction=superfact Accessed 16 April 2008.

Fruit Farming (2008). In: Encyclopædia Britannica. Available online at http://www.britannica.com/eb/article-67942 Accessed 16 April 2008.

Govindasamy, R., Thornsbury, S. (2006). Theme overview: fresh produce marketing – critical trends and issues. Choices: The Magazine of Food, Farm, and Resource Issues, 4th Quarter, 21(4).

Grassi, D. (2006). False documents of undocumented remain problematic. *The American Chronicle*, May 17.

Hewitt, T. (2006). Florida tomato enterprise budget. Available online at http://nfrec.ifas.ufl.edu/Hewitt/budgets.htm Accessed 28 April 2008.

Kohls, R.I., Uhl, J.N. (1998). Marketing of Agricultural Products, 8th edn. Prentice Hall, Boston, ME, USA.

Mehta, K., Gabbard, S., Barrat, V., Lewis, M., Carroll, D., Mines, R. (2000). A demographic and employment profile of united states farmworkers. United States Department of Labor – Office of the Assistant Secretary for Policy. Available online at http://www.doleta.gov/agworker/report_8.pdf Accessed 26 April 2008.

Orange Pippin (2008). Pink Lady Apple. Orange Pippin: Specialist information about about apples and orchard fruit. Available online at http://www.orangepippin.com/apples/pinklady.htm Accessed 5 May 2008.

Patton, D. (2008). UK retailers urged to step up developing world suppliers. Food Navigator.com – Europe. Available online at http://www.foodnavigator.com/news/ng.asp?id=84346 Accessed 6 May 2008.

Peapod (2008). Peapod, Inc. Corporate fact sheet. Peapod.com. Available online at: http://www.peapod.com/corpinfo/peapodFacts.pdf

Prevor, J. (2006). Building a career in the produce industry: The excitement, the passion and the opportunity of a lifetime. White paper prepared for the Produce Marketing Association Educational Foundation for the Pack Family/PMA Career Pathways Fund Fellows of 2006.

Rabobank, Food and Agribusiness Research (2004). 2004 North American Food & Agribusiness Outlook, pp. 62–63.

Schaffner, D.J., Schroder, W.R., Earle, M.D. (1998). Food Marketing: An International Perspective. McGraw-Hill Companies, Boston, ME, USA.

Stacey, C. (2008). Food miles. BBC Food: Food Matters. Available online at http://www.bbc.co.uk/food/food_matters/foodmiles.shtml Accessed 6 May 2008.

Sterns, J.A. (2008). Alliances and innovation – lessons from agribusinesses in Florida, USA. Plenary paper session presentation, Ismaili Economic Forum, Dubai, UAE, April 26–27.

Supermarket News (2008a). GS1 group working on a standard performance scorecard. Available online at http://supermarketnews.com/technology_logistics/ar/gs1_scorecard_0404/ Accessed 28 April 2008.

Supermarket News (2008b). SN's top 75 retailers for 2008. Available online at http://supermarketnews.com/profiles/2008-top-75/ Accessed 28 April 2008.

USDA-AMS (2008). Wholesale and farmers markets: Farmers markets. United States Department of Agriculture-Agricultural Marketing Service. Available online at http://www.ams.usda.gov/AMSv1.0/ Accessed 16 April 2008.

USDA-ERS (2001). Changing dynamics in produce marketing. U.S. fresh fruit and vegetable marketing: Emerging trade practices, trends, and issues. United States Department of Agriculture-Economic Research Service AER-795. Available online at http://www.ers.usda.gov/publications/AgOutlook/Mar2001/AO279e.pdf Accessed 6 May 2008.

USDA-ERS (2008a). Food CPI, prices, and expenditures: analysis and forecasts of the CPI for food: food price outlook, 2008. United States Department of Agriculture-Economic Research Service Briefing Room. Available online at http://www.ers.usda.gov/Briefing/cpifoodandexpenditures/consumerpriceindex.htm Accessed 16 April 2008.

USDA-ERS (2008b). Fruits and tree nuts: Background. United States Department of Agriculture-Economic Research Service Briefing Room. Available online at http://www.ers.usda.gov/Briefing/FruitAndTreeNuts/ Accessed 16 April 2008.

USDA-ERS (2008c). Vegetables and melons: Background. United States Department of Agriculture-Economic Research Service Briefing Room. Available online at http://www.ers.usda.gov/Briefing/Vegetables/Background.htm Accessed 16 April 2008.

USDA-RBCDS Cooperative Services (1995). What are cooperatives? Cooperative Information Report 10, Revised March 1995. United States Department of Agriculture-Rural Development. Available online at http://www.rurdev.usda.gov/rbs/pub/cir10.pdf Accessed 16 April 2008.

USDA-Rural Development (2008). Business and cooperative programs: Cooperative programs current data-number of cooperatives and memberships by major business activity 2006. United States Department of Agriculture-Rural Development. Available online at http://www.rurdev.usda.gov/rbs/coops/data.htm Accessed 16 April 2008.

Williamson, O.E. (1985). The Economic Institutions of Capitalism. The Free Press, Macmillan, Inc., New York, NY, USA.

8

Quality Management: An Industrial Approach to Produce Handling

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Postharvest Handling: A Systems Approach
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I. Introduction

The global fresh produce market is a complex multi-billion dollar business, involving a wide range of small- to large-scale supply chains. Advances in postharvest science and technological innovations in produce handling for long-term preservation and maintenance of quality and safety have contributed to year-round supply and availability of agricultural produce grown in diverse climates that are continents apart. Consequently, bananas produced in Ecuador, pineapples grown in Ghana, or kiwifruit grown in New Zealand can be purchased in top quality condition elsewhere in supermarkets in parts of Europe, North America, Asia and Africa. With the rising influence of multinational firms in the globalization of fresh produce supply chains, and increasing epidemiological evidence which positively link high consumption of fruit and vegetables with a reduced incidence of cardiovascular and other chronic diseases, such as cancer (Ness and Powles, 1997; Lamp, 1999; Kaur and Kapoor, 2001; Su and Arab, 2006), the market for fresh produce has continued to expand during the past decade.

In comparison to other items of international trade, agricultural and horticultural produce are highly perishable and variable in their physico-chemical properties, nutritional composition and other quality attributes. Because they are living things, even after harvest they continue to respire and undergo further biochemical and physiological changes during the course of postharvest handling, up to the point of end use. These unique attributes pose considerable challenges for all participants in the supply chain management of fresh produce, from field to end-user. To ensure reliable supply of produce with desirable and consistent quality attributes which meet or exceed consumer expectations, appropriate postharvest technologies must be deployed at all steps in the supply chain, to reduce the incidence of losses and maintain quality (Opara et al., 2002). In addition to managing produce to maintain quality and meet market specifications, the fresh produce sector must also adopt an industrial approach to the management of the produce-handling system to ensure effective and efficient delivery of good quality and safe produce.

The fresh produce market has experienced significant change, driven in large part by increased consumer demand and sophistication, and corresponding adaptations by streamlined supply chains. These changes are accompanied by consolidation of retailers and distributors to reduce costs and streamline and improve supply-chain management practices, expansion of product offerings and movement towards year-round supply, and increases in imports. Large supermarket chains continue to adopt measures to lower labor and capital costs, promote product differentiation and improve consumer services, in order to remain profitable in an increasingly competitive environment. Innovations in procurement and distribution of produce, such as inventory mechanization and automation, direct delivery by suppliers, use of specialty wholesalers and fixed contracts with suppliers, help to improve cost efficiencies and streamline the supply chain.

Global production and marketing of fresh fruit and vegetables has increased sharply during the past quarter of a century, with international trade in fruit and vegetables expanding more rapidly than trade in other agricultural commodities, especially since the 1980s (Huang, 2004). Production grew from 0.81 billion metric tons in 1990 to 1.2 billion metric tons in 2002, while harvest area increased from 72.2 to 96.6 million hectares (Cook, 2003). Although exports remain only about 10% of total production, world fruit and vegetable exports (both fresh and processed) increased from US$51 billion in 1990 to US$72.7 billion in 1996, dropping slightly to US$69.8 billion in 2001. The share of fruit and vegetables in world agricultural trade has also increased from a nominal value of US$3.4 billion (10.6%) in 1961 to nearly US$70 (16.9%) in 2001 (Huang, 2004).

The continuing global rise in consumer demand for fresh produce is further exemplified by recent market trends in the US and Europe. The value of fresh produce (fruit and vegetables) sold to consumers in the US was valued at over US$ 70 billion in 1997 (Govindasamy and Thornsbury, 2006), while the estimated value of fresh produce sold through retail and food service channels alone surpassed US$84.5 billion in 2001 (Cook, 2003). Minimally processed produce sales, such as fresh-cut and packaged salad, rose even more significantly, from 1% to 15%, during the 10-year period from 1987 to 1997. This growth reflects increasing consumer demand for variety, quality and convenience. There has also been an approximate three-fold increase in the share of sales by produce wholesalers to the food service channel, over the same time period, from 8% in 1987 to 21% in 1997 (Govindasamy and Thornsbury, 2006), reflecting the rise in food dollars spent in the food service/restaurant sector (approaching half of the US consumers' total food dollars). The rising proportion of food service/restaurant sales is another reflection of consumer desire for convenience and value-added products. Similarly, Europe-wide fresh produce sales through supermarket channels alone (excluding greengrocers and food service) were estimated to exceed US$73 billion in 2002, with a total final sale exceeding US$100 billion (Cook, 2003).

The significant rise in global fresh fruit and vegetable production and sales during the last quarter of a century resulted in the fruit and vegetable market becoming one of the fastest growing components of all agricultural markets (EC, 2007). This growth, in both production and sales, also corresponded to increases in per capita intake (WHO/FAO, 2005; Hodder, 2005). A recent analysis of the evolution of world fruit and vegetable markets by the European Commission (EC) based on statistics from the Food and Agriculture Organization (FAO) showed that global fruit and vegetable consumption increased by an average of 4.5% per annum between 1990 and 2004 (EC, 2007). Between 1980 and 2001, per capital global consumption of major fruit and vegetables increased substantially by double digits (Hodder, 2005).

Accurate data on global intake of fruit and vegetables is lacking, due to the use of different assessment methods by researchers and the absence of dietary intake assessment programs in many countries. As part of a comparative risk assessment (CRA) to estimate the global health effect of low fruit and vegetable intake conducted by the World Health Organization (WHO) within its Global Burden of Disease 2000 Study, Pomerleau et al. (2004) estimated worldwide fruit and vegetable intakes from 26 national population-based surveys, complemented with food supply statistics. Using a regional sub-classification based on child and adult male mortality levels (A: very low; B: low; C: low child and high adult; D: high; E: high child and very high adult), the results showed that intakes varied considerably by region, gender and age (overall median = 223 grams per person per day). Highest fruit and vegetable mean intake was in Europe (A: median = 449 grams per person per day) and the Western Pacific Region (A: median = 384 grams per person per day). However, the lowest intakes were found in America (B: 192 grams per person per day), Europe (C: 217 grams per person per day), South East Asia (B: 223 grams per person per day), South East Asia (D: 244 grams per person per day), and Africa (E: 246 grams per person per day), respectively. These results and recent analysis that support the new collaborative WHO/FAO global strategies on diet, physical activity and health (WHO, 2003a,b,c; WHO, 2004; FAO, 2005; Smith and Eyzaguirre, 2007) showed that despite the rise in fruit and vegetable intake during the past 25 years, global consumption is still well below the minimum recommended intake of 400 grams per person per day. A recent joint FAO/WHO workshop on fruit and vegetables for health outlines a framework to promote increased production and consumption of fruits and vegetables (WHO/FAO, 2005).

While the global fresh produce market continues to grow, this market is increasingly complex, like all agriculture. However, unlike many agricultural sectors, fresh produce markets frequently involve much higher risks, with the potential for corresponding higher returns. Postharvest innovation in handling and distribution technology, retailer and wholesaler consolidation, changing legal environment, international standards and agreements, food safety issues and health concerns create new challenges and new opportunities in a sector where per hectare cost of production is already high, and traditional government safety nets for industry do not normally exist.

This chapter reviews the current approaches to produce quality management, from the principles and practice of produce inspection and quality control to quality assurance, and discusses specific quality management procedures and regimes, ranging from good agricultural practice (GAP), HACCP and ISO standards to total quality management (TQM). Finally, I conclude this chapter with a highlight of the current and future prospects for an industrial approach to quality management in fresh produce handling.

II. Global issues impacting quality management in produce handling

A. Dynamic and interconnected supply chains

To access and retain their share in local and export markets, fresh produce supply chains must adopt a business approach to quality management of their products and processes. This requires understanding of the fact that fresh produce intended for market passes along a complex, dynamic and interconnected supply chain from fields, where they are grown, right along the supply chain to the end-user (see Chapters 6 and 7). Thus, a breakdown at any point in the supply chain can easily result in the collapse of the whole, highlighting the important and interconnected roles of all participants (see Chapter 1). The participants in the supply chain include farmers/producers and postharvest handlers, such as buyers, packers and exporters, who consolidate produce and transport it to distribution points, and importers, distributors, wholesalers and retailers who buy, distribute and sell the produce, to consumers who buy the produce. As more and more produce is consumed farther away from its region or country of origin, global supermarket chains have continued to exert considerable influence on both the supply and quality of produce.

There are also external factors and organizations which affect the supply chain and influence the smooth flow of produce. These include climate change which affects weather conditions (temperature, rainfall, sunshine, floods, and storms) that cannot be controlled, but represent critical factors affecting crop productivity and logistics, suppliers whose products (seeds, fertilizers, agrochemicals, equipment) are needed for increasing production and handling the produce, and financial institutions. Each of these participants, both those central to the chain itself and those who affect it from outside, perform critical roles which affect the whole produce-handling system.

B. Changing market requirements

The rise in global demand for fresh produce is also matched by rapid changes in consumer demand about the source, quality, safety, convenience and other attributes of the produce they purchase, and this trend is likely to continue in the foreseeable future. Produce safety and integrity is clearly non-negotiable, and is a basic entry-level requirement for a supplier to meet all the quality protocols and regimes to guarantee safe food. Because all produce suppliers must meet these standards, meeting the standards is, therefore, no longer an asset in gaining competitive business advantage. Consequently, greater attention is paid to ensuring that quality standards and protocols are met efficiently, emphasizing the need to deploy appropriate quality management systems.

In addition, fresh produce suppliers have to meet ever-increasing environmental, social and food quality standards, and have to demonstrate compliance with these standards using the principles of traceability (see Chapter 12) and due diligence. These standards and legislations (both national and regional) have become non-negotiable market requirements, and must be met by small-, medium- and large-scale suppliers (see Chapter 9). Accordingly, only those suppliers who develop a long-term integrated quality management strategy for responding to market signals are likely to survive in the competitive world of fresh produce trade.

There are medium- to long-term strategic imperatives for companies to adopt an integrated industrial approach to quality and supply chain management:

1. consumer safety: recent, unprecedented, food scares, including fresh produce, have heightened consumer concern about food safety and driven food safety standards to ever greater complexity;
2. reputation: just like any other asset, fresh produce companies need to manage their reputation to be able to retain existing customers and expand into new markets. Because consumers and investors trust and value a company's name and image, any damage to reputation can lead to loss of market share and have a long-term effect on consumer behavior;

3. sustainability: companies are driven by the need to ensure sustainable supply and sustainable markets. They want to know that they can rely on producers to continually supply high-quality produce without being threatened by environmental degradation or conflict.

C. Demand for healthful and convenient fresh produce

One of the most exciting scientific discoveries in the last two decades has been evidence of the protective effects of a group of nutrients against cell oxidation (see Chapter 5). Fruits and vegetables contain naturally occurring compounds that impart bright color to them and act as antioxidants in the human body by scavenging harmful free radicals, which have been implicated in most degenerative diseases (Kaur and Kapoor, 2001). Many epidemiological and human intervention studies have shown positive correlations between the intake of fruit and vegetables and the prevention of diseases, such as cardiovascular disease and several forms of cancer (Steinmetz and Potter, 1996; Ness and Powles, 1997; Joseph et al., 1999; Wargovich, 2000; Southon, 2000; Prior and Cao, 2000; Cuthbertson, 2002; Hyson, 2002; Kalt, 2002; Goldberg, 2003; Desjardins, 2007). Potter (1997) concluded that fruit and vegetables provide the best polypharmacy against the development of malignancy in tissues. Overall, epidemiological evidence linking increasing consumption of fresh fruit and vegetables to higher protection against cardiovascular diseases, cancer and other human health problems have been attributed mainly to their content of beneficial bioactive compounds, such as vitamins, phenolic compounds, lycopene and other carotenoids, which act as antioxidants.

With rapid changes in lifestyles associated with rising income, and growing middle class populations in both developed and developing countries, people are spending less time preparing meals, thereby driving the upsurge in demand for "convenient" foods, including fresh-cut produce (see Chapters 3 and 10). Consumer demand for fresh-cut fruits and vegetables has continued to grow due, mainly, to increasing rising consumer health consciousness and public interest in the role of food in maintaining and improving overall human well-being (Allende et al., 2006). Fresh-cut products help remove the barrier of inconvenience of eating fruit and vegetables. The global fresh-cut market (see also Chapter 10) is expanding, and poses new quality management challenges for safety and traceability beyond current practices for whole produce.

While research scientists continue to document more evidence linking fresh produce consumption to human health status, especially the incidence of cardiovascular and degenerative diseases, the impact of issues related to human health on fresh produce trade and promotion can be expected to increase in importance in the medium- to long-term. In the meantime, however, most suppliers understand and compete mainly on produce attributes, such as taste, versatility and convenience (Opara, 2000b). While these are undeniably of major importance in an increasingly competitive food market, supply chain managers must also position themselves to be able to differentiate and manage their fresh produce to meet the needs and expectations of the growing consumer demand for healthy produce.

D. Ethical commerce and ethical consumerism

According to Coles and Harris (2006), the concept of ethical consumerism has emerged over the past 15 years to describe actions taken by individuals seeking to actively support products according to their perceived ethical credentials. Related to consumer concern for sustainability of the human food production system with regard to its deleterious impacts on the environment, ethical consumerism is now a growing phenomenon (Shaw and Clark, 1999; Auger et al., 2000; Carrigan and Attalla, 2001), and it has become a major driver of a diverse range of ethical approaches to fresh produce trade. Alternative approaches, such as fair-trade, conservation-driven trade and trade in organic produce, started as market niches, but are making their presence felt in the mainstream commercial fresh produce market (Beard, 2005; Coles and Harris, 2006; Fairtrade Foundation, 2008). Changing consumer attitudes and approaches to buying and consuming fresh produce have made retailers, mainly supermarkets, adopt and implement a wide range of standards and codes of practice to segregate and promote their products. Such standards will have major implications on the way in which fresh produce is grown, handled and distributed. In response to increasing consumer awareness of the ethical choices they can exercise when purchasing produce, supply chain managers, as well as exporters, need to take into account the increasing importance that consumers attach to ethical choice in their purchasing behavior. Such responses may involve turning consumers' ethical trends into new opportunities for fresh produce business. Integrated quality management systems are necessary to segregate produce from a wide range of production systems to meet the ethical choices exercised by consumers.

E. Contract farming and multiple sourcing

Successful supply chain management of fresh produce requires adequate, reliable and timely inflow and outflow of top quality products from point of production to the end-user. This is a particularly challenging task given the huge variability in produce quality attributes and yield, even within the same production site, across different locations or seasons (see Chapter 11). To meet the seemingly insatiable consumer demand for a steady supply of diverse types of produce, supply chain operators, such as supermarkets, adopt a wide range of category management practices, including sourcing from diverse areas. While this measure contributes to the availability of large quantities of produce in the market, it does pose additional challenges for quality management, including unreliable suppliers, unpredictable quantity and quality, and seasonality of production.

Contract farming helps to address some of these issues. To be successful, however, the contractor must invest in training and appropriate quality management systems down the supply chain to assist the growers, who often lack knowledge of basic good agricultural practices (GAP) and record keeping necessary to ensure quality and safe produce. The case for investment in quality management systems in the fresh produce supply chain is illustrated by the success and difficulties faced by the Carrefour's quality line (CQL) produce quality management system in China

(Hu and Dandan, 2007). Small-scale farmers account for more than 90% of total agricultural population in China, cultivating an average 0.4 hectares. Carrefour works only with large-scale farmers for "management convenience," presumably due to higher transaction costs and risks related to purchasing, quality and safety management of produce from small-scale farmers.

III. Meaning, perspectives and orientations of quality

A. What is quality?

> "Quality is an unusual slippery context, easy to visualize but exasperatingly difficult to define."
>
> *(Garvin, 1988)*

Quality is a dynamic concept and has several elements related to agreed specifications, performance and consumer perceptions (Garvin, 1984a). A quality product (or service) will consistently meet the continuously negotiated expectations of customers and other stakeholders in a way that represents value for all involved (Kruithof and Ryall, 1994). The quality of fresh agricultural produce is assessed from the relative values of several attributes which, considered together, determine the acceptability of the produce to the buyer, and ultimately the consumer (see also Chapters 4 and 17). These attributes may be perceptible by the senses (firmness, color, flavor), as well as imperceptible (organics/naturalness, genetically modified plants, safety, cultural attitudes).

Buyers perceive that the products of certain suppliers are significantly higher in quality than those of their competition, and they buy accordingly (Feigenbaum, 1983). Quality and excellence are related to consumer perception of the product and its safety. The lack of quality as related to safety, health and wholesomeness can result in personal injury, sickness, or even death (Tybor et al., 1988). Consequently, quality has become the single most important force leading to business success in markets.

Given the multiple steps in the industrial supply chain of modern business, and the associated stakeholder interests and roles, many have their preferred definitions of quality (see also Chapters 2, 4, 9 and 11). Quality as a goal should be formulated from the perspective of the consumer; thus, the expression "quality" requires a comparison of the criteria with reality. Several experts have proposed brief definitions of quality: "conformance to requirements" (Crosby, 1979), "fitness for purpose" (Juran, 1988), "the sum of the attributes or properties that describe the product" (McDermott and Cound, 1971), "conformance to a customer's price-limited need" (Groocock, 1986), "conformance to a customer's price-limited anticipated needs" (Lidror and Prussia, 1990), and other analogous definitions.

A definition of quality was formulated by the International Organization for Standardization (ISO) in Europe; "Quality is the degree in which the whole of characteristics of a product meets the requirements that spring from the goal of use."

ISO9000:2000 takes a broader and more generalized view of quality, emphasizing the "customer and other interested parties." It defines quality as the "degree to which a set of inherent characteristics fulfils requirements." According to the glossary of the European Organization for Quality Control (Lásztity, 2004), quality may be defined as: "The totality of features and characteristics of a product or service that bear on its ability to satisfy a given need." More simply, quality may be defined as fitness for purpose. In the case of food products, such as fruit and vegetables, quality primarily involves safety, nutritive value and acceptance. The International Quality Association (IQA) draws attention to the numerous definitions of quality on its website (www.iqa.org), demonstrating the difficulty of naming quality, and in the end, it opts for a customer focus of quality.

Following a critical review of historical conceptions and definitions of quality, Straker (2001a,b) argued that quality must be viewed as a game involving many players, where success depends on understanding and mapping the processes of the game beyond current main focus on customer and products. The author proposed a somewhat unifying systems definition of quality: "quality means understanding and optimizing the whole system of value exchange." Thus, success in quality (i.e. making the game work) requires action on the words: understanding, optimizing, system, value and exchange. According to Straker (2001a), it means understanding how things truly work, both individually and as systems; it means understanding people, what they value and how they effectively trade with others; and it means working out how these imperfect systems can be optimized so businesses continue to thrive. Optimizing means making compromises, but we now have a wide range of new and emerging postharvest technologies to manage product quality and control and manipulate the postharvest environment and other related compromises.

The foregoing discussion shows that the perception of "quality" is an almost impossible and elusive term to define, and this difficulty is not confined to agribusiness. Just as we know a good room when we use one, but cannot define exactly what makes it good, we can name its attributes of quality, but cannot define quality itself. Our perception of the same "good quality" room will also depend on whether we used it for rest or study. Hence, one way to find a good definition of anything is to take a broader view, by considering the different perspectives and orientations of quality, and understanding the elements of quality, such as product attributes and standards, as discussed in the following sections.

B. Perspectives and orientations of quality

As a result of socioeconomic changes affecting consumer and agribusiness organizations, the concept of food quality is continuously evolving, even in the same region or country, not to mention the big differences between countries with different climatic conditions and levels of industrial development. Thus, the term quality encapsulates something different for various stakeholders in the food supply chain, including growers, distributors, marketers and consumers. From the perspective of the processed food industry that manufacture items from raw agricultural produce, there are two most important requirements: (a) is the produce (raw material) suitable for manufacture of a food product, which meets the demands of the consumer? If yes, to what extent? And (b) does the raw material correspond to the requirements of up-to-date processing and handling technology at commercially reasonable costs? From the perspective of the food producer/consumer, quality will include the following requirements:

- to what extent does a product meet the demands of a given group of consumers?
- what is the generally accepted "goodness" of the product, or to what extent does the food correspond to regulations?
- is the product preferred, and to what extent, in comparison with other products, does it belong to the same category?
- which specific attributes make it preferable?

Hence, satisfactory food product quality means meeting and exceeding the requirements of the end-user. At its very basic level, quality answers two questions: "What is wanted?" and "How do we achieve it?" While the first question appears straightforward as it focuses on the product, the main area of considerable debate has always been on the processes and systems that influence quality.

In an interpretative review of perspectives and orientations of quality, Shewfelt (1999) argued that product quality is often defined from a product or consumer (end-user) orientation, and that a combination of product attributes constitute quality. The consumer's perception and response to those attributes is referred to as acceptability. On the basis of this differentiation, the "product" orientation of quality focuses on product specifications and attributes which are objectively quantifiable, such as size, shape, sweetness, color and texture, while the "consumer" orientation views quality from the perspective of meeting the expectations of the end-user. Thus, for example, an apple cultivar with large size fruit and high sugar content may be viewed as having "higher" or "better" quality from a product perspective, while a consumer market segment, such as business and first class airline passengers, may prefer apples that are smaller in size and less sweet. In the same way, fruit destined for fresh market consumption will have different desirable quality attributes in comparison to those destined for food processing plants. In agri-food business, therefore, quality is not simply a degree of excellence, peculiar character, or distinguishing attribute, as often defined. Quality as a goal should be formulated from the perspective of the consumer. Thus, the expression "quality" requires a comparison of the criteria with reality.

However, following a review of Shewfelt (1999) and other related literature, Abbot (1999) stated that the components of quality attributes vary with the context of space and time in the supply chain, and argued that the concept of quality encompasses both perception and acceptability. In recent times, there has been considerable research interest in the application of consumer science towards better understanding of fruit acceptance (Alavoine et al., 1990; Crisosto et al., 2003; Harker et al., 2003a,b; Jaeger et al., 2005; Opara et al., 2007) and other types of fresh food (Radman et al., 2005).

In summary, most postharvest researchers, producers and handlers view quality from a product orientation in terms of specific attributes of the product itself, such as vitamin C content, sugar content, firmness, acidity, or color. On the other hand, consumers, marketers and economists are more likely to be consumer-oriented, and describe quality in terms of what the consumer wants and needs (Shewfelt, 1999). While the decision of consumers at the point of purchase of fresh produce is normally based on appearance and textural quality, their repeat purchases depend largely upon their satisfaction with flavor (taste and aroma) and total experience with the product. Consumers are also interested in the health-promoting attributes (e.g. the antioxidant content) and nutritional quality (e.g. fiber content) of fresh produce (Kader, 1988).

C. Product quality attributes

The quality of food may be described by the determination of physical, chemical, technological, microbiological and organoleptic properties. These properties allow objective measurement and, by evaluation of this data, the determination of quality. Nevertheless, it should be mentioned that there are some additional factors, in many cases independent from the characteristics of food products, which influence consumer preferences; for example, price, conditions of sale, origin and product reputation.

Quality attributes should be expressed quantitatively in measurable terms and evaluated objectively. Quality of design or development is the cumulative of product characteristics or a measure of how well the product achieves its expected purpose. Quality of conformance is a realization of the quality of design. Quality attributes of fresh produce include appearance (size, shape, color, gloss, and freedom from defects and decay), texture (firmness, crispness, juiciness, mealiness and toughness), flavor (sweetness, sourness or acidity, astringency, aroma and off-flavors), and nutritive value (vitamins, minerals, dietary fiber, phytonutrients) (Kader, 2001). The relative importance of each quality attribute varies with the type of produce and end-use (Kader, 1992).

There are a wide range of objective instruments for sensing and measuring the quality attributes of fresh produce, including texture, appearance, volatiles and other chemical constituents (Abbott, 1999; Nguyen et al., 2000; Opara, 2000a). Some measuring devices are destructive (required penetration or removal of tissue), while others are non-destructive, and the choice of any method or combination of methods depends on type of produce, cost and availability of the device. While most commercial packing houses adopt automatic sorting (see Chapters 14 and 15) of produce, based on size (mass), the use of non-destructive techniques for measuring internal quality attributes, such as presence of defects (e.g. watercore) and chemical/nutritional quality attributes (e.g. flavor, vitamin C), is largely confined to research laboratories. In the meantime, both researchers and industry practitioners will continue to depend on destructive techniques to evaluate fresh produce quality, such as the refractometer for soluble solids content (SSC) (°Brix), titration for titratable acidity and the penetrometer for firmness measurement.

Measurement of the quality attributes of produce is important in quality management during produce handling. Measurements provide a comparison against industry standards (see section D) and limits of acceptability by the consumer. Kader (1999) proposed the minimum SSC and maximum titratable acidity for acceptable flavor quality of a range of fruits (Table 8.1). The author noted that while these values will not guarantee the optimum flavor quality for each consumer, they ensure a minimum acceptability level for the majority of consumers. Kader (1999) also rightly cautions that the use of these indices in a quality assurance program must be coupled with tolerances of deviation from the proposed averages, because of the large variation among cultivars, production areas and seasons, maturity at harvest and ripeness stage at the time of evaluation.

D. Product quality standards

Quality standards are specifications of the quality attributes of produce which permit global understanding and facilitate trade. Often referred to as "grade standards," they identify the degrees of quality in a commodity that are the basis of its usability and value (see Chapter 9). If properly developed and enforced, they become essential tools of quality assurance during produce marketing, and provide a common language for trade among growers, handlers, processors, exporters and importers. Some production areas, e.g. California in the US, enforce minimum standards concerning produce quality, maturity, container, marking, size and packing requirements (Kader, 2001).

Table 8.1 Proposed minimum soluble solids content (SSC) and maximum titratable acidity (TA) for acceptable flavor quality of fruits (Kader, 1999)

Fruit	Minimum SSC%	Maximum TA%
Apple	10.5–12.5 (depending on cultivar)	
Apricot	10	0.8
Blueberry	10	–
Cherry	14–16 (depending on cultivar)	
Grape	14–17.5 (depending on cultivar) or SSC/TA ratio of 20+	
Grapefruit	SSC/TA ratio of 6+	
Kiwifruit	14	–
Mandarin	SSC/TA ratio of 8+	
Mango	12–14 (depending on cultivar)	
Muskmelon	10	–
Nectarine	10	0.6
Orange	SSC/TA ratio of 8+	
Papaya	11.5	–
Peach	10	0.6
Pear	13	–
Persimmon	18	–
Pineapple	12	1.0
Plum	12	0.8
Pomegranate	17	1.4
Raspberry	8	0.8
Strawberry	7	0.8
Watermelon	10	–

The use of standards permits organized marketing, mutual understanding and fairness in the marketplace, and protects consumers from otherwise unsatisfactory and poor quality produce. In some countries, the Department of Agriculture or related agency is responsible for enforcing the laws governing the sale (including import and export) of general foods, as well as specific foods such as those labeled as organic.

In the US, the standards for fresh fruit and vegetable grades are voluntary, except when required by industry marketing orders, by the buyer, or for export marketing. The USDA Agricultural Marketing Service is responsible for developing, amending and implementing grade standards (http://www.ams.usda.gov/standards).

The international standards for fruits and vegetables were introduced by the Organization for Economic Cooperation and Development (OECD) and currently there are standards for over 40 commodities (OECD, 1983). Each standard includes three quality classes with appropriate tolerances: Extra class = superior quality (equivalent to "US Fancy"); Class I = good quality (equivalent to "US No. 1"), which covers the bulk of produce entering international trade; and Class II = marketable quality (equivalent to "US No. 2"). In the European Union (EU), OECD standards or their equivalents are mandatory for imported and exported fresh fruit and vegetables.

IV. Approaches to quality management

A. The need for an industrial approach

The fresh fruit and vegetable industry has the potential to benefit greatly from recent advances in quality management techniques that have revitalized the electronics, automotive, food processing and other industries. Major improvements in profits and quality have resulted by progressing from inspection to find and remove defects, to quality control systems reducing defects, to quality assurance programs and total quality management approaches that involve the complete business cycle.

Most businesses in the fresh produce postharvest system have only an inspection function as an integral part of their operations. However, quality control and other managerial tools for monitoring and controlling fresh produce quality now are being developed to overcome difficulties unique to this industry. The most basic difficulty is the inherent lack of control during the growing process (see also Chapter 20). Extreme variation in quality exists even under the best known cultural conditions including soil preparation, certified seed, plant spacing, fertilizing, irrigation and other care. Improvements in the quality of fresh produce available to consumers at reasonable prices will require that production and delivery businesses in the postharvest system implement appropriate quality management systems to supply consistent quality.

Agricultural production and postharvest systems for produce consist of a series of steps or processes, equipment and human resources that are complexly independent. Achieving high-quality produce should be the aim and responsibility of each member in the production and distribution system. Inferior quality reflects on the entire postharvest system.

Retail stores and consumers require produce with consistent quality. The most reliable path to success in the fresh produce industry is to offer products with superior and consistent properties. In the future, as consumers expect and demand higher quality products, producers must respond to maintain or increase market share. Producers must be sensitive to the fluctuating and dynamic requirements of consumers. The quality of harvested crops must be maintained between field and consumer. The packing house serves as the point of integration in the handling system, by converting bulk loads of variable quality into a uniform pack with consistent quality. Hence, quality management strategies must be developed to decrease variability, enhance quality and maintain stability within production and postharvest systems (see also Chapters 13 and 16).

B. Quality inspection

The goal of inspection is to certify that lots have been separated into different grades or specifications to differentiate between various levels of acceptability (see also Chapters 14 and 15). The produce lots rated as conforming are accepted, and others are rejected. Grade inspection of agricultural products is the comparison of items at the end of a production process with accepted specifications or other recognized requirements. While specifications can be used to motivate and reward producers to supply products of improved quality, quality inspection is no more than a postmortem procedure performed after the product has been prepared and just before shipment to ensure that it meets contract specifications.

Produce inspection may be conducted on a continuous or sample basis (Kader, 2001). In the first approach, depending on the size of the operation, one or more quality inspectors are assigned to a packing house to carry out periodic quality checks of the produce along the packing lines. In the second approach, representative samples of a prescribed number of units (e.g. cartons, boxes, pallets) are randomly selected from a given lot, and inspected to determine whether the product meets the relevant grade standards. It is a common practice to issue certificates to the enterprise unit (e.g. packing house) at the end of inspection on the basis of the relevant official standards (see also Chapters 8 and 9).

Achieving and maintaining uniformity of inspection in the industry is important to ensure equity and harmony. To ensure uniformity of practice among inspectors (Kader, 2001):

1. they are trained to apply the standards;
2. visual aids (e.g. color charts, models, diagrams, photographs) are used whenever possible;
3. objective methods for determining quality and maturity are used whenever feasible and practical; and
4. good working environments with proper lighting are provided.

Recent innovations in information and communication technologies (ICTs), such as high resolution and portable digital cameras, mobile phones and laptop computers, provide quality inspectors with handy tools for image and data capture, analysis and transmission. Advanced information and communication technologies allow quality inspectors to interact on a real-time basis with quality experts, packing house operators and other stakeholders regarding the quality of produce. In particular, the availability of high resolution color images provides a quick, visual confirmation of fresh product appearance and defects, damage from shifted loads, brands and container markings, and container condition. Furthermore, providing access to the data and images via the Internet can facilitate electronic commerce, and assist in timely resolution of disputes concerning produce quality or condition of shipments.

C. Quality control (QC)

Meaning and scope of quality control

Quality control of produce and postharvest handling conditions is essential to optimize product quality, assure product uniformity and minimize production costs. Prior to the application of quality control in industry, quality production was achieved mainly through inspection focused on removing defective items. Quality control (QC) is, therefore, more than inspection and it consists of systematized activities or processes of maintaining an acceptable quality level to the consumer. Lásztity (2004) argued that QC in production is the most important in the chain of quality control systems, because if the production control system acts effectively and honestly, the products coming into trade fulfill the requirements concerning safe food supply and consumer protection. The author summarized the purposes of controlling activity in production as follows:

- to minimize or limit variation in the product, while maintaining the standard, set by management, to which purchasers or users are accustomed;
- to minimize or eliminate waste of materials, energy and time, and so control production costs.

QC may be divided into three broad stages, namely process control, assessment of the quality of the produce and sampling of the packaged produce (Lásztity, 2004). The important elements of process control include:

1. detailed production planning and supervision;
2. scheduling of materials and resources;
3. tracking the flow of product through the process;
4. management of orders, recipes, and batches; and
5. evaluation of process and product data.

The purpose of assessing produce quality as part of QC procedures is to prevent the distribution and sale of produce that:

1. do not meet the quality standards or specifications;
2. may be injurious to the consumer and general public; and
3. are packaged or labeled with wrong or misleading information.

Checking the final produce and produce unit (such as pallet) may be accomplished:

1. by means of electronic devices, detection of minute pieces of metal or phytosanitary breach in the product or package will be followed by automatic rejection;
2. by subjection of packages to simulated mechanical and environmental stress as a test of the effectiveness of the package; and
3. by storage of produce samples under normal and extreme conditions of temperature and humidity for the accepted shelf life, and then examination by a taste panel or other appropriate laboratory analytical means.

Effective QC practices prevent dispensable and wrong actions, from production to packing and delivery of produce. QC also keeps operations and related end-products from deviating from consumer expectations. Progress in QC should result in decreasing rejections according to quality inspection results. To achieve quality of conformance, it is suggested a systematic approach is followed to control the main handling stages. In fresh produce handling, these stages include crop production operations, harvesting, transporting to the packing house, receiving, sorting, packing and delivery of the final product.

For QC to be successful, product specifications should include the relevant quality factors or characteristic attributes, and delineated criteria (with definitions and descriptions). Specifications must be understood easily, simple, precise and practicable, using the measuring techniques available to the producer or at any other stage in the supply chain. Thus, high inspection reliability can be achieved best by clarifying the quality criteria.

To promote international trade in fruits and vegetables, the OECD (OECD, 1983) established and applied international standards. To make the specifications for quality control clear, explanatory brochures provide well-designed common interpretations for the various provisions contained in the standards through the use of clear terminology, illustrations and color photographs. A study carried out under the OECD scheme shows much influence of the standardization of the marketing of fruits and vegetables. The producer must realize that the standardization of products begins on the tree or in the field, and must endeavor constantly to adapt to market requirements.

Outlines of quality control techniques

Data collection

Data on fresh produce quality attributes and incidence of defects should be recorded for statistical analysis, including descriptive statistics, frequency distributions, histograms and graphs. The recording of quality attribute measurements must save effort in filling forms and should have clear instructions that do not require the control charts typical of manufacturing applications (see Figure 8.1). Statistically valid sampling at every change-over point to determine if processes are under control, and to identify corrective actions, is the main means of controlling the quality of agricultural products as they flow from the field through the marketing and distribution system (Lidror and Prussia, 1990). Earlier methods of data collection and recording

Peach quality control—on receiving.

Date ________________ *Specifications*: size (diameter) [″]

Ground color (chip #) [ ]

Crew (opt.) ___________ Serious defects ________________

Sample size = 50

Warning limit = 30 defectives, for under size only.
(sign W for warning, near to findings #).

Code (crew)	Arrival time	Bins		Findings			Marks		Calculated bonus (%)
				Under size #	Under color #	Serious defects #	Under quality	Quality value	
			1						
			2						
			3						
			4						
			5						
			6						
			7						
			8						
			9						
			10						

$$\text{Under quality} = \frac{\%\ \text{under size}}{100} + \frac{\%\ \text{under color} + \%\ \text{serious defects}}{200}$$

Quality value = 1.00 − under quality

Calculated bonus = 20% × quality value (= % of additional payment)

Figure 8.1 Inspection form for peaches at receiving. Source: Lidror and Prussia (1993).

involved the use of blackboards and log books. With recent advances in information and communication technologies, modern packing houses for fresh produce handling include electronic data capture systems, real-time analysis, display and transmission of the results of statistical analysis. Such integrated information systems make large amounts of data available in real-time to authorized stakeholders in the supply chain, using password access. Data input and access could be accomplished using information system technologies, such as local intranet, the Internet and mobile phones. Despite their obvious benefits in facilitating the management of large amounts of data, electronic information systems are prone to fraud and abuse when access authorization is compromised. Modern electronic information systems are also

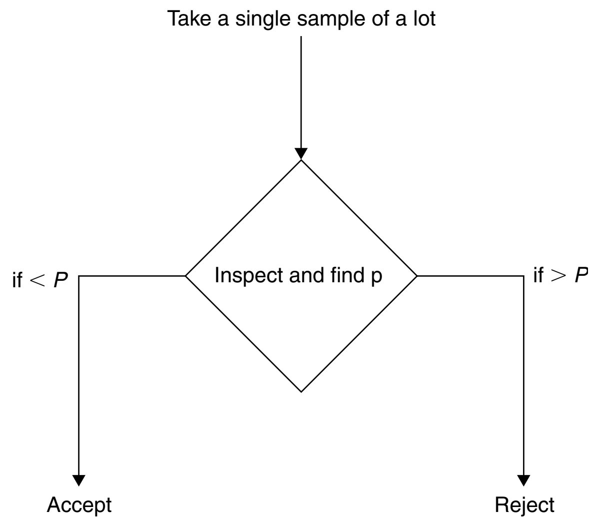

Figure 8.2 Single sampling plan for produce attributes. P, predetermined proportion number; p, inspected proportion (percentage defective). Source: Lidror and Prussia (1993).

highly dependent on functional and reliable support infrastructure, such as telecommunications and uninterrupted power supply, which is currently a challenge in many developing and transitional economies exporting fresh fruit and vegetables.

Sampling inspection

Sampling inspection is examination determining if the lot of fresh produce meets specifications. Diverse sampling plans are discussed in basic publications and manuals for statistical QC methods (McDermott and Cound, 1971; Shainnin, 1971; Brumbaugh, 1982; Feigenbaum, 1983; Messina, 1987).

Any sampling plan is dependent on lot size, planned sample size, and the anticipated acceptance of percentage of defective produce items. When using a single sampling plan (Figure 8.2), the rejection of a lot on the basis of substandard quality is not an ideal test of the quality of the lot, due to significant variations that occur in quality within and across lots of fresh produce. Results supply feedback information needed for improvement or for pricing according to quality level, identified through testing.

By using a multistage sequential sampling plan, the efficiency of decision-making improves, and rejection decisions are increasingly accurate at the cost of increased sampling complexity (Figure 8.3). Any sampling plan has a certain element of risk, represented by its operating characteristic (OC) curve, often discussed in statistical QC method manuals. Deriving the OC curve for some situations may clarify matters and lessen the perceived problems of involved mathematics needed for statistical sampling. The most suitable sampling plan and sample sizes must be identified for each purpose, for example, single, double, or multistage plans.

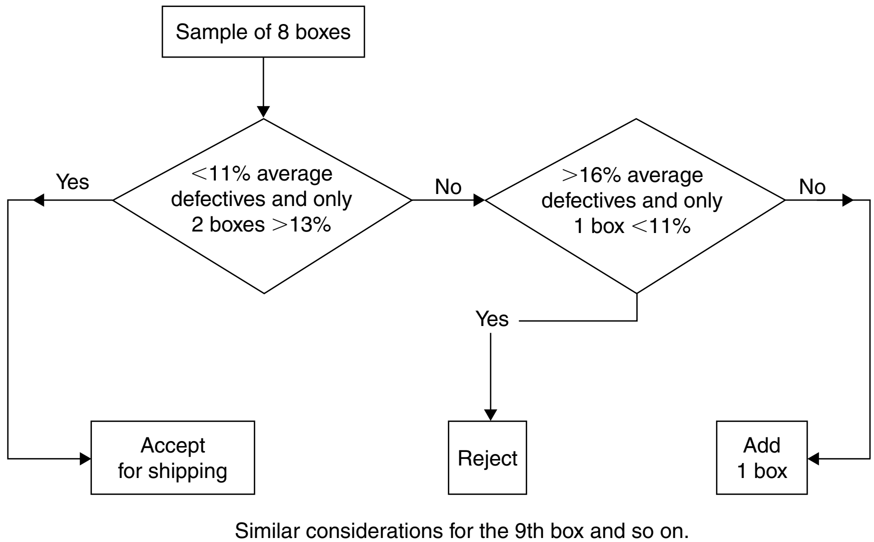

Figure 8.3 Example of part of a sequential sampling plan (for quality control of produce attributes at the shipping point). Decisions for a lot, at the second stage, after taking 8 boxes. Similar considerations will be made after the 9th box, and so on. Source: Lidror et al. (1992).

From acceptance sampling inspection to quality control

Traditionally, inspection data have been used to classify produce as "acceptable" or "rejected." Quality may be improved if supervisors are concerned about the production process. Quality improvements can be achieved by quality monitoring and control, checking if the production process is within statistical control, using corrective actions, or pricing according to established quality. If a process is working properly or has not been altered improperly, it will produce an acceptable product.

Ordinary and advanced QC techniques, generally used in manufacturing, are Pareto analysis, cause and effect analysis, scatter diagrams (regressions) and statistical process control (SPC) methods and charts. The techniques are discussed in manuals for statistical QC methods. The SPC charts consist of two basic types; attributes and variables, each with its own techniques for analysis. For fresh agricultural produce, it is more convenient to use attribute control charts than variable control charts to analyze "go–no go" data. Feedback and results may be used for troubleshooting, improving processes, corrective actions or pricing decisions according to quality evaluation.

QC methods are used to identify and measure the assignable and common causes of variation, so that the appropriate strategy can be developed to reduce the degree of variation. QC methods may provide immediate reliable feedback on process performance, prevent problems that occur on the packing line, determine when to adjust the process and assess how effective the process is. The P charts for attribute inspection are used to determine if the percentage defective is larger than is reasonable to expect under specific conditions (Figure 8.4). Flow chart techniques are very useful for selecting the most effective sampling points in the flow of fresh fruits and vegetables from field to market (Figure 8.5).

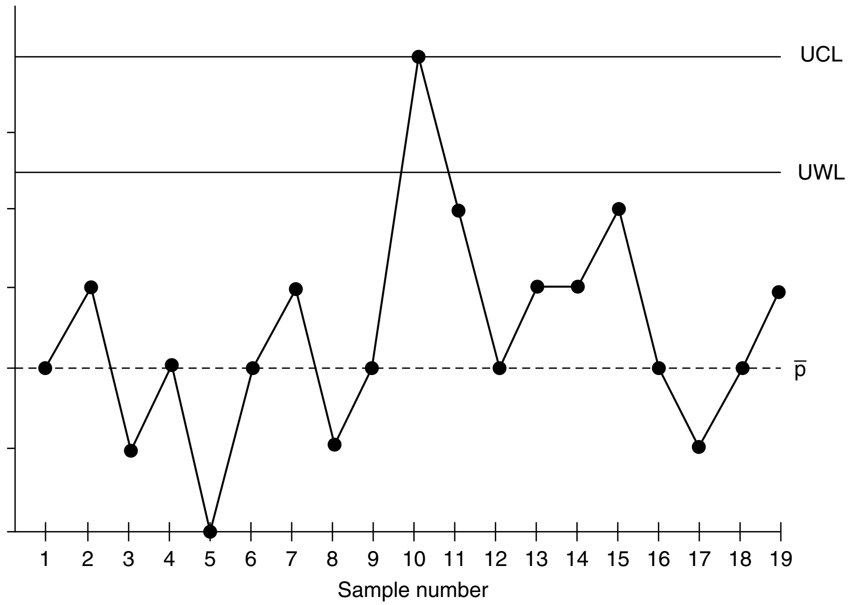

Figure 8.4 P chart for the fruit-sorting process (for quality control of produce attributes at sorting belts). $\overline{P}$, expected defective proportion; $\overline{STD}$, expected standard deviation; UCL, upper control line, $\overline{p} + 3\,\overline{STD}$; UWL, upper warning line, $\overline{p} + 2\,\overline{STD}$. Source: Lidror and Prussia (1993).

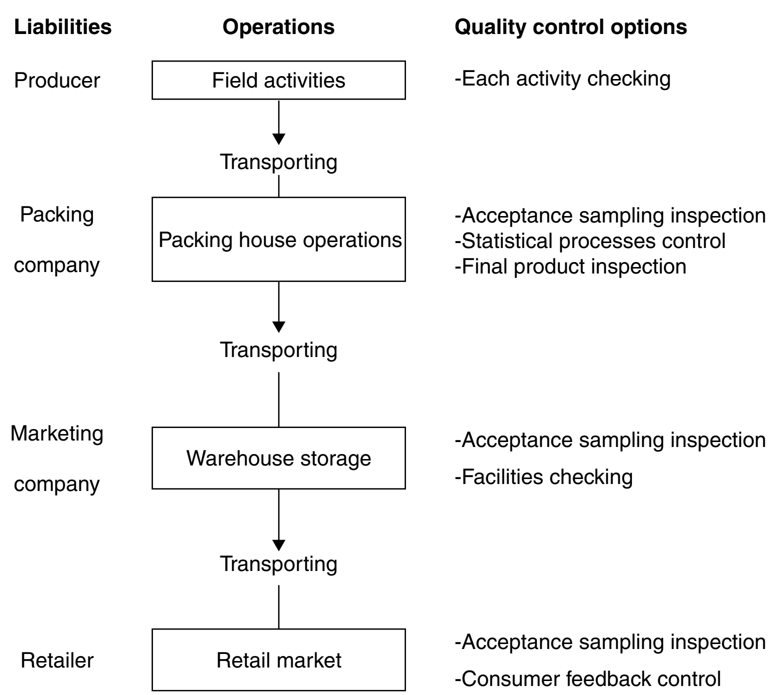

Figure 8.5 Typical flow chart for fresh produce with selected sampling and process control points. Source: Lidror and Prussia (1993).

Researchers and manufacturers have intensified efforts to mechanize and automate the separation of a given commodity into various grades, and to eliminate defective units (Kader, 2001). The use of computer-aided video inspection and grading is now an integral part of most commercial produce packing lines, thanks to the availability of low-cost, high capacity microcomputers and solid-state imaging systems. For instance, solid-state video camera or light reflectance systems are used for detection of external defects, and X-ray or light transmittance systems are used for detecting internal defects (Abbott et al., 1997; NRAES, 1997). High capital cost, low reliability and efficiency still remain major obstacles to the deployment of these and other non-destructive systems in quality control of fresh produce.

Product quality control reporting

In the fresh produce industry, the responsibility for ensuring that growers understand and accept their responsibilities rests with the produce buyer, and the point of transfer of responsibility from grower to buyer is normally on entry to the packing house. An essential part of the overall quality control procedure is that the outcome of quality control activities is documented and reported to ensure that the produce is safe, and meets the correct standards and specifications, as well as legal requirements. It is essential to explain the purpose and use of records to the relevant stakeholders to ensure transparency in the marketing process. Standard product quality control reports should include the following:

- product, variety;
- date of receipt, time of receipt and inspection;
- source, grower's code or name;
- total of consignment and total inspected;
- weight (or count) to be recorded;
- temperature on receipt;
- quality and condition of product; and
- final decision (accept/accept with terms on further sorting/reject with explanation of reason).

D. Quality assurance (QA)

Meaning and importance of QA

QA comprises of all planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality. It is the system whose function is to assure that the overall QC job is being done effectively (Hubbard, 1999; Kader, 2001). Because of the interrelatedness between QA and QC, the terms are often mistakenly used interchangeably to cover the planning, development and implementation of inspection and testing techniques. However, the existence of a successful QA system presupposes the existence of a working QC procedure and, together, these take a long time and a lot of training to achieve. While QC focuses on inspection of the product against set standards or specifications, QA focuses on creating systems to ensure that the product meets the required standards, and is applied not only to the intermediate and final products, but also to the inputs, raw materials and products procured from outside the organization. Once developed and adopted, the QA system of a production enterprise cannot be altered at the moment of implementation in a production line. However, QA systems must be subject to constant review and improvement, to suit future business conditions (Hubbard, 1999).

A rather broad view of quality assurance embraces all processes related to maintaining and improving quality conformance, including the systems approach for quality management, TQM and QC facilities, essential feedback information and quality pricing for producers (Gudnason, 1982). The first generation of quality maintenance in industry involved only quality inspection at the end of a production process. The second generation involved QC during the execution of a process. The development of the third generation is now expanding, to the extent that QA facilities and techniques become an integral part of a total management system. QA methods used successfully by manufacturing industries are not directly transferable to packing house operations, but newly developed and adapted QA programs for agricultural fresh produce should improve consistency and reduce losses in harvesting, transportation, packing and all other handling operations.

An effective quality control and assurance (QA) system through the entire post-harvest handling stages between production and retail (Table 8.2) is essential, to provide a consistent good quality supply of fresh horticultural crops to the consumers,

Table 8.2 Quality assurance procedures during handling of horticultural perishables (Kader, 2001)

Handling steps	Quality assurance procedures
Harvesting	Training workers on proper maturity and quality selection
Packing house operations	Checking product maturity, quality, and temperature upon arrival Implementing an effective sanitation program to reduce microbial load Checking packaging materials and shipping containers to ensure they meet specifications Training workers on proper grading by quality (defects, color, size), packing and other packing house operations Inspecting a random sample of the packed product to ensure that it meets grade specification Monitoring product temperature to assure completion of the cooling process Maintaining effective communications with quality inspectors and receivers to correct any deficiencies as soon as they are identified
Transportation	Inspecting all transport vehicles before loading for functionality and cleanliness Training workers on proper loading and placement of temperature recording devices in each load Keeping records of all shipments as part of the “traceback” system
Handling at destination	Checking product quality upon receipt and moving it quickly to the appropriate storage area Shipping product from distribution center to retail markets without delay and on a first in/first out basis unless its condition necessitates a different order

and to protect the reputation of a given brand (Kader, 2001). In produce handling QA starts with the selection of the genotype (see also Chapter 21), and its proper time to harvest for the best appearance, textural, flavor (taste and aroma) and nutritional (including antioxidant) quality. It also includes careful harvesting operations and handling to minimize physical injuries, because each postharvest handling step has the potential to either maintain or reduce quality, and in a few cases (such as ripening of climacteric fruits) it can enhance eating quality of individual units of the commodity (Cavalieri, 1999; Kader, 1988; Kader, 1992). Exposing fresh produce to temperature, relative humidity (RH), and/or concentrations of oxygen, carbon dioxide and ethylene outside its optimum ranges will accelerate the degradation of all quality attributes (Opara et al., 2000). Similarly, the loss of flavor and nutritional quality of fresh intact or cut fruits and vegetables occurs at a faster rate than the loss of texture and appearance quality attributes. Hence, QC/QA programs should be based on all quality attributes, and not only on external factors, such as appearance, as is commonly practiced.

In summary, the implementation of a QA system has become a strategic business management tool that offers a multitude of benefits to the business enterprise far beyond immediate profits. If properly designed and implemented it reduces losses (Opara et al., 2002), prevents customer complaints, enhances their confidence and promotes company image and brand. A QA system also increases efficiencies and lowers costs, maintains and improves both process and product consistency and reliability.

Systems used for quality assurance

Systems control for field activities

The grower or field production manager is responsible for growing, harvesting and delivering the crop to the postharvest operation. Each field activity, for example, cultivation, fertilization, irrigation, pest control, harvesting and transporting, should be specified and planned before it is conducted. To maintain the desired end-product quality, every activity must be examined on completion and performance level should be recorded. The quality inspector should check performance of all relevant activities. Consequently, produce arriving at the packing house or factory should meet the previously agreed quality specifications.

Statistically analyzed data provide valuable feedback information about field activities, growing methods, areas or blocks and fields or orchards. The data can be used for corrective actions, pricing to individual growers, incentives or rewards, and as a guide on how to manage subsequent operations efficiently.

Sampling at packing house entrance

When products move from the field to the packing house, the responsibility for quality usually changes. Transport systems for fresh fruit and vegetable crops conventionally accumulate the product by lots. A quality sampling inspection technique is suitable for monitoring each lot at the change-over point. On reception of the produce at the packing house, inspectors take samples, inspect the product and record their findings.

"Acceptance inspections" at reception points are traditionally the most critical part of the quality control system for the food industry (Kramer, 1973). Most contracts to growers, packing houses and processors contain some incentive clauses for quality attributes. Each packing house manager intends to include some terms that best suit his requirements. Cooperatives sometimes institute quality inspections at the entrance to the packing house owned by the growers themselves. Effective control systems are necessary to disqualify low quality fruit, and to motivate the growers, through financial incentives, to produce high-quality produce, because quality factors influence the marketplace.

Most fruits and vegetables in the US are subject to inspection tests for minimum quality before they can be used at a processing plant or shipped from a packing house (Lidror and Prussia, 1993). Additional grade standards apply to fresh fruit. A suitable example is a controlled production and quality system that was developed for exported citrus fruit and put into partial operation on a national scale in Israel (Lidror et al., 1986). To determine quality, every lot of citrus fruit for export was sampled at the packing house entrance. Fruit samples were collected from every truck or trailer as it reached the packing house gate. Samples were examined immediately, and the results indicated either the interim storage treatment or when and to which production line to feed the fruit, according to its quality on arrival from the orchard. This approach ensured uniform quality on each line giving improved productivity and quality. Growers can use the supplied feedback information to improve their harvesting operations.

Process control in packing house operations

When products flow in a continuous process, such as on a sorting or packaging line in a packing house, a control inspection (using statistical sampling or charts techniques) is suitable for monitoring production. Inspection should be conducted near the most quality-affecting activities to provide prompt feedback. Factors influencing quality should be evaluated immediately to permit rapid adjustments to the process or the initiation of corrective actions.

Statistical analysis of data from frequently gathered samples following the sorting operation provides valuable information about grading and sorting, growers or even individual fields and processing methods. Results of data analysis can be used for:

- corrective action and appropriate changes;
- maintaining control of sorting and other operations;
- providing warnings and incentives to sorting groups;
- planning efficient execution of subsequent treatments.

Some packing houses systematically check samples online at the feeding belts. The results may be used both as indications for further processing operations and for cross-checking the entrance inspection. The entrance inspection provides growers with immediate feedback about various quality parameters of their own produce.

An experiment was conducted to establish a process control technique similar to SPC for the official quality inspection at the end of the citrus grade sorting operation in packing houses in Israel. A similar experiment was later performed in selected peach packing houses in the US. Inspectors were asked to draw samples of 20 fruits at constant short intervals, and evaluate selected factors. Easy-to-use control forms were provided and marked with upper control limits (UCL) for the defective proportion of the sorted fruit. Figure 8.6 shows an example of a quality control form for peach sorting. Inspectors were instructed what actions to take if the defective proportion was above the predetermined limits; either to warn the foreman or, in the case of unacceptable proportion of defective produce, adjust the process or undertake a critical sampling procedure.

Peach quality control—on line, grade A (U.S. No.1).

Sample size = *20* Upper limit = *3* defectives

Date	Time	.	Defectives		W,* C	Specify major defects
			No. 2	Under grade		
		1				
		2				
		3				
		4				
		5				
		6				
		7				
		8				
		9				
		10				
		11				
		12				
		13				
		14				
		15				
		.				
		.				
		.				
		.				
		.				

* Sign W for Warning if = 3 defectives (No. 2 + undergrades)
Sign C for Corrective action if >3 defectives.

Figure 8.6 Control form for peaches at sorting belt. Source: Lidror and Prussia (1993).

Final product quality examination

Statistical sampling is the principal method for monitoring final product quality. Food processing plants and some packing houses use quality control laboratories to monitor final product quality, as demanded by some customers. Packing houses also use simple sampling techniques for final product quality examination at the end of the packing line. The results of sample evaluation are used to monitor the product and take corrective actions at processing operations. For example, to reduce supervising errors made by the sorters and packers and compare quality data from marketing company with quality data from packing house.

Agricultural fresh produce must be certified officially through inspection of grading in most of the world's markets. Inspectors are present to sample final products for almost every import and export delivery, and to certify produce conformance to grade standards. Shipments of poor quality may be rejected or downgraded at a delivery point, packing house, storehouse, export terminal, warehouse or market by authorized inspectors.

Sampling at export terminals

An acceptance sampling inspection method ordinarily is used at the entrance to export terminals by inspectors. A statistical sequential sampling procedure has been developed for citrus delivery inspection using a microcomputer and portable terminals (Lidror et al., 1992). The sampling procedure aimed at identifying deliveries with a high probability of substandard quality (Figure 8.7). When applied, the number of packs that were to be sampled was reduced, whereas reliability was improved, shifting focus to deliveries most likely to be of unacceptable quality. The results showed a reduction in time needed to inspect trucks, and an increase in the number of deliveries that were permitted to unload directly for export. The sampling procedure is immediate and more efficient, reliable and objective than the usual procedure for inspection control.

To integrate the conclusions of different inspectors and unify the significance of decisions by inspectors at export terminals, a computerized system based on internal control was developed and examined (Lidror and Prussia, 1989). The internal control was operated continuously to improve the official inspection service based on systematic feedback of quality data analysis. It became clear that both quality

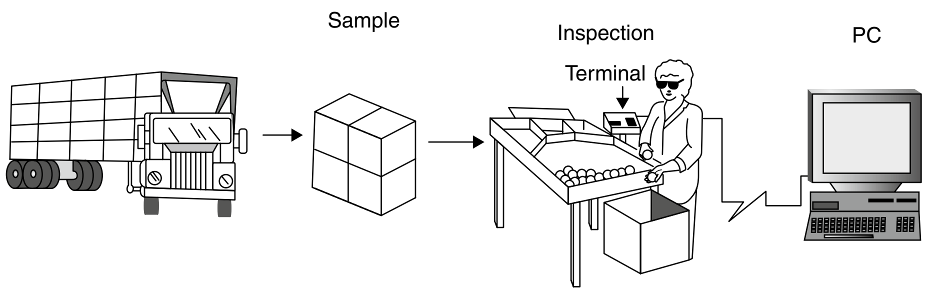

Figure 8.7 Computerized citrus quality control at shipping point. Source: Lidror and Prussia (1993).

criteria and the sampling procedure needed to be defined more precisely. Inspection reliability improvement can be reached by continuous control with feedback of correct and incorrect decisions. This feedback system enhanced inspector ability, developed uniform criteria for decision-making, and achieved higher reliability in decision-making. Differences among inspectors were reduced when they became more conscious of certain relevant criteria.

A quality control system for fresh fruit and vegetables was developed and instituted by Agrexco (Agricultural Export Company, Israel), and has been operating on a national scale. It included sampling and inspection of products, computerized statistical data processing, quality improvements through incentive payments awarded to the numerous producers, and immediate information feedback to the producers and to the export authorities (Lidror and Kissos, 1986). The quality control center comprised sampling teams stationed near the air and sea export terminals, sampling by specially designed procedures, inspecting the incoming products from the domestic grower, and submitting the results to statistical processing and analysis by a central computer system (Lidror and Silberstein, 1986).

This information on product quality reached producers very quickly, and they could improve the quality of their products as soon as the following day. A significant improvement was noted in the quality level of all the products supplied for export and controlled by the quality system. Mechanical damage was reduced to less than half, rot was reduced to an acceptable minimum, and sizing and package marking were improved in most of the products (Lidror and Kissos, 1986; Lidror and Silberstein, 1986).

The Citrus Marketing Board of Israel sampled the loaded trucks coming from packing houses at the entrance to ports of export (Davidson et al., 1977). The samples were inspected carefully for grade, size and packaging at a special station by quality checking staff. The collected data were computer processed, and the output on waste and substandard inspection factors was used for information and monitoring purposes. A major portion of this sample was stored under predicted conditions for a simulated delay. After ten days under controlled conditions, blemishes that had developed were inspected at the checking station for decay, and data were computer-processed to determine packing house quality rewards and debits.

Sampling at markets

An unusual and noteworthy company, with an effective quality assurance program for many years, is the Outspan Company (South African Citrus Board). The Outspan Company maintains a waste sample examination line at a European warehouse to check the quality of citrus fruit exported from South Africa to Europe, to gather data used to make incentive payments and awards to the packing houses in South Africa. Supermarket chains in Europe sample almost every dispatch at delivery centers and inspect the quality carefully for suitability to the local quality requirements.

Most countries conduct official acceptance sampling inspections for imported agricultural produce on entry into the country. Large marketing companies carry out acceptance sampling inspections for agricultural products at the entrance to the market. The collected quality data can be used to monitor incoming quality for acceptance or rejection of deliveries, pricing to trade companies, choosing markets and further treatments needed by the produce.

Quality assurance techniques for enhancing produce quality

Improving quality by total quality management

A systems approach to TQM considers all the interactions necessary among the various elements, and facilitates an integrated awareness of the importance of quality throughout the production process (Badiru, 1990). Communication, cooperation and coordination facilitate TQM. Production management must play an active role in implementing a systems approach, not only by proclaiming the need for quality improvement, but also by committing the necessary resources to its attainment.

Quality definitions must be discussed and acknowledged by everyone in the production chain. Clear specifications are needed when controlling a process such as harvesting or sorting. For example, the instructions given to the harvesters must be known to the inspector who examines the received produce. The inspector should, in turn, notify the harvester about defects that should have been prevented.

A quality assurance manual should be prepared and internally distributed by the operation, describing the quality assurance program, to present all written descriptions of operating procedures and to supply details of quality assurance policy, plans and procedures to workers, supervisors, managers and all others involved. The manual must clarify the responsibilities of each group or individual and identify the exchanges of information necessary between various sectors, producers, companies or organizations. The concepts must be followed throughout the production process, considering it a complete system, and be accepted by most of the producers, public and private organizations and individuals (Lidror et al., 1986).

Quality policy

Everyone who participates in, and has responsibilities for, any fraction of the agricultural production chain, for example, growers, packing house companies, contractors and marketing and exporting organizations, must make a quality policy statement. For example, a policy may be to implement a quality assurance program as a management tool for improving product quality consistency and ensuring that each shipment meets or exceeds quality specifications. Policy objectives lead to the development of a description of actions to fulfill the quality policy by incorporating it into a manual, making immediate improvements whenever needed, and evaluating the quality program after each season for any required changes.

Corrective action investigations

If product quality deviates from expectations, a case study or a corrective action, such as a problem-solving step, must be completed. The purpose of a case study is to find the cause of any reduction in quality level and to make the changes necessary to raise the quality to expected levels or to adjust the processing variables to maintain the output at a desired set point. An investigation must be conducted when customer inspection records show unexplained changes in quality, customer complaints indicate a change in quality, or a request is made by a supervisor of the producer or the packing house. A production organization may appoint a corrective action team whenever necessary, manned by high-level personnel.

E. Quality improvement (QI)

The development and application of quality assurance systems has enabled production organizations to guarantee the quality of fresh produce by addressing "system" issues related to the produce, processes and needs of the end-user. However, there was a major shift in quality philosophy, termed quality improvement, which largely involved the ideas of total quality control and zero defects (Darr, 1991). In the early 1960s, QI broaden the responsibility for quality management from the quality controllers to everyone in the organization. According to Parton (1996), a central feature of the QI approach is the establishment of QI within the production process, controlled by those operating the process. When deployed, QA results in process improvements which, in turn, lead to continuous quality improvement, because the creativity and resourcefulness of the personnel are harnessed to ensure that the production process is adequately controlled and quality meets or exceeds end-user expectations.

Table 8.3 illustrates some of the features of QI vis-à-vis QA based on QA traditional application. While QA tends to focus on identifying who caused the problem and solves it using a feedback mechanism, QI focuses on improving processes, recognizing that most problems (~85%) are system-based (Deming, 1982). By controlling the incidence of defects and variations in a feed forward system, QI enhances the ability of the business organization to deliver products and services that better meet the customer expectations, and represents a stronger consumer-orientation. Studman et al. (2000) reported the successful application of QI principles for quality management of fresh apples in Shanxi Province, China.

While QI may be considered as an enlargement of the vision represented by QA, it should be noted that some of the criticisms of QA (Darr, 1991; Parton, 1996) listed in Table 8.3 are perhaps more common in such sectors as education, research or public health, where the concept of QA is less developed in comparison to the industrial

Table 8.3 A comparison of the features of quality assurance and quality improvement (after Parton, 1996)

Quality assurance	Quality improvement
Who-focused (−ve)	Why-focused (+ve)
Retrospective	Prospective
Externally directed	Internally directed
Involves only the few	Involves many
Reactive	Proactive
Event-based	Process-based
Inspection approach	Process approach
Quality is separate activity	Quality is integral activity
Focus on solving problems	Focus on improving process

agricultural production, where the focus on meeting consumer demands has resulted in a widespread deployment of quality management systems.

V. Quality management systems and regimes

A. Meaning and rationale

A quality management system (QMS) or standard constitutes a formal record of an organization's method of managing the quality of its products and services (Beckford, 1998). If properly developed and implemented, a QMS enables a production organization to demonstrate internally and externally (i.e. to its customer and a relevant accreditation agency) that it has set up an effective system for managing the quality of its products and services. QMS also assists an organization in attempting to formalize its activities, and meet consistency of outputs in quantity, quality and service. A quality certification is awarded by the accrediting agency to an organization that meets the accreditation standards and this achievement is often considered very important, because in certain regions and industries, there is a tendency for some organizations to deal only with accredited organizations.

Credible fresh produce suppliers will procure only from sources that can demonstrate an appropriate and documented QA system. In order to meet current laws and regulatory guidelines for trade, appropriate quality management systems (QMS) should be put in place based on the principles of good agricultural practice (GAP), hazard analysis critical control point (HACCP) and other industrial quality regimes such as the International Standards Organization (ISO) standards and guidelines. Each of the named quality management regimes contributes towards guaranteeing that all significant stages of production from "field to plate" are controlled, to minimize hazards and maintain produce quality.

While agribusinesses may adopt quality management procedures such as QC and QA to comply with standards or codes of practice and meet consumer demands, it is no longer sufficient for a company to be responsible; it must also be seen to be responsible. Consequently, production organizations put in place auditable quality management systems that demonstrate to their stakeholders what they are doing to guarantee the quality and safety of produce, in addition to addressing social and environmental issues.

Apart from putting in place a demonstrable quality management system, the application of relevant postharvest technologies is vital, such as the cool chain to reduce the temperature of the harvested product to its optimum level and maintaining the product at this temperature throughout the transport and marketing operation. The cool chain monitoring should be continuous throughout the supply chain from harvest to final destination. While thermometers and other environmental sensors may be available to record and monitor desired environmental factors, a quality management system will address the process and organizational issues related to why, what, who, when, where, how and what next. The following sections examine some of the industrial approaches to quality management of fresh produce, from the management of field production to TQM of the enterprise.

B. Good hygiene practices (GHPs)

The safety of fresh horticultural produce is generally considered to be low-risk, providing that it has been produced and handled in clean, hygienic conditions. The level of risk may, however, increase as it is processed further in the food chain. All fresh produce must satisfy microbial specifications set by supermarkets, to confirm that the safety and quality management systems practiced on farms are in place and comply with the hygiene and safety laws.

GHPs, including cleaning and sanitation, form an integral part of the broader principles of good manufacturing practice (GMP) for the production and delivery of safe, wholesome products to the consumer. GHP outlines the basic measures which businesses should meet and which are the prerequisite(s) to other approaches, particularly HACCP. GHP requires:

1. the hygienic design and construction of food manufacturing premises;
2. the hygienic design, construction and proper use of machinery;
3. cleaning and disinfection procedures (including pest control); and
4. general hygienic and safety practices in food processing.

The last requirement includes microbial quality of raw foods, hygienic operation of each process step, the hygiene of personnel and their training in the hygiene and safety of food (Jouve et al., 1999). Based on a definition of hygiene as "ensuring that all measures are taken to ensure the safety and wholesomeness of foodstuffs," Porter (1998) identified five components of GHP:

- premises: well protected and in good repair;
- people: adequately trained with good standards of personal hygiene;
- equipment: suitable equipment for the job;
- controls: good control over the process, including adequate cleaning and sanitation; and
- systems: assessment of risks and the implementation of written systems and records.

The goals of GHP are to prevent entrance of hazards into the food chain, particularly at production facilities, and to eliminate the hazards when they do occur. A good hygiene program achieves these goals by two main approaches (Lelieveld et al., 2005), namely:

1. limiting the hazards related to production environment, people and equipment, through relatively simple methods (in relation to HACCP and other safety management systems), that are still sufficiently robust to ensure consistently effective results; and
2. providing adequate protection against negative influences related to the same sources that are not "hazards" in the strict sense, but which do impair quality (spoilage organisms, non-toxic taints, non-hazardous foreign materials, e.g. hair).

C. Good agricultural practices (GAPs)

The various steps in the postharvest handling of produce, from harvesting to end-use, have to be carefully controlled in order to ensure the quality and safety of both fresh produce and processed products. Strictly following GAPs is one of the first steps to ensure product wholesomeness. GAPs are therefore, a preventative approach to produce quality and safety management. In the natural environment of orchards and field crop farms, microorganisms and spores are widespread, where plants, animals, soil, water and even humans serve as reservoirs and sources. The application of pesticides and other chemicals to control pests and diseases represents a major source of health and safety hazard associated with fresh fruit and vegetable production and consumption. The application of GAPs is essential to control and eliminate these hazards.

GAPs consists of the methods of land use and production management which can best achieve the objectives of safe and quality produce, without compromising agronomic and environmental sustainability. GAPs start before the crop is planted. They require establishing and following sound criteria for selecting suitable land and crop varieties, and soil, water and crop management systems including pesticides, fertilizers and other agri-chemicals. As part of GAPs, growers must adopt authorized safe uses of pesticides under actual conditions necessary for effective and reliable pest control. This also includes recommended uses that consider public and occupational health and environmental safety considerations. Therefore, GAPs are designed to: (a) ensure a reliable supply of high-quality and safe produce for consumers; (b) ensure a return on investment for producers; and, (c) have a positive impact, or at least not a negative impact, on the environment.

GHP as an element of GAPs is an effective way to manage the microbiological, chemical and physical hazards that are likely to occur at different stages of production (see Chapter 13). GHP also offers the mechanism and means to establish control procedures and remedial actions for each hazard, together with a system of record-keeping. In fresh fruit and vegetable production, such hazards include contaminated soils, waste disposal, microbial or chemical contamination on growing crop, presence of bacterial pathogens, parasites, viruses, or environmental contaminants such as pollutants in irrigation water, inappropriate use of pesticides, microbiological, and chemical, biological and physical contamination of harvested crop. These hazards can occur at each of the different production stages (Table 8.4), and prevention and reduction of any such hazard requires the establishment of control procedures, and complete record-keeping. Production organizations should develop GAP manuals adapted to their needs to document processes, controls and identify factors specific to their conditions that impact safe growing and handling of produce.

There are several different codes of practice that describe the methods of land use which can best achieve the objectives of agronomic and environmental sustainability (see www.nri.org/NRET/SPCDR/Chapter1/elements-1-5-htm) designed by producer organizations, importer and retailer consortia and government agencies representing consumers (such as the National Food Standards Agency). Many global supermarket chains also have their own codes of practice, which their suppliers must adopt. In the

Table 8.4 Hazards that can occur at different stages of production which are amenable to GAP

Preharvest production activity	Potential hazard
Field/orchard selection	Soil contamination with chemical and biological hazards
Dual/multiple land use	Livestock grazing, disposal of waste
Fertilization	Microbial or chemical contamination on crop
Irrigation	Bacterial pathogens, parasites, viruses or environmental contaminants
Pest and disease control	Inappropriate use of pesticides, fungicides and other agrichemicals
Field machine operations and repair	Oil spill and contamination of crop, soil and water
Harvesting	Biological, physical and chemical contamination of harvested crops
Packing house operations	Microbiological and chemical contamination of produce
Water use for washing produce and containers	Microbiological contamination of water
Storage	Microbiological and chemical contamination of produce, environmental (e.g. temperature) and atmospheric (gas concentrations) factors
Transportation and distribution of produce	Handling temperature and other environmental and atmospheric factors
	Physical damage, which can also allow opportunistic microbial hazards and decay to occur

US, retailers use a different standard called SQF 2000, which is based on the principles of HACCP (http://www.sgs.com/sgs/psc_serv.snf/pages/SQF+2000+…).

In the EU, the EUREP-GAP guidelines and the individual codes of practice adopted by some retailers outline the actions required to ensure that export produce has a positive environmental impact, including conservation (soil, water and genetic resources) and protection (forests, water sources, air quality and natural habitats). The European Retailers Group (EUREP) aims to consolidate the agronomic and environmental components of all such codes into one collective set of guidelines under the EUREP Good Agricultural Practice (EUREPGAP). The goals are to present a clear and unified message to suppliers, and to reduce the confusion that arises from the various codes. The rules and procedures which growers or traders must comply with to qualify for EUREPGAP certification are outlined on the EUREP website (www.eurep.org).

The guidelines covered in the "Guide to Minimize Microbial Food Safety Hazards for Fresh Fruits and Vegetables" which was published by the US Food and Drug Administration covers commonly accepted GAPs in fields, and in packing and cooling operations. The guidelines are available on www.foodsafety.gov/dms/prodguid.html.

Production organizations wishing to evaluate the status of their GAPs can follow general guidelines covering up to three stages summarized in Table 8.5. Documentation and auditing are critical elements of a good GAP policy and practice.

Table 8.5 Generalized guidelines for an organization to self-evaluate its readiness for, and status of, GAP

Stage	Actions
GAP Stage I	• Outline your company's commitments to GAP and other food safety regimes. The US FDA "Guide to Minimize Microbial Food Safety Hazards for Fresh Fruit and Vegetables" describes many of these regimes and practices • Document your GAPs program • Prepare product safety manuals that have been developed for each major step in the production chain, including: (a) water quality and soil health; (b) sanitation in the field and other units; (c) use of fertilizer and chemicals; (d) staff health and hygiene practices; and (e) traceability
GAP Stage II	• Establish self-audit criteria and audit each major operation • Document each audit review for future reference
GAP Stage III	• Conduct and document a third party verification audit for GAPs on some of your major operations • Carry out periodic analysis of water, chemicals and pesticide residue, and microbiological hazards using own or accredited laboratory

In summary, a good agricultural practice has the following features:

- it is management led, with senior management taking responsibility for its implementation, while the process remains participatory and inclusive of staff;
- it is adopted company-wide, or at least is applied to an entire production site such as orchard/farm and packing house;
- it focuses on prevention (proactive) rather than detection (reactive) of bad practice; and
- it is considered and used as a part of the overall routine quality and safety management system.

D. ISO standard for quality management system (ISO 9000 series)

Overview of standards of quality management

Setting quality management standards is one of the first issues in developing a comprehensive quality assurance system, and increasingly many production organizations rely on "off-the-shelf" standards rather than developing their own (Howard, 2000). There are several quality management standards, such as ISO 9000, Business Excellence Model (BEM), Environmental Standards, Six Sigma and Investors in People Standard (IIP), which determine the extent to which quality principles should be integrated within organizational policy, structure, systems and processes across the organization. Some standards focus on specific aspects of the business organization, while others are comprehensive. The IIP, for instance, was developed in 1990 by a UK government-convened task force to address, in part, a perceived deficiency in the ISO 9000 series, i.e. the lack of a framework for human resources management.

All standards of quality management provide a framework designed to ensure excellent outputs from a system where the procedural, policy and resource inputs conform to a flexible but defined quality specification. A production organization can pursue accreditation of its quality management system to reassure clients, consumers and other stakeholders about their commitment to quality and safety, and that certain international standards are achieved and maintained during production and delivery of produce.

Selecting a standard for a quality management system should be based on its treatment of those components of the organization where quality is most critical, and its overall relevance or application to the nature of the production organization. An organization may also require particular standards of management to be met by one or more of its clients in the supply chain. Overall, a suitable standard should have the following characteristics:

1. written in clear and unambiguous language;
2. specifically set out what is expected;
3. measurable, to enable the organization assess its performance in meeting set standards; and
4. realistic and achievable, such that the organization must have the resources available to meet the standard.

Scope and features of the ISO 9000 series

An International Standard Organization (ISO) standard is a normative document, developed according to consensus procedures, which has been approved by the ISO membership and expert panel members. All requirements of this international standard are generic, and are intended to be applicable to all organizations, irrespective of type, size and product. The ISO has published many standards applicable to a wide range of industries and activities, but the quality management system is based on the ISO 9000 series of standards.

ISO 9000 is one of a series of quality management systems developed over a long period of time, beginning with quality standards in the defense industry (Beckford, 1998). Over the years, the ISO 9000 series has emerged as the established and recognized global standard to which industries seek accreditation of their quality management systems. They provide a framework by which an organization can establish, implement and monitor quality systems in a structured manner. The goal of the ISO 9000 series therefore, is to enable organizations to demonstrate their commitment to achieving customer satisfaction by preventing problems in their products and service at all stages from production to delivery (Howard, 2000).

The ISO 9000 series consists of two sets of documents, dealing with quality assurance standards as the basis of assessment (ISO 9000, 9001, 9002 and 9003), and quality management (ISO 9004). Table 8.6 outlines the main topics covered in each series.

Among the ISO 9000 standards, ISO 9001 is appropriate for design, development, production, installation and servicing, and it sets out twenty clauses specifying the areas to examine (Table 8.7). A production organization that wants to demonstrate its ability to consistently provide product that meets customer and applicable regulatory requirements, and to enhance customer satisfaction through the effective application of the system, can utilize ISO 9001 to specify the requirements for its quality management system. Such requirements include processes for continual improvement

Table 8.6 Contents of the ISO 9000 series

Series	Content
ISO 9000–0	Concepts and applications
ISO 9000–1	Quality management and assurance standards: guide
ISO 9000–2	ISO 9001/9002/9003 application guide
ISO 9000–3	ISO 9001 applied to software development, supply and maintenance
ISO 9000–4	Dependability Program Management Guide
ISO 90001	Quality systems: design, development, production, installation and service
ISO 90002	Quality systems: quality assurance production and installation
ISO 90003	Quality systems: quality assurance, final inspection and test
ISO 90004–1	Quality management and quality systems elements: guide
ISO 90004–2	Quality management and quality systems elements: guide for services
ISO 90004–3	Processed materials: guide
ISO 90004–4	Quality improvement: guide
ISO 90004–5	Quality plan: guide
ISO 90004–6	Quality assurance for project management: guide
ISO 90004–7	Configuration management: guide

Table 8.7 Clauses contained in ISO 9001

Number	Clause
	Management responsibility
	Quality system
	Contract review
	Design control
	Document and data control
	Purchasing
	Control of customer supplied products
	Product identification and traceability
	Process control
	Inspection and testing
	Control of inspections measuring and test equipment
	Inspection and test status
	Control of no-conforming product
	Corrective and preventive action
	Handling, storage, packaging, preservation and delivery
	Control of quality record
	Internal quality audits
	Training
	Servicing
	Statistical techniques

of the system and the assurance of conformity to customer and applicable regulatory requirements. The key components of ISO 9001 include quality management system, management responsibility, resource management, product realization and measurement, analysis and improvement.

Using ISO 9000 to construct a quality management system

In line with any aspect of quality management, the development of an effective quality management system relies upon a systematic approach to provide guidelines and instructions which ensure that the system developed meets the organizational objectives and goals for quality. The ISO 9000 series is often used for this purpose, involving several steps. A 13-step program of actions was proposed by Kanji and Asher (1996a), starting with obtaining the commitment to the approach and finally, maintaining the quality management system by internal audit (Table 8.8). Commitment to a quality management system must be distinguished from commitment to quality itself; the former is implicit in the latter but not the former. A commitment only to QMS will not assist the pursuit of quality, but will only enable the management to know exactly who to blame for bad quality. Thus, for a QMS to be effective, it must be part of an integrated organizational approach and commitment to quality. Further explanations and interpretations of the steps to a quality management system can be found in Kanji and Asher (1996b) and Beckford (1998).

E. Hazard analysis and critical control point (HACCP)

HACCP is a systematic approach to hazard identification, assessment of risk and control. When implemented correctly, it ensures that every step in the process to grow, harvest, prepare and market vegetables or fruits results in food that is safe to eat. Thus, whether the produce comes from a smallholder or a commercial orchard, its safety can be assured if it has been produced under HACCP-controlled processes. National and international food safety regulatory bodies have recognized the usefulness of HACCP and its "principles," and they have been incorporated into legislative requirements by both the EU, in the general hygiene regulations for managing food safety (93/43/EEC), and the FDA in the US (CPR-123).

HACCP management procedures for quality and safety management were originally developed in the late 1960s to ensure food safety in the US space program.

Table 8.8 Steps towards developing a quality management system (Kanji & Asher, 1996a)

Step 1	Obtain management understanding of, and commitment to, the quality management approach
Step 2	Define the scope of the activities to be included in the QMS
Step 3	Define the organizational structures and responsibilities of those within the scope of the QMS
Step 4	Audit the existing systems and procedures against the requirements of the standard
Step 5	Develop a plan to write the necessary procedures
Step 6	Train sufficient personnel to write their own procedures
Step 7	Draft and edit the procedures and gain agreement on them
Step 8	Compile a draft quality manual
Step 9	Implement the system on a trial basis
Step 10	Train internal auditors to carry out audits of the system and its operations
Step 11	Revise the operations of the system in light of the results of audits and other information
Step 12	Apply for registration (sometimes called third-party approval) from an accredited body
Step 13	Maintain the system by internal audit, using it as an opportunity to improve

In the early 1970s, the FDA started to use the HACCP approach for the inspection of factories manufacturing low-acid foods. Since then, an increasing number of fresh and processed food industries have adopted HACCP for quality control and assurance programs. HACCP is a food safety management system involving systematic and logical assessment of all steps in a food production and processing operation (Savage 1995; MOH 1997; Kennedy 1998). It aims to identify stages that are critical to the safety of the product, and allow management to concentrate its scarce technical resources on steps which critically affect the product safety. HACCP transforms a food production and handling operation from the traditional control philosophy, based primarily on end-point testing, to a preventative approach. It provides a structured approach to the assurance of the quality and safety of specific products and their processes, involving (a) identification of hazards of concern such as pathogens; (b) identification of the specific requirements for their control; and, (c) mechanisms to continuously measure the effectiveness of the HACCP system.

There are seven basic principles which must be followed in establishing a HACCP-based quality management program (Table 8.9). In the HACCP approach to quality and safety management, a hazard is defined as a potential to cause harm to consumer safety or product spoilage. A critical control point is a location, stage, operation, step or raw material which, if not controlled, provides a threat (risk) to consumer safety, or the product acceptability. The establishment of monitoring procedures for HACCP systems, stipulated in Principle 4, is somewhat different from that for conventional quality systems, because in food production organizations a CCP is intended to prevent a catastrophic event (harm, injury to the end-user) resulting from microbiological, chemical and physical hazards. Therefore, from the monitoring viewpoint, a failure in a CCP may be considered a critical defect. Hence, a critical defect is a defect that

Table 8.9 Basic principles incorporated in the HACCP system

S/No.	Principle	Explanatory notes
1	Conducting hazard analysis	Identify hazards and assess their severity and risk Assess risk associated with growing, harvesting, raw materials and ingredients, processing, manufacturing, distribution, marketing preparation and consumption of food
2	Identifying the critical points for each step	Determine the critical control points (CCPs) required to control the identified hazards
3	Establishing critical limits	Establish the critical limits that must be met at each identified CCP
4	Establishing monitoring requirements	Establish procedures to monitor the control of each CCP
5	Taking corrective action	Establish corrective action to be taken when there is deviation identified by monitoring each CCP, indicating that a CCP is not under control
6	Keeping records	Establish effective record keeping systems that document the HACCP plan
7	Verifying the HACCP system is working correctly	Establish procedures to verify that the HACCP system is working effectively

may result in hazardous or unsafe conditions for individual usage, depending upon the product. The monitoring of a CCP must be continuous, or at a level to ensure that product safety is maintained at each CCP.

Comprehensive understanding of the whole production process is necessary in order to identify the most suitable means of monitoring CCPs. Measurements which provide rapid results, such as non-contact or non-destructive tests, are preferable to traditional lengthy microbiological methods. The preference for rapid non-destructive testing highlights the importance of a multidisciplinary team of specialists who have adequate technical knowledge to be able to analyze the whole process, and who can contribute to the overall HACCP project. The interrelatedness of the seven principles of HACCP also stress the partnership that exists along the supply chain, which enables each stakeholder (i.e. grower, supplier, transporter, exporter, importer and retailer) to share the responsibility for providing safe, high-quality produce to end-users.

Growers, postharvest operators, wholesalers, retailers, consumers and regulatory agencies need to be aware of the range of potential biological, chemical and physical food safety hazards which affect fresh produce and their sources (Table 8.10). Although HACCP was developed initially and is still mainly applied to ensure the microbiological safety of foods, it is applicable to other forms of hazard, such as chemical and physical contaminants, that are associated with food production. When properly integrated into the overall quality management system of a production organization, HACCP ensures consistent product quality or increased production efficiency.

In practice, the seven principles of HACCP (Table 8.9) have been expanded into fourteen generalized stages or requirements (Table 8.11). The explanatory notes emphasize the overriding importance of team selection, to ensure that the right

Table 8.10 Biological, chemical and physical hazards associated with food production which can be controlled by implementing an HACCP quality management system

Type of hazard	Sources of hazard
Biological	Pathogenic bacteria, e.g. *Escherichi coli*, *Salmonella* spp., usually associated with faecal contamination from warm-blooded animals, or others, e.g. *Listeria monocytogenes*, commonly found in contaminated soil, water and ruminants Naturally occurring plant toxins, e.g. alkaloids, cyanogen glycosides Fungal, e.g. ergot, mycotoxins Parasites, e.g. *Cyclospora*, *Entamoeba*, *Giardia*, *Cryptosporidium* Viruses, e.g. hepatitis A, Norwalk virus, Rotavirus
Chemical	Pesticide, insecticide and fungicide residues (international food law includes maximum residue levels for named compounds to be used on specific fruit and vegetables) Heavy metals, e.g. zinc, lead, aluminum Mineral oils, e.g. diesel, grease, hydraulic oil
Physical	Glass, metal, stones, hair Wood and twigs Pieces of bone and plastic

Table 8.11 Fourteen stages of developing a HACCP plan

Stage	Activity	Explanatory notes
1	Define terms of reference (ToR)	Clearly defined ToR, including location, processes, intended use, categories of hazards, safe limits
2	Select HACCP team	Select a multidisciplinary, skilled team to cover the development, maintenance and review of HACCP plan
3	Describe the product	Nature and type(s) of product, packaging, storage, shelf life, composition
4	Identify intended use	Fresh consumption, raw material for industrial processing
5	Construct a flow diagram	A simple way to facilitate hazard analysis; includes all steps identified in Stage 7.
6	Confirm flow diagram	Step 5 may contain errors, missing steps, production inputs, etc. Rigorous scrutiny is vital to develop a correct and agreed flow diagram
7	List potential hazards and identify control measures 1. Conduct a hazard analysis	Brainstorming session and concept mapping are useful techniques Consider all potential sources of hazard: microbiological, chemical, physical It is too early to generate CCPs at this stage
8	Determine CCPs 2. Determine the critical control points	Avoid subjectively and apply a decision tree to each step of the process where a potential hazard exists
9	Establish critical limits for CCPs 3. Establish critical limit(s)	Sources of information on critical limits include legislation and directives, research data, expert panels/systems They must be measurable and include tolerances
10	Establish monitoring systems for each CCP 4. Establish a system to monitor control of the CCP	Generation data for auditing, choose appropriate frequency of monitoring, define responsibilities, document procedures
11	Establish corrective action plan for each CCP 5. Establish corrective action to be undertaken when monitoring indicates that a particular CCP is not under control	Includes adjusting production plan and equipment, review procedures
12	Verification 6. Establish procedures for verification to confirm that HACCP is working effectively	This is concerned with correct functioning of the entire production process, including auditing, microbiological tests, consumer/end-use studies, review of health-related issues associated with production and produce
13	Establish documentation and record keeping. 7. Establish documentation concerning all procedures and record appropriate to these principles and their applications	Develop a HACCP manual, operation and maintenance manuals, sources and conditions of input materials, etc.
14	Review HACCP plan	Must be periodic, and if there are changes in issues like relevant legislation, emergence of new hazards, and changes in process parameters and conditions, staffing, equipment

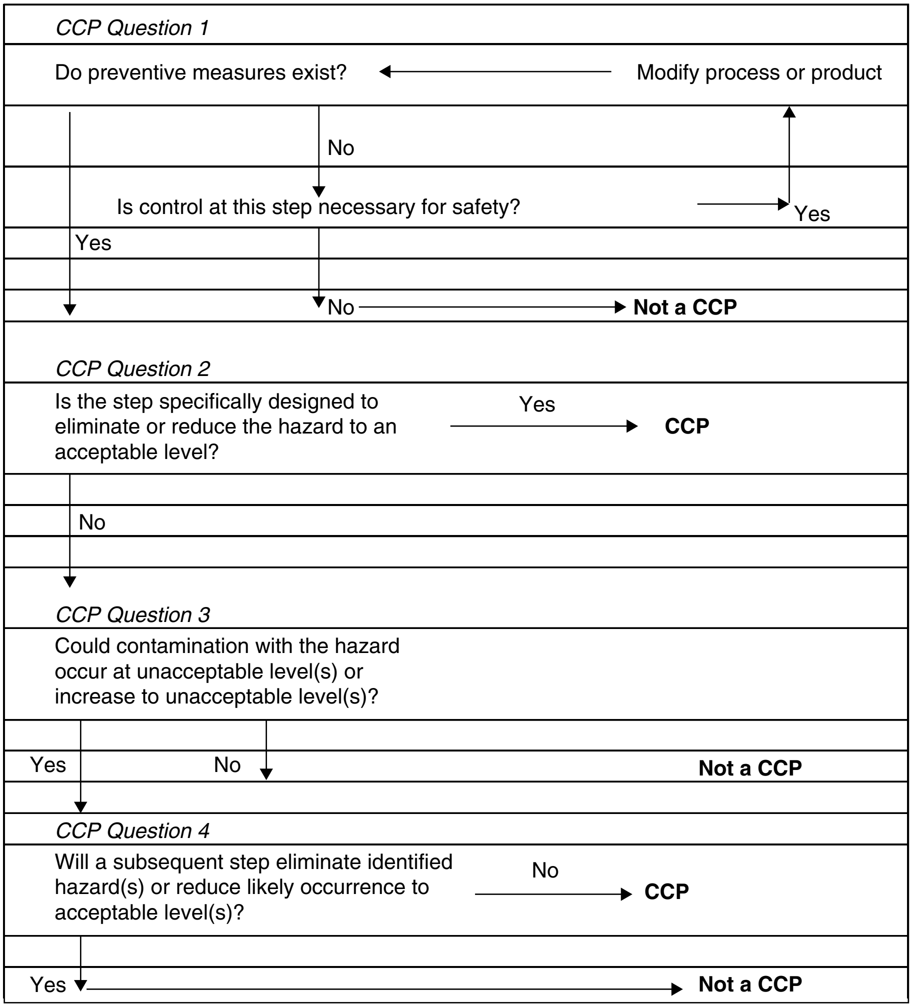

Figure 8.8 Decision tree for establishing a CCP in developing an HACCP system. Adapted from Wright (2001).

answers are sought to cover the complex set of stages involved in production through delivery. Choosing a CCP is one of the most difficult decisions facing a HACCP team, and a decision tree is an invaluable tool (Figure 8.8).

In summary, the complexity of the fresh produce chain and the increasing potential for safety breaches calls for the need to provide the consumer with value and reassurance. HACCP is a risk management tool, not a risk assessment tool. It is only one part of the risk analysis process that has been defined as risk assessment, risk management and risk communication (Jouve et al., 1998). HACCP has been widely adopted in the food industry, including produce handling, because it is simple to understand and use (HACCP, 2000). To ensure appropriate levels of hazard control, it is vital to carefully select the CCPs, set control parameters and their limits, and apply simple but effective tools for microbiological risk assessment, which are needed to prioritize risk containment and elimination in the production chain.

F. Total quality management (TQM)

TQM is common sense

(Flood, 1993)

Depending on the organization, industry and country, the application of total quality management (TQM) in business practice has evolved through several distinct steps or phases, including a focus on product quality, on product process quality, service quality, service process quality, business planning, strategic business planning and integrated strategic quality planning (Godfrey, 2001). The initial focus on product quality from the grower's viewpoint was clearly the case in agricultural production organizations, since agricultural trade at that stage was driven mainly by sale of surplus produce and exchange for other goods and services.

TQM is a structured and organized management approach, with the ultimate goal of meeting customer expectations. Its main application is on the management process, which is responsible for planning, controlling and creating quality culture and continuous improvement, to function effectively and ultimately to reach levels of high quality. As the name implies, TQM involves everyone in an organization, resulting in a change to the way people do things, and relies on trust between management and staff.

The TQM philosophy is a holistic approach to address overall organizational performance. Central to the TQM philosophy is that all organizational functions are focused on meeting customer needs and organizational objectives. This company-wide approach views an organization as a collection of processes that must be continuously improved by incorporating the knowledge, skills and experience of all workers. If properly developed and implemented, TQM restores the balance of power between management and staff, with a shared vision for quality.

The fundamental concept of TQM is that the problem of failures and their effects has an influence on the performance of an organization which is far greater than is commonly appreciated. This broad view of failure places the emphasis on prevention, leading to the question: is the production process capable of producing the required quality? The core responsibility in TQM lies with management and management leadership of the organization. Instead of focusing on specific products or operational units, management can ask broad questions that address the system (us) and not him, her or them, based on the "Right First Time" principles as reported by Lees (1996): Can we make it ok, are we making it ok, have we made it ok, and could we make it better?

James (1996) described TQM as "essentially about the development of an ideology, a philosophy, methods and actions that are designed to satisfy customers completely, through their continuous improvement." The author identifies four principal objectives for a quality-oriented organization, namely:

- customer satisfaction;
- customer orientation;
- customer satisfaction; and
- a learning environment for staff.

Table 8.12 Eleven steps to total quality management (TQM) (Flood, 1993)

Step 1	Develop an understanding of organizational design and organizational behavior
Step 2	Set up a steering committee
Step 3	Set organizational mission
Step 4	Set up next layers of quality councils
Step 5	Design or choose educational modules
Step 6	Set local missions
Step 7	Undertake customer analysis
Step 8	Choose projects for implementation
Step 9	Choose tools for implementation
Step 10	Implement educational modules and communicate details of the project(s)
Step 11	Implement projects

Flood (1993) proposed a broad-based eleven-step program for implementing TQM, which is applicable to production organizations (Table 8.12). For an organization embarking on TQM, the author suggests six questions which must be addressed to focus on its purposes: (a) what do we think we do? (b) are we doing what we think we do? (c) why are we doing it? (d) are we doing the right thing? (e) what else could we do? and (f) what would be the benefit of doing something else? Beckford (1998) argues that if TQM is to be genuinely total then it must use a methodology, such as total system intervention, which embraces all potential methods.

TQM is a continuous process of improvement applicable to whole organizations, groups of people and individuals, and it is this focus on "continuous improvement" that distinguishes TQM from other quality management regimes. This improvement of processes arises when people in the organization know what to do and how to do it, have the right tools to do it, are able to measure the resultant improvement of the process against existing levels of success and receive feedback.

To provide continuous performance improvement, TQM must adhere to four guiding principles, namely (Kanji and Asher, 1995): (a) delight the customer; (b) people-based management; (c) continuous improvement; and (d) management by fact. To drive the improvement process, Kanji and Asher (1995) translated these core principles into eight practical concepts which show how to make them work. These concepts are:

- customer satisfaction;
- internal customers are real;
- all work is a process;
- measurements;
- teamwork;
- people make quality;
- continuous improvement cycle; and
- prevention.

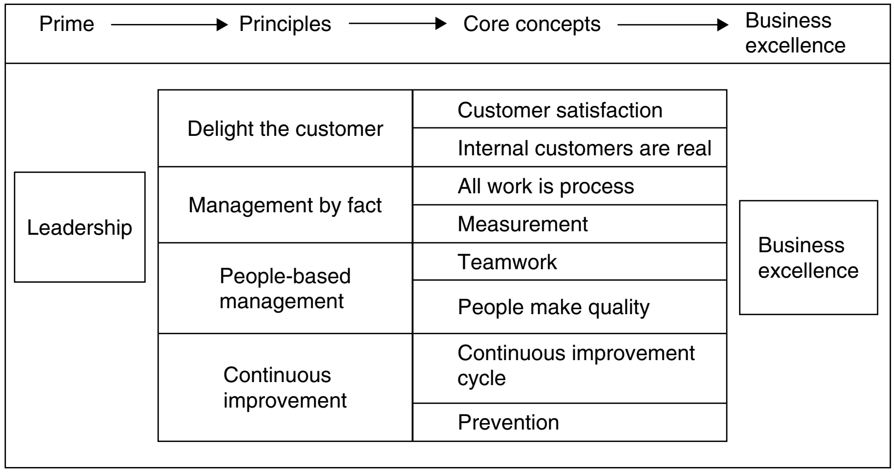

Figure 8.9 Relationships between leadership, basic principles and core concepts of TQM. Adapted from Kanji (1998).

Figure 8.9 shows a unified model of TQM, which incorporates the principles and concepts towards business excellence. The model highlights the prime role of top management leadership in guiding the organization through TQM principles and core concepts, in order to achieve business excellence. Kanji (1998) provides an extended discussion of the principles and concepts of TQM, including its relationship with ISO 9000, and suggests a framework for process innovation incorporating process definition, process improvement and process management.

Before concluding this chapter, let us examine the issue of the cost of quality. While most people would agree that quality is important as a strategic business weapon, the cost of quality is often not quantified. The costs of quality can be divided into: (a) direct costs, occurring as a result of the non-achievement of quality and visibly attributable to that fact; and, (b) invisible costs unnecessarily incurred by any organization which does not have an effective quality system in place (Beckford, 1998). Often, the relationship between invisible costs and lack of quality may not be recognized by the production organization. Visible costs arise when a consignment is defective and has to be rejected or returned; where the quality of produce or information received needs to be validated before delivery or end-use; and where produce are inspected and defective lots are removed. Invisible costs of quality, are, however, much more difficult to identify, quantify or correct, but include loss of customer confidence and repeat purchase, loss of brand and company reputation, potential loss of dissatisfied staff, and higher production cost through greater inspection.

From both organizational and TQM perspectives, the results of total quality are almost universally accepted to include lower costs, higher revenues, delighted customers and empowered employees (Godfrey, 2001). These benefits demonstrate the significant paradigm shift from managing quality to conform to product specifications and standards, to meeting and exceeding the needs and expectations of the end-user and other stakeholders. The quality horizon has thus expanded to include having the right attributes, correct, accessible and traceable documentation and error-free inventory. It also comprises the proper operation of critical business processes to assure delivery on-time, technical support and no failures in expected performance. Quality management activities, therefore, involve reducing and possibly eliminating all costs of poor quality.

VI. Current and future prospects for produce quality management

Rapid changes are taking place in the global fresh produce market. The focus of this chapter is on the review of industrial approaches to fresh produce quality management, which, when applied in a coordinated fashion, represent strategies for agribusinesses to remain competitive, profitable and economically viable in a changing market. In combination with the growing demand for a steady supply of a wide range of top quality produce, fueled in part by changing lifestyles and increasing scientific evidence linking fresh produce consumption to reduced incidence of cardiovascular and degenerative diseases, the consolidation of fresh produce supply chains (including supermarket chains) into multinational and transnational corporations is reshaping the way that food systems are governed and managed. The ongoing transformation presents new challenges for quality management of fresh produce in dealing with product variability (both quality and quantity), as well as managing the processes and institutions involved in the supply chain (see also Chapter 2). While appropriate postharvest technologies are essential to ensure the delivery of produce that meets end-user expectations, the deployment of innovative industrial quality management systems to postharvest handling and marketing can assist producers, businesses and policy makers to anticipate and respond to the challenges of global fresh produce marketing in ways that reduce losses, enhance profitability and sustain agribusiness.

Armed with their increasing influence, most of the multinationals and large supermarket chains reduce the number of their fresh produce suppliers, focusing on contract farmers (or specialized production) for each product category. At the same time, pressures to demonstrate ethical and environmental sustainability in the supply chain and quality management are also increasing in response to market demands, making it vital to maintain close relationships between suppliers and retailers for efficient supply chain management and consumer satisfaction. These new ethical and environmental dimensions to the relationships among stakeholders necessitate the application of sound organizational and industrial management regimes to manage produce, process and organizational quality.

The dramatic growth in global trade in fresh produce has also increased the risk of consumer exposure to food-related illnesses and diseases. Supermarket chains now have well-established produce quality assurance systems to meet the requirements of stringent national and regional food legislation, which have been introduced to protect the public from pathogens and other harmful substances, while ensuring the sensory quality of produce. QA systems have become an integral part of overall good business management practice. These systems guarantee that product specifications, including safety and quality attributes, are adhered to in a timely fashion, at minimal cost and in compliance with existing regulations.

Agricultural produce are inherently variable in quality and quantity due to several factors. Differences in agro-climatology (e.g. rainfall, solar radiation, humidity, topography, temperature), growing practices, postharvest handling, storage systems and staff performance in the supply chain contribute to variations in product quality. Complex consumer preferences and perceptions of quality, which require considerable product segregation and assurance of quality and safety, further exacerbate the problem of managing the sources of variability.

For many years, high production volumes and cost-saving have been viewed as the key to the profitability of agriculture and other enterprises. With significant advances in breeding and production practices, crop yields have increased dramatically during the past 50 years. The application of sophisticated postharvest handling and storage technologies with efficient marketing structures has guaranteed the year-round supply of most food crops in the international market. Indeed, periodic or seasonal oversupply is a problem in some commodities and regions. In modern business, however, new scientific tools and management strategies have become available, bringing with them a surge of interest and opportunities in the competitive implications of product quality (Garvin, 1984b; Opara, 2000a,b,c). Product quality and its management have now become important strategic tools and skills to access and retain market share. With increasing sophistication of markets, and consumer demand for products and services that often challenge current production practices, new business and quality management models are required to determine the extent to which consumers, and society in general, are willing to bear the cost of quality and safe produce delivery. Economic, technical, safety and environmental challenges ensure a future for quality management in produce handling. Cooperation and interaction between researchers, production organizations, consumers and other stakeholders is critical for successful management of fresh produce quality and safety.

Bibliography

Abbott, J.A. (1999). Quality measurement of fruits and vegetables. Postharvest Biol. Technol., 15, 207–225.

Abbott, J.A., Lu, R., Upchurch, B.L., Stroshine, R. (1997). Technologies for nondestructive quality evaluation of fruits and vegetables. Hort. Rev., 20, 1–120.

Alavoine, F., Crochon, M., Bouillon, C. (1990). Practical methods to estimate taste quality of fruit, how to tell it to the consumer. Acta Hort., 259, 61–68.

Allende, A., Tomas-Barberan, F.A., Gil, M.I. (2006). Minimal processing for healthy traditional foods. Food Sci. & Tech., 17, 513–519.

Auger, P., Devinney, T.M., Louviere, J.J. (2000). Wither ethical consumerism: do consumers value ethical attributes? Australian Graduate School of Management, University of New South Wales, Working Paper.

Badiru, A.B. (1990). A systems approach to total quality management. Indus. Eng., 22(3), 33–36.

Beard, M. (2005). Ethical shopping bears fruit for fair-trade farmers. *The Independent* Tuesday 1 March, UK.

Beckford, J. (1998). Quality: A Critical Introduction. Routledge, Florence, KY, USA.

Brumbaugh, P.S. (1982). Quality control. In: Handbook of Industrial Engineering, G. Salvendy (ed.). John Wiley & Sons, New York, NY, USA, pp. 8.3–1, 8–3.23.

Carrigan, M., Attalla, A. (2001). The myth of the ethical consumer – do ethics matter in purchase behavior? J. of Consumer Marketing, 18, 560–577.

Cavalieri, R.P. (ed.) (1999). Fresh fruits and vegetable, quality and food safety. Postharvest Biol. Technol., 15, 195–340.

Coles, A., Harris, L. (2006). Ethical consumers and e-commerce: The emergence and growth of Fair Trade in the UK. Journal of Research for Consumers, Issue 10, http, //www.jrconsumers.com.

Cook, R.L. (2003). The evolving global marketplace for fruits and vegetables. Agricultural Marketing Resource Center, University of California, Davis, CA, USA.

Crisosto, C.H., Crisosto, G.M., Metheney, P. (2003). Consumer acceptance of "Brooks" and "Bing" cherries is mainly dependent on fruit SSC and visual skin color. Postharvest Bio. Technol., 28, 159–167.

Crosby, P.B. (1979). Quality Is Free. McGraw-Hill, New York, NY, USA.

Cuthbertson, W.F.J. (2002). Are the effects of dietary fruit and vegetables on human health related to those of chronic dietary restrictions on animal longevity and disease? British J. Nutr., 87, 17–88.

Darr, K. (1991). Quality improvement and quality assurance compared. Hospital Topics, Summer, 4–5.

Davidson, M., Peres, H., Shalit, D. (1977). Quality control system for Israel citrus export. Proc. Int. Soc. Citriculture, 1, 319–337.

Deming, W.E. (1982). Quality, productivity, and competitive position. MIT, Centre for Advanced Engineering Study, Cambridge, MA, USA.

Desjardins, Y. (ed.) (2007). Proceedings of the 1st International Symposium on Human Health Effects of Fruits and Vegetables, Acta Hort., 744.

EC (2007). European Commission: Agricultural commodity markets, past developments – fruits and vegetables. Directorate-General for Agriculture and Rural Development, Directorate G. Economic analyses and evaluation, G.5 Agricultural trade policy analysis http, //ec.europa.eu/agriculture/analysis/tradepol/worldmarkets/fruitveg/ Accessed 17 April 2008.

Fairtrade Foundation (2008). Chronology of Fair Trade in the UK. www.fairtrade.org.uk Accessed 27 February 2008.

FAO (2006). Food and Agriculture Organization of the United Nations: More fruit and vegetables. Available from http, //fao.org/ag/magazine/0606sp2.htm Accessed 17 April 2008.

Feigenbaum, A.V. (1983). Total Quality Control, 3rd edn. McGraw-Hill, New York, NY, USA.

Flood, R. (1993). Beyond TQM. John Wiley & Sons Ltd, New York, NY, USA.

Garvin, D.A. (1984a). Product quality: an important strategic weapon. Business Horizons, 27(3), 40–43.

Garvin, D.A. (1984b). What does "product quality" really mean? The Sloan Management Review, 26(1), 25–43.

Garvin, D.A. (1988). Managing Quality. The Free Press, New York, NY, USA.

Godfrey, A.B. (2001). Total Quality Management. Chapter 14. In: Total Quality Management, J.M. Juran. McGraw-Hill, Blackclick, OH, USA.

Goldberg, G. (ed.) (2003). Plants: Diet and Health. The report of a British Nutrition Foundation Task Force. Blackwell Science, Oxford, UK.

Govindasamy, R., Thornsbury, S. (2006). Theme overview: fresh produce marketing, critical trends and issues. Choices, 21(4), 225–227.

Groocock, J.M. (1986). The Chain of Quality, Market Dominance through Product Superiority. John Wiley & Sons, New York, NY, USA.

Gudnason, C.H. (1982). The quality assurance system. In: Handbook of lndustrial Engineering, G. Salvendy (ed.), Sections 8.1.1–8.1.17. John Wiley & Sons, New York, NY, USA.

HACCP (2000). Regulatory Assessment of HACCP. Food Control, 11(5), 341–422. (A series of papers dealing with principles and experience of implementation of HACCP system in different countries.)

Harker, F.R., Gunson, F.A., Jaeger, S.R. (2003a). The case for fruit quality: an interpretive review of consumer attitudes, and preferences for apples. Postharvest Biol. Technol., 28, 333–347.

Harker, F.R., Lau, K., Gunson, F.A. (2003b). Juiciness of fresh fruit: a time-intensity study. Postharvest Biology and Technology, 29, 55–60.

Hodder, A. (2005). World production of fruit and vegetables. In: WHO/FAO (2005). World Health Organization/Food and Agriculture Organization of the United Nations: Fruit and Vegetables for Health. Report of a Joint FAO/WHO Workshop, 1–3 September Kobe, Japan, 2004, pp. 10–11. Available at http, //www.who.int/dietphysicalactivity/fruit/en/index1.html Accessed 17 April 2008.

Howard, H. (2000). Managing quality. Scitech Educational, Broadstairs, Kent, UK.

Hu, D., Dandan, X. (2007). China: Case studies of Carrefour's quality lines. Regoverning Markets Innovative Practice Series. IIED, London, UK.

Huang, S.W., Calvin, L., Coyle, W., Dyck, J.H., Ito, K., Kelch, D.R., Lucier, G., Perez, A., Pollack, S., Pryor, S., Regmi, A., Shane, M., Shields, D., Stout, J., Worth, T. (2004). Global trade patterns in fruits and vegetables. Agriculture and Trade Report No. WRS-04-06, USDA, Econ. Res. Serv.

Hubbard, M.R. (1999). Choosing a quality control system. Technomic Publ. Co.

Hyson, D. (2002). The health benefits of fruit and vegetables. A scientific overview for health professionals. Produce for Better Health Foundation, Wilmington, DE, USA.

Jaeger, S.R., Rossiter, K.L., Lau, K. (2005). Consumer perceptions of novel fruit and familiar fruit: a repertory grid application. J. Sci. Food and Agric., 85(3), 480–488.

James, P. (1996). Total Quality Management. Prentice Hall, USA.

Joseph, J.A., Shukit-Hale, B., Denovisa, N.A., Bielinski, D., Martin, A., McEwen, J.J., Bickford, P.C. (1999). Reversal of age-related declines in neuronal signal transduction, cognitive and motor behavioural deficits with blueberry, strawberry, spinach or strawberry dietary supplementation. J. Neurosciences, 19, 8114–8121.

Jouve, J.L., Stringer, M.F., Baird-Parker, A.C. (1998). Food safety management tools. ILSI, Brussels, Belgium.

Jouve, J.L., Stringer, M.F., Baird-Parker, A.C. (1999). Food safety management tools. Food Sci. Technol. Today, 12(3), 82–91.

Juran, J.M. (ed.) (1988). Quality Control Handbook, rev. McGraw-Hill, New York, NY, USA.

Kader, A.A. (2001). Quality assurance of harvested horticultural perishables. Acta Hort., 553, 51–55.

Kader, A.A. (ed.) (1992). Postharvest Technology of Horticultural Crops, 2nd edn. Univ. Calif., Div. of Agr. and Nat. Resources, Publ. 3311, CA, USA .

Kader, A.A. (1988). Influence of preharvest and postharvest environment on nutritional composition of fruits and vegetables. In: Horticulture and human health, contributions of fruits and vegetables, B. Quebedeaux, F.A. Bliss (eds). Prentice-Hall, Englewood Cliffs, NJ, USA, pp. 18–32.

Kader, A.A. (1999). Fruit maturity, ripening, and quality relationships. Acta Hort., 485, 203–208.

Kalt, W. (2002). Health functional phytochemicals of fruits. Horticultural Reviews, 27, 269–315.

Kanji, G.K., Asher, M. (1995). Total Quality Management – A Systematic Approach. Productivity Press, Madras, India.

Kanji, G.K., Asher, M. (1996a). Implementation and pitfalls of total quality management. Total Quality Management, 7, 331–343.

Kanji, G.K., Asher, M. (1996b). 100 Methods for Total Quality Management. Sage, London, UK.

Kanji, G.K. (1998). An innovative approach to make ISO 9000 standards more effective. Total Quality Management & Business Excellence, 9(1), 67–78.

Kaur, C., Kapoor, H.C. (2001). Antioxidants in fruits and vegetables – the millennium health. Int. J. Food Sci. Technol., 36, 703–725.

Kennedy, G. (1998). Introduction of HACCP into the smallgoods industry. Food Australia, 50(2), 80–82.

Kramer, A. (1973). Fruits and vegetables. In: Quality Control for the Food Industry, A. Kramer & B.A. Twigg (eds), Vol. 2. AVI, Westport, CT, USA, pp. 157–228.

Kruithof, J., Ryall, J. (1994). The quality standards handbook: how to understand and implement quality systems and ISO 9000 standards in a context of total quality and continuous improvement. The Business Library, Melbourne, Australia.

Lamp, J.W. (1999). Health effects of vegetables and fruit: assessing mechanisms of action in human experimental studies. Amer. J. Clinical Nutr., 70, 475S–490S.

Lásztity, R. (2004). Food Quality and Standards. In: Food and Agricultural Sciences, Engineering and Technology Resources, Radomir Lasztity (ed.). In: Encyclopedia of Life Support Systems (EOLSS), developed under the auspices of the UNESCO, Eolss Publishers, Oxford, UK. Available online at http, //www.eolss.net Accessed 23 January 2007.

Lees, F.P. (1996). Loss prevention in the process industries. Hazards identification, assessment and control, 2nd edn. Vol. 1: Butterworth-Heinemann, Oxford, UK.

Lelieveld, H.L.M., Mostert, M.A., Holah, J. (eds) (2005). Handbook of hygiene control in the food industry. CRC Press, Boca Raton, FL, USA.

Lidror, A., Silberstein, B.A. (1986). Quality control of growing house tomatoes for export. Acta Hort., 191, 381–385.

Lidror, A., Kissos, P. (1986). Quality assurance of vegetables exported from Israel. In: Proceedings of the Sixth International Conference of the Society for Quality Assurance, Z. Bluvband (ed.). Ortra Ltd., Tel Aviv, Israel, pp. 6.3.1, 1–4.

Lidror, A., Prigojin, I., Pasternak, H. (1992). Quality inspection of fruit and vegetables with computer support, ASAE Paper 92-6001. Amer. Soc. Agric. Engineering, St. Joseph, MI, USA.

Lidror, A., Alper, Y., Prigojin, I. (1986). Controlled production and quality systems for citrus fruit. In: Proceedings of the 4th Meeting of Industrial Engineers in Israel, M.J. Rosenblatt (ed.). Ortra Ltd, Tel Aviv, Israel, pp. 1–3.

Lidror, A., Prussia, S.E. (1989). Human factors principals for agricultural quality control, ASAE Paper 89–1116. Amer. Soc. Agric. Engineering, St. Joseph, MI, USA.

Lidror, A., Prussia, S.E. (1993). Quality management: An industrial approach to produce handling. In: Postharvest Handling: A Systems Approach, R.L. Shewfelt, S.E. Prussia (eds), 1st edn. Academic Press, San Diego, CA, USA, pp. 277–291.

Lidror, A., Prussia, S.E. (1990). Applications of quality assurance techniques to production and handling agricultural crops. J. Food Qual., 13(3), 171–184.

McDermott, T.C., Cound, D.M. (1971). Inspection and quality control. In: Handbook of Industrial Engineering and Management, W.G. Ireson, E.L. Grant (eds). Prentice-Hall, Englewood Cliffs, NJ, USA, pp. 703–751.

Messina, W.S. (1987). Statistical Quality Control for Manufacturing Managers. John Wiley & Sons, New York, NY, USA.

MOH (1997). An introduction to HACCP. Food safety information for New Zealand businesses, revised edition. Ministry of Health, Wellington, New Zealand.

Ness, A.R., Powles, J.W. (1997). Fruit and vegetables and cardiovascular disease: a review. Int. J. Epidemiol., 26, 1–13.

Nguyen, H.X., Opara, L.U., Studman, C.J. (2000). Twist test measurement of mango texture. In: Australian Center for International Agricultural Research (ACIAR) Publication No. 100, Highley et al. (eds). pp. 145–149.

NRAES (1997). Sensors for nondestructive testing – measuring the quality of fresh fruits and vegetables. International Conference Proceedings, NRAES – 97. Northeast Regional Agricultural Engineering Service, Ithaca, NY, USA.

Opara, L.U. (2000a). Scientific tools for quality management in agricultural produce. In: Australian Center for International Agricultural Research (ACIAR) Publication No. 100, Highley et al. (eds). pp. 651–655.

Opara, L.U. (2000b). New market-pull factors influencing perceptions of quality in agribusiness marketing (or quality assurance for whom?). In: Australian Center for International Agricultural Research (ACIAR) Publication No. 100, Highley et al. (eds). pp. 244–252.

Opara, L.U. (2000c). Quality Assurance of fresh produce in New Zealand – a personal view. In: Australian Center for International Agricultural Research (ACIAR) Publication No. 100, Highley et al. (eds). pp. 639–650.

Opara, L.U., Nguyen, H.X., To, L.V. (2000). Postharvest technology for Vietnamese "Buoi" mangoes. In: Australian Center for International Agricultural Research (ACIAR) Publication No. 100, Highley et al. (eds). pp. 633–638.

Opara, L.U., Al-Said, F.A., Al-Abri, A. (2007). Assessment of what the consumer values in fresh fruit quality: case study of Oman. New Zealand J. Crop and Hort. Sci., 35, 235–243.

Opara, L.U., Al-Senani, Y.S., Al-Shukeili, T.Y. (2002). Reducing postharvest food losses and wastage – the neglected dimension in waste management. Proceedings of the International Conference on Waste Management, Al Bustan Palace Hotel, Muscat, 16–18 December.

Organization for Economic Cooperation and Development (1983). The OECD Scheme for the Application of International Standards for Fruit and Vegetables. Organization for Economic Co-operation and Development, Publications Office, Paris, France.

Parton, K.A. (1996). Quality, quality assurance and quality improvement in agronomic research. Invited paper presented to the Australian Agronomic Society, http//www.regional.org.au/au/asa/1996/1996/Invited/04parton.htm?print=1 Accessed 17 October 2007.

Pomerleau, J., Lock, K., McKee, M., Altmann, D.R. (2004). The challenge of measuring global fruit and vegetable intake. J. Nutr., 134, 1175–1180.

Porter, A. (1998). Quality and product safety management. Food Sci. Technol. Today, 12, 160–165.

Potter, J.D. (1997). Cancer prevention, epidemiology and experiment. Cancer Lett., 114, 7–9.

Prior, R.L., Cao, G. (2000). Antioxidant phytochemicals in fruits and vegetables; diet and health implications. HortScience, 35, 588–592.

Radman, M., Camanzi, L., Kolega, A. (2005). Preferences and buying behaviour of beef consumers in Tuscany. J. Central European Agric., 6(1), 99–106.

Savage, R.A. (1995). Hazard analysis critical control point: a review. Food Reviews International, 11, 575–595.

Shainnin, D. (1971). Quality control. In: Industrial Engineering Handbook, H.B. Maynard. (ed.). McGraw-Hill, New York, NY, USA, pp. 8.1.19–8–1–39.

Shaw, D., Clark, I. (1999). Belief formation in ethical consumer groups: an exploratory study. Marketing Intelligence & Planning, 17, 109–119.

Shewfelt, R.L. (1999). What is quality?. Postharvest Biol. Technol., 15, 197–200.

Smith, F.I., Eyzaguirre, P. (2007). African leafy vegetables: their role in the World Health Organization's global fruit and vegetable initiative. African J. Food Agric. Nutrition and Development, 7(3), 1–17.

Southon, S. (2000). Increased fruit and vegetable consumption with the EU: potential health benefits. Food Research International, 33, 211–217.

Steinmetz, K.A., Potter, J.D. (1996). Vegetables, fruit, and cancer prevention: a review. J. Amer. Diet. Assoc., 96, 1027–1039.

Straker, D. (2001a). What is Quality? Part 1. Quality World, April Issue. The Journal of the Chartered Quality Institute, UK.

Straker, D. (2001b). What is Quality? Part 2. Quality World, May Issue. The Journal of the Chartered Quality Institute, UK.

Studman, C.J., Opara, L.U., DongXing, Z. (2000). Improvement of quality of apples in Shanxi Province, China. Australian Center for International Agricultural Research (ACIAR) Publication No. 100, pp. 236–243.

Su, L.J., Arab, L. (2006). Salad and raw vegetable consumption and nutritional status in the US population: Results from the third national health and nutrition examination survey. J. Amer. Dietetic Assoc., 106, 1394–1404.

Tybor, P.T., Hurst, W.C., Reynolds, A-E., Schuler, G.A. (1988). Quality control: A model program for the food industry. Coop. Ext. Ser. Bull. No. 997. Univ. of Georgia, Athens, GA, USA.

Wargovich, M.J. (2000). Anticancer properties of fruits and vegetables. HortScience, 35, 573–575.

WHO (2003a). World Health Organization: Fruit and Vegetable Promotion Initiative – report of the meeting, Geneva, 25–27 August. www.who.int Accessed 17 April 2008.

WHO (2003b). World Health Organization: Diet, nutrition and the prevention of chronic diseases. Report of a Joint FAO/WHO Expert Consultation, WHO Technical Report Series #916, Geneva, 2003.

WHO (2003c). World Health Organization: Fruit, vegetables and NCD disease prevention. www.who.int/hpr/global.strategy.shtml Accessed 17 April 2008.

WHO (2004) World Health Organization: Global strategy on diet, physical activity and health. http, //www.who.int/dietphysicalactivity/Accessed 17 April 2008.

WHO/FAO (2005). World Health Organization/Food and Agriculture Organization of the United Nations: Fruit and Vegetables for Health. Report of a Joint FAO/WHO.

Workshop, 1–3 September Kobe, Japan, 2004. Available online at http://www.who.int/dietphysicalactivity/fruit/en/index1.html Accessed 17 April 2008.

Wright, J. (2001). Biosolid recycling and food safety issues. In: Food Safety and Food Quality, R.E. (ed.) Hester. Royal Society of Chemistry, Cambridge, UK, pp. 43–78.

9

Postharvest Regulation and Quality Standards on Fresh Produce

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I. Setting the task

The orchard has been irrigated, fertilized and pruned. Disease, insect and weed problems have been addressed. The crop is mature, the yield set, and the picking crews can be set to work. The postharvest phase of the crop begins. By this stage, the producer must have decided which supply chains to participate in, and thus the intended market for the crop. The final value achieved for the crop will depend on the marketing and technical nous of this chain to present and manage "quality" in the product.

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So, we are led to the hoary issue of a definition for "quality." Of course there is no single answer, and the term "product quality" has as many definitions as there are participants in the supply chain. For example, to the product supply manager and to the retailer, a major component of "quality" is product shelf life. To the government regulator, quality is often primarily conceived in terms of public risk. But, typically, there is more than one government regulator. For example, that branch concerned with quarantine risk will cast "quality" in terms of entomological and microbiological issues. Another branch of government concerned with human health risk (food safety) will cast "quality" in terms of the presence of chemical residues and microbial contaminants. To the retail client, "quality" is often viewed in terms of issues related to the remaining shelf life of the product, and aesthetic issues which affect consumer purchase decisions (fruit color, size, shape, blemish size and frequency). To the end consumer, fruit "quality" is best described in terms of both shelf life and the eating experience. The latter is a function of fruit firmness, sugar content, organic acid content and tissue juiciness. As with all stages in the supply chain, though, the consumer is not a single entity, and many fractions exist. For example, different ethnic or age groups may have different taste preferences. Further, some consumers link "quality" to the issue of local production or to organic production practices. Such consumers often implicitly link these production aspects to eating quality. Other consumers place value on larger environmental issues, such as "production without destruction" (e.g. use of crop netting rather than killing of flying foxes or birds), or on issues related to CO_2 emissions (e.g. food miles).

This chapter summarizes regulations which exist to enforce "quality" in fresh produce, postharvest. These regulations may be imposed by any step in the supply chain, may impact broadly (e.g. a microbiological standard) or may pertain to a narrow market segment (e.g. organic product). The particular issue of eating quality is considered further, in terms of the drivers for adoption of standards.

II. Regulation modifies supply chain behavior

A supply chain is a commercial construct and, as such, is driven by issues extending beyond the biology of the commodity. Certainly production and postharvest technical issues are fundamental considerations to a supply chain. But, beyond this technical foundation, the commercial viability of a supply chain is determined, in substantive measure, by the social and regulative milieu in which it is set.

A. "Supra-regulations"

The broad social milieu can often be relatively static, changing "slower than the eye can see." Further, this milieu is effectively beyond the influence of any individual business, and so the influence of this "supra-regulation" on supply chain viability is often ignored. At other times, an abrupt change in social or regulative conditions occurs, with a corresponding abrupt change in trading conditions. The following are examples of broad issues that affect the postharvest viability of a given supply chain.

Global trade environment

It is technically possible to grow horticultural crops in harsh environments through the creation of protected environments. Conversely, in an era of cheap transport, it is possible to air- and sea-freight produce across the world. The economic viability of such activities is not an "absolute," but is a function of broader economic and political settings.

As an undergraduate, I was greatly impressed on a tour of a local (Australian) Department of Primary Industries postharvest physiology laboratory. It was explained that insurance premiums on shipments of citrus to the UK were effectively unaffordable, because of the high incidence of physiological disorders and disease, but that after a range of technical postharvest "fixes," it was not necessary to insure the loads. However, the entry of the UK into the (then) European Common Market fundamentally altered trade between Australia and the UK, and citrus exports to the UK withered, as Europe raised a trade tariff barrier. The "technical fix" was overwhelmed by changes in the terms of trade. The overriding "quality" criterion became country of origin.

National policy: infrastructure

The viability, or even possibility, of a supply chain depends on the national infrastructure available for use: on the quality of the electricity supply to the cold rooms of the packing house, of the roads and railways, the availability of refrigerated transport, the efficiency of the sea and air ports, and the frequency of scheduled services, the quality of communication systems (telephone, broadband) and the size of the domestic market. All of these items are influenced by government policy.

China has provided spectacular examples of national infrastructure development in the last few decades (Table 9.1). Special development zones have been designated and supported with land reform, transport, power, water and civil infrastructure. Where horticultural production is a focus, areas suited to production in terms of soil type have been identified; water allocations and postharvest facilities provided (e.g. improved market facilities). Land reform has split the communal farms for individual use, and then allowed consolidation of land parcels for agribusiness activity. Large production units and associated packing facilities are private, but often supported by state capital.

National policy: labor market and immigration

Farm viability is highly influenced by the cost of harvest labor. In developed countries, this cost is typically high relative to that in developing nations, supported by government-imposed regulation on the minimum cost of labor. For example, the Australian horticultural industry relies, to a surprising degree, on "backpackers." These workers are allowed in to the country on short-term working visa schemes, but have a high turnover on farms, and a low (horticultural) skill level. Immigration regulations in other nations favor different solutions. In Israel, the horticultural sector effectively lost the use of Palestinian labor, but has been supported by south-east Asian (particularly Thai) labor, present on two-year working visas. The southern US horticultural industry has traditionally utilized Mexican labor. Changes in government policy relevant to the labor market or immigration can thus have a rapid impact on

Table 9.1 Excerpt from a Shaanxi province Department of Agriculture brochure, extolling 12 horticultural investment opportunities. (Shaanxi fruit Industry, Shaanxi Provincial fruit Administrative Bureau, http://www.sxfruit.com.)

No.	Item	Constructing contents	Total investment
1	Apple deep processing and integrated utilization	It is planned to construct an airconditioning storage with a capacity of 5000 tons, a 2 000 000 tons/hour processing line with grading, polishing and packaging, apple dehydrating processing line with a capacity of 5000 tons, pectic processing line with an annual processing capacity of 600 tons, protein beverage processing line with an annual capacity of 20 000 tons and a set of apple fragrance equipment with an annual capacity of 12 tons	185.07 million RMB Yuan
2	12 000 ha green fruits base and apple commercial processing line with a capacity of 50 000 tons	It is planned to construct 12 000 ha green fruits production base in Baishui, Pucheng, Heyang and Hancheng counties; It is planned to construct 10 pre-cooling cold storages with a capacity of 300 tons; one apple processing line with an annual capacity of 50 000 tons, two vehicles with a freezing system	65 million RMB Yuan
7	Construction on 5000 tons C.A. storage	To construct 5000 tons C.A. storage	40.79 million RMB Yuan
11	Construction on 5000 tons C.A. storage	To construct 5000 tons C.A. storage, to facilitate refrigeration equipment, computer lab and auxiliary equipment	40 million RMB Yuan
12	Construction on Pink Lady apple production base	To construct 33.3 ha demonstration apple orchard, to renovate 333.3 ha old fashion apple orchard into organic Pink Lady apple orchard, to construct one apple photoemission selecting line and one fruit quality inspection centre	51.55 million RMB Yuan

horticultural operations, both pre- and postharvest. Immigration policy also often drives population growth, and certainly contributes to ethnic diversity in the population, creating domestic markets for horticultural produce that are larger, but also more diverse in taste preferences.

National policy: taxation policy

Taxation policy influences investment activity and thus, can influence horticultural supply chains. For example in Australia, managed investment schemes in forestry and perennial crop horticulture offered a tax-effective treatment of funds for urban professionals on higher marginal tax rates. Large amounts of capital were accessed by these schemes, with funds invested into “corporate farming” exercises (i.e. large, professionally-managed operations rather than family farms), often with distinct marketing arrangements. However, in 2007, the Australian Taxation Office removed tax concessions for managed investment schemes operating horticultural enterprises, curbing the level of investment in this sector.

Intellectual property rights

Successful marketing requires a point of differentiation for the product. With plant variety rights, a tool exists to enforce differentiation. A new variety may be released under exclusive production and marketing arrangements (Figure 9.1). Such a marketing arrangement allows for “easy” implementation of a quality standard, and of standard

Figure 9.1 "Calypso" mango fruit, a variety available under exclusive production and marketing arrangements. Fruit have been sorted non-destructively (using near-infrared spectroscopy) on dry matter content at the time of harvest. After two days of ripening, low dry matter fruit remain green relative to high dry matter fruit. Dry matter at harvest is related to fruit maturity and thus subsequent rate of ripening, and also to fruit eating quality as indexed by TSS of ripened fruit.

pre- and postharvest practices. Similarly, the intellectual property of new technologies for postharvest storage or sorting may be protected, and thus commercially controlled. As participants in the supply chain other than the grower are encouraged to invest into R&D, it is inevitable that there will be an increasing incidence of exclusive marketing arrangements for postharvest technologies (e.g. Maxtend, a modified atmosphere control system for shipping containers, is licensed to Mitsubishi, see www.maxtend.com.au)

A carbon tax?

At this point in time we can only begin to speculate on the impact of carbon trading schemes on horticultural pricing structures (e.g. through the cost of fertilizer and transport) and thus, on market positioning. If beef prices rise due to greenhouse gas charges imposed on methane production or to loss of soil carbon (organic matter) in deforested grazing land, or due to the increased cost of grains given competition from the bio-fuels sector, the demand for horticultural produce may rise. But such projections are tenuous, and rely on an interaction of national and international regulations.

Summary

Directly or indirectly, "supra-regulations" impact the horticultural sector. Although these issues are basically beyond the control of a given supply chain, it is useful to acknowledge their impact. "Watershed" changes in such regulations, e.g. in immigration policy or carbon trading, require businesses to formulate a strategic position in the new trading environment.

For the remainder of this chapter, we examine issues of regulation that are more directly focused on horticulture, and that have a shorter term impact.

III. The goals of regulation directed at the horticultural sector

Broadly speaking, regulation targeted at the horticultural sector is enacted in an attempt to benefit either the consumer or the producer. Occasionally, the two aims are intertwined. Broadly speaking, there are two sources of regulation. One source is from "outside" the supply chain, with the regulation imposed on the entire product sector. The other source is from "within" a supply chain.

In the not-so-distant past, agricultural industries in many Western countries were regulated in terms of marketing arrangements, often in an attempt to limit production. These practices were aimed at providing a benefit to the producer, and were based on an ethic of "rural socialism." These practices belong to an era of large rural populations in democratic systems, in which the rural vote was important. Marketing boards with quasi-government agency status were given authority to require all growers to market through a single desk. Such exclusivity improved the marketing clout of that body, albeit at the loss of individual freedom. These arrangements typically served to preserve a pricing level, and to maintain production in certain areas.

As marketing boards curtail individual activity, they are considered to stifle entrepreneurial activity, and thus to run counter to free trade principles. Such arrangements are, therefore, targeted in international trade negotiations under the World Trade Organization (WTO). For example, the South African "state ordained" horticultural marketing body was dismantled, following the passing of the Agricultural Marketing Act 1996, with over 60 export licences granted for deciduous fruit alone in the first season following deregulation (Scrimgeour and Sheppard, 1998).

However, a similar result can often be achieved by a very dominant, if not exclusive, private marketing entity. In the South African example, the original marketing board has morphed into the dominant export marketing company, Capespan, with annual sales of deciduous fruits, citrus, subtropical fruit, vegetables, fruit juice and wines of around $US1 billion per annum. Another example is provided by the New Zealand based Zespri (kiwifruit) group, with growers exclusively supplying Zespri rewarded with loyalty payments. Such voluntary arrangements militate against further deregulation while maintaining a "critical mass" of supply (Asia Fruit Magazine, 2007a).

Other "producer-centric" regulation is also being eliminated. For example, the Australian producer group Queensland Fruit and Vegetable Growers lost the right to compulsorily acquire a levy on all horticultural product sold. The group reincarnated in August 2004 as "Growcom," but now must seek voluntary support from growers to maintain a program of research, marketing and political advocacy (Growcom, 2007).

Current attempts to regulate the fresh produce sector typically aim for a gain to wider society or for a gain in "quality" for one or more elements of the supply chain. Examples include:

1. Fair trading: most countries regulate all commerce in terms of fair trading provisions. In the horticultural area, this includes enforcement of product identity and content labeling (e.g. accuracy of weight or count labels). In the

US, traders of fresh produce must obtain a licence under the Perishable Agricultural Commodities Act (1930). This act allows for the enforcement of contracts between buyers and sellers (USDA, 2007a). Similarly, the Australian Horticulture Code of Conduct (enacted in May 2007) requires written agreements between buyers and sellers, ensuring that the parties define and document the level of any required quality attributes (Horticulture Media Advisor, 2007).

2. Product origin: there is an increasing requirement for traceability (see Chapter 12) from the broad level of labeling country of origin, to the specific level of traceability of every lot from orchard to retail outlet.
3. Quarantine issues: typically entomological or microbiological. In responding to quarantine regulations technical fixes, such as vapor heat treatment or gamma irradiation, may be applied with potential impact on shelf life (i.e. loss of “quality”).
4. Food safety: typically heavy metal and organic chemical residues and microbiological contamination. Regulations typically favor supply chains that can provide records of chemical usage and practices undertaken, and that are amenable to inspection (e.g. central packing houses rather than dispersed packing).
5. Product size, color and appearance: retailers usually set product specification in terms of these esthetic issues.
6. Eating quality: uncommonly, a retail client may also enforce product specifications on this aspect of quality.
7. Organic production: specific supply chains may require organic production, vetted by various certification schemes.
8. “Local food:” this concept is perhaps best developed in Europe, where the use of geographic names in labeling is regulated (European Commission – Agriculture and Rural Development, 2007). In Japan, consumers identify specific product qualities by region, and retailers may label product with locality and even the identity of the farmer (Figure 9.2).
9. Other environmental issues: some consumers/supply chains/governments weight production issues such as water use and wildlife “friendliness” (e.g. netting to exclude flying foxes), and postharvest issues such as type of packaging and “food miles.”

Of the above examples, the first four are government regulated, while the remaining five are usually supply-chain regulated.

IV. Levels and examples of regulation

Regulation of postharvest handling of horticultural produce exists at an international level, a national level and at the level of the individual supply chain. Indeed, there is a web of intergovernmental and non-government (NGO) organizations, national and sub-national (state) government agencies, and various supply chains involved in the setting of regulations and standards. Fortunately, there is a trend towards standardization and rationalization among these various organizations.

Figure 9.2 Advertising material from the Japanese retail chain Diaea (2004), including information on production locality and a photograph of the grower. The "stamp" indicates fruit has been "light sorted," i.e. graded to a sweetness level using near-infrared spectroscopy.

In this text we are not directly concerned with the economic regulators of the horticultural industry, such as import tariffs or import volume limits, set by national governments. However, the reality is that global horticultural trade is constantly shifting in response to the "real-politik" of trading disputes between countries, with phytosanitary standards and research used as ammunition in this tussle. For example, a single issue of Asia Fruit Magazine (2007b) reported the following issues:

1. Thailand has traditionally been a relatively open market for horticultural products. Balmer (2007) reported that Thailand is implementing plant quarantine regulations which are consistent with WTO standards on sanitary and phytosanitary conditions. However, the commercial impact of these actions is significant. For example, it is predicted that air freight programs of mixed loads

destined for the modern retail trade from Australia will be devastated if it is necessary to fumigate product on arrival.
2. Baker (2007) reported that heat-treated Taiwanese mangoes reached the Australian market in May 2007 after a three year bid by Taiwan. It was noted that the removal of trade barriers in Australia was encouraging new importers, but some were importing sporadically, resulting in a market that was competitive and prone to disruption.
3. New Zealand estimated trade tariffs cost the NZ fresh produce sector US$133 million annually, with a 12% increase in tariffs paid since 2004 (Asia Fruit Magazine, 2007a).
4. It was reported that the WTO proposed that developed countries should cut import tariffs on "tropical" products from developing countries, including India and China, as a "sweetener" for those countries to agree to a reduction in trade protection measures in other sectors (Asia Fruit Magazine, 2007c).
5. Fresh produce exports from China to the EU were reported to total around 200 000 tonnes, with only 1000 tonnes exported from the EU to China. EU representatives have protested the difficulties encountered in gaining access to the Chinese market (Asia Fruit Magazine, 2007d).

Global horticultural trade is also influenced by "private" regulations, i.e. regulations within a supply chain. For example, the same issue of *Asia Fruit Magazine* records the following issues:

1. Collen (2007) reported that traders of Chinese "certified organic" product were questioning the status of the product, given that over 430 institutions offer organic certification in China, and that counterfeit organic labels existed. Further, it was noted that food control is spread over a number of government departments, leading to inconsistent regulation and a concern whether produce is meeting international food safety standards.
2. Ahold, Carrefour, Delhaize, Metro, Migros, Tesco and Wal-Mart, seven of the world's largest retailers, were reported to have agreed to use four global food safety initiative schemes: BRC (British Retail Consortium global food standard); IFS (International Food Standard); SQF 2000 (Safe Quality Food scheme); and the HACCP scheme (Asia Fruit Magazine, 2007e).

V. International trade regulation

The following section briefly describes the framework in which regulation of fresh produce quality operates.

A. The World Trade Organization (WTO)

The World Trade Organization (WTO) acts in the field of regulation related to free trade. Support programs that stimulate production directly and import tariffs on imported product must be reduced for a nation to participate in the WTO (Agriculture

Agreement) framework, on the basis that policies which support domestic prices, or subsidize production in some other way, will lead to domestic overproduction. Overproduction is considered likely to cause pressure against imports or the offering of export subsidies, resulting in "dumping" of product on world markets (World Trade Organization, 2007). The strengthening of the New Zealand horticultural sector following deregulation represents an apparent success story for this thesis (Bell and Elliot, 1993).

WTO members were required to estimate the annual value of agricultural production support ("total aggregate measurement of support") for the base years of 1986–1988. Developed countries agreed to a 20% reduction of the support level over six years from 1995, while developing countries agreed to a 13% reduction over ten years, and least-developed countries were not required to make any reduction.

Programs that are not considered to have a direct affect on production (e.g. a nationally funded R&D program, an infrastructure program or a food security program) are exempt from this process. Certain other payments made directly to farmers that do not stimulate production, such as drought support, industry restructuring programs, and environmental and regional assistance programs, are also exempted. There is also a further category of permitted direct payments to farmers for limiting production for qualified government assistance programs to encourage agricultural and rural development in developing countries and other small scale support (5% or less of the total value of the product in the case of developed countries and 10% or less for developing countries).

The inherent expectation is that developed countries should have no import restriction on, or production support to, horticultural produce. The major barrier to trade, then, becomes quarantine or food safety issues. Of course, there are always gray areas, with good scope for legal maneuvering between trading nations! Sound science on the underlying quarantine issues is required. However, incomplete science or bad science may be used to justify trade restrictions. Resolution of such issues typically involves diplomatic trade-offs, involving a compromise on one trade issue in order to achieve success on another. The resolution process is effectively beyond the capacity of a marketing or industry group, and relies upon government support, and thus, on political lobbying by industry groups for allocation of resources. For example, in the 1990s export of Philippine grown mangoes to Australia was blocked on the basis of the potential to import mango seed weevil into Australia. The Philippines subsequently blocked importation of live cattle from Australia, a likely retaliatory measure. Australian aid funds were sourced to assist in the development of processes to disinfest mango shipments of seed weevil.

To resolve trade disputes, the WTO provides a forum (court) for "independent arbitration." For phytosanitary related disputes, such decisions come down to a risk analysis on the possibility of transfer of a pest or pathogen. For example, the US and New Zealand have long sought to export apples to Japan and Australia, respectively, but in both cases have been blocked on the basis that the apple disease fireblight exists in the US and New Zealand, but not in Japan and Australia. Controversy exists on the technical side as to whether fireblight can be transmitted via the fruit alone. The mechanism in such actions is that a trading body will propose to market fruit, in this case from the US or New Zealand to Japan or Australia. This proposal will be vetted by the quarantine service of the importing nation, and may be opposed on scientific grounds (e.g. the risk of introducing fireblight disease). The technical merits of this objection may be argued against by, typically, a government supported research agency from the country of origin (the USDA and HortResearch in this case). If the matter is not resolved between the parties, the case may be taken to the WTO for a ruling. Such rulings may be appealed, so the process typically takes many years to resolve. Responding to a 2003 WTO ruling, Japan allowed import of mature symptomless fruit, but required field inspections of US orchards by Japanese inspectors three times a year. Compliance complexity and cost effectively prevented any trade. This requirement was removed by a WTO ruling in 2005. New Zealand is still seeking access to the Australian market in 2007, with the matter taken to the WTO.

B. International bilateral trade agreements

Governments may negotiate trade agreements outside of the general WTO framework. Typically this involves a compromise between the parties, with reduction in regulatory and tariff barriers in various commodity classes. For example, in the 2004 US–Australia free trade agreement (Australian Government – Department of Foreign Affairs and Trade, 2007), Australia agreed to provide immediate duty-free tariff treatment on all incoming US fruit imports, removing a 5% tariff, and to resolve outstanding phytosanitary issues, e.g. for apples, Florida citrus and stone fruits. The US agreed to grant duty-free access for over half of the listed fruit, including oranges, tree nuts, mandarins and strawberries, and to phase out import tariffs (from rates as high as 30%) on the remaining fruit products, including pecans, dried apricots, peaches, pears and canned fruit over the next 4 to 18 years, while maintaining phytosanitary restrictions on many fruits, such as avocados and tropical fruit.

VI. A language for regulation

The success of a regulation exercise rests on the ability of the participants to understand the intended requirements. As noted earlier, many countries have entered free trade agreements reducing tariff barriers to trade, but quality and food safety standards have served to moderate the flow of imported product. Obviously, the resolution of disputes between trading partners is likely to be less contentious if all parties are using a “common language.”

Grade standards can improve marketing efficiency by providing a common language for understanding of the product to both sellers and buyers (Florkowski, 1999). This comment is valid for communication both up and down the supply chain. For example, the producer must be able to interpret and effectively measure the standards set by a retailer, while the retailer must set meaningful standards and adjust these standards according to production limits. However, the supply chain effectively consists of a series of tribes trading with each other, with each of these tribes varying in dialect or language. As well as being literally true in international trade, the metaphor here is in the “language” used by each group to describe their product and, in particular, to describe quality in their product.

Production description languages are an attempt to use a common set of descriptors across the supply chain. Such documentation exercises may be simple and visual (a poster produced by a marketing organization detailing quality characteristics, displayed on the wall of a packing house), through to complete manuals. The languages may be produced for use within a single supply chain, for use at a national level (e.g. Story and Martyine, 1996), or for international use (e.g. OECD, 2006).

In the context of achieving mutual understanding for readers of this section – let us differentiate between a specification, a standard and certification. A specification is an “exact statement of particulars.” A standard is a published specification, used as a “rule” for a level of performance. The enforcement of a standard requires an inspection process in which a product is certified to conform to the specification, and so meet the standard. The organization involved in setting the specifications which set a standard may also act in certification, or the two functions may be separated.

A. Codex

The Codex Alimentarius Commission (CAC) was created in 1963 by the FAO, WHO and other bodies to develop food standards, guidelines and codes of practice, with the aim of protecting the health of consumers, ensuring fair trade practices in the food trade and promoting coordination of work on food standards (Codex Alimentarius Commission, 2007a). In these activities the CAC acts as an aide to the WTO, allowing for the minimization of “the negative effects of technical regulations on international trade.” The CAC aims to act as the internationally recognized body for food standards, with its norms applied to the widest extent possible by all members as a basis for domestic regulation and international trade. The CAC has created a set of internationally agreed standards which are available for use in domestic regulation and international trade. Guidance is also provided to member countries on labeling and import/export inspection and certification systems. The CAC also offers advice on food safety management systems (e.g. Pineiro and Diaz, 2007).

The CAC does not conduct any direct technical work on standards, but rather it relies on expert committees convened by the FAO and WHO, and upon the technical work of member nations. For example, the Joint FAO/WHO Meetings on Pesticide Residues and the Joint FAO/WHO Expert Meeting on Microbiological Risk Assessments are independent of the CAC (Codex Alimentarius Commission, 2007b).

The growth in global food trade has resulted in a substantial growth in membership of the CAC, with developing countries now accounting for a majority of total membership. To achieve agreement across all members however, CAC product specifications can be a case of the lowest common denominator. The CAC has been successful, however, in the setting of maximum heavy metal, chemical residue and microbiological contamination criteria. Otherwise, Codex specifications generally relate to issues such as labeling of country of origin, fruit size and esthetic issues, with attributes related to eating quality rarely included (table grapes being one

CODEX STANDARD FOR TABLE GRAPES (CODEX STAN 255-2007)
1. DEFINITION OF PRODUCE

2. PROVISIONS CONCERNING QUALITY
2.1 MINIMUM REQUIREMENTS
2.1.1 The bunches must have been carefully picked
2.1.2 Maturity Requirements
Table grapes must display satisfactory ripeness. In order to satisfy this requirement, the fruit must have obtained a refractometric index of at least 16° Brix. Fruit with a lower refractometric index are accepted provided the sugar/acid ratio is at least equal to:
(a) 20:1 if the Brix level is greater than or equal to 12.5° and less than 14° Brix
(b) 18:1 if the Brix level is greater than or equal to 14° and less than 16° Brix
2.2 CLASSIFICATION
2.2.1 "Extra" Class Table grapes in this class must be of superior quality
2.2.2 Class I Table grapes in this class must be of good quality
2.2.3 Class II Table grapes which do not qualify for inclusion in the higher classes

3. PROVISIONS CONCERNING SIZING
Size is determined by the weight of the bunch
3.1 MINIMUM BUNCH WEIGHT The minimum bunch weight shall be 75 gr

4. PROVISIONS CONCERNING TOLERANCES
4.1 QUALITY TOLERANCES
4.1.1 "Extra" Class Five percent by weight of bunches not satisfying the class requirements
4.1.2 Class I
Ten percent by weight of bunches not satisfying the class requirements
4.1.3 Class II
Ten percent by weight of bunches satisfying neither the class or minimum requirements,
4.2 SIZE TOLERANCES

5. PROVISIONS CONCERNING PRESENTATION
5.1 UNIFORMITY
5.2 PACKAGING
5.2.1 Description of Containers

6. MARKING OR LABELLING
6.1 CONSUMER PACKAGES
6.1.1 Nature of Produce
6.2 NON-RETAIL CONTAINERS
6.2.1 Identification
6.2.2 Nature of Produce
6.2.3 Origin of Produce Country of origin, optionally, district
6.2.4 Commercial Identification
6.2.5 Official Inspection Mark (optional)

7. CONTAMINANTS
7.1 PESTICIDE RESIDUES
7.2 OTHER CONTAMINANTS

8. HYGIENE
8.1 Recommended International Code of Practice
8.2 Principles for the Establishment and Application of Microbiological Criteria for Foods

Figure 9.3 Summary of the Codex specification for table grapes.
Source: www.codexalimenatrius.net Accessed 9 December 2007.

exception, Figure 9.3). Codex specifications exist for many processed fruit and vegetables (frozen, canned, dried, etc.), and for pineapple, papaya, mango, prickly pear, carambola, litchi, avocado, limes, pommelos, guavas, chayotas, ginger, grapefruit, longans, asparagus, cape gooseberry, pitahayas, oranges, rambutan and table grapes (in order of appearance on the Codex web page) as fresh fruit. A focus to date on tropical fruit is obvious.

B. The Organisation for Economic Co-operation and Development (OECD)

The Organisation for Economic Co-operation and Development (OECD) is a group of 30 countries committed to "democracy and the market economy" which acts with an aim to "facilitate international trade through the harmonization, implementation and interpretation of marketing standards." The OECD claims to be the "main reference for the certification and standardization of certain agricultural commodities." The OECD is active in developing standards in collaboration with the UNECE and Codex, offering a range of explanatory brochures of the standards, and in promoting uniform quality assurance and inspection systems under its "Scheme for the Application of International Standards for Fruit and Vegetables" (including a methods manual on testing fruit and vegetable eating quality, OECD, 2006). The OECD and UNECE standards on fresh fruit and vegetables are identical, with the OECD website on these standards (OECD, 2007) linked to that of UNECE (2007).

C. The United Nations Economic Commission for Europe (UNECE)

The United Nations Economic Commission for Europe (UNECE) was established in 1947 and includes the countries of North America, Europe and Russia. UNECE reports to the United Nations Economic and Social Council. Within UNECE, the "Specialized Section on the Standardization of Fresh Fruit and Vegetables" is part of the Working Party on Agricultural Quality Standards. This body sets standards on fresh fruits and vegetables intended for application at the point of export, and so informs the CAC (United Nations Economic and Social Council, 2006; United Nations Economic Commission for Europe, 2007a).

The function of this body is illustrated by summarizing the outcomes of one of its meetings (United Nations Economic Commission for Europe, 2007b). The fifty-second session of the Specialized Section on the Standardization of Fresh Fruit and Vegetables was held in Geneva between May 16 and 19, 2006, and was attended by representatives of 16 European nations, Morocco, New Zealand, South Africa, Turkey and the US (i.e. exporters of horticultural produce to Europe). The meeting considered modifications on UNECE standards on potatoes, melons, bilberries and blueberries, cherries, peaches and nectarines, table grapes, truffles and apples. For example, the "minimum maturity requirement" for peaches and nectarines was defined by the following criteria: "the refractometric index of the pulp measured at the middle point of the fruit flesh at the equatorial section must be greater than or equal to 8° Brix and the firmness must be lower than 6.5 kg, measured with a plunger of 8 mm diameter (0.5 cm^2) at two points of the equatorial section of the fruit, with skin intact, except for fruits with Brix values greater than 10.5°, in which case firmness must be lower than 8 kg/0.5 m^2."

This group is quite active. Standards recommended by this group inform the OECD, Codex and GlobalGAP standards (see discussion below).

D. National standards

Every trading country should maintain standards on the quality of traded horticultural produce. The standards should be, at a minimum, those of the Codex Alimentarius, and are likely to be informed by the OECD–UNECE standards. Each nation will differ in its mechanism to enforce quarantine and food safety standards, with the Australian structure presented by way of example in this section. Going beyond these issues, the example of the national grade standards and inspection service offered within the US, and the additional regulation criterion of locality offered within Europe, are also presented in this section. Finally, the specifications required in the national standards of a developing economy, the Philippines, are considered. Over time, all countries are likely to adopt similar standards.

Australia

Fresh fruit and vegetable quality is regulated in terms of quarantine and food safety issues by several federal government agencies, notably the Australian Quarantine Inspection Service (AQIS) and Food Safety Australia and New Zealand (FSANZ), respectively. Codex standards apply to all imported fresh fruit and vegetables, but government-based regulation of eating quality, per se, does not exist.

Food Safety Australia and New Zealand (2007) (FSANZ) is a regulatory body that defines maximum allowable chemical residue and microbial loads on fruit and vegetables. FSANZ does not monitor these levels, leaving this to state agencies or commercial practices. However, it can be involved in dispute resolution. This body is also responsible for the registration of chemicals for use on a given crop. As the cost of preparing a case for registration is high, this process is a major issue for horticultural crops of relatively low total farmgate value. An international standard on chemical registration would be very useful.

The Australian Quarantine Inspection Service (AQIS) is charged with the responsibility of preventing entry of unwanted fruit and vegetable pests and diseases into the country. The service also issues statements of compliance for specified treatments (e.g. vapor heat treatment) of produce destined for export markets. Within the country, quarantine issues are dealt with by State Agriculture Departments. For example, papaya fruit fly is a serious pest of tropical fruit that entered Australia through the Cairns airport, presumably with a passenger carrying infected fruit and despite AQIS inspection. The state agriculture agency enforced bans on fruit transport through road blocks in concentric rings around Cairns until the pest was eliminated (Australian Quarantine Inspection Service, 2007a). Similarly, when citrus canker appeared on a mandarin farm in Emerald, Central Queensland, despite AQIS inspection of all imported equipment and budwood, the state agriculture agency enforced bans on fruit and equipment movement, and oversaw destruction of all citrus trees in a 200 kilometer radius (Australian Quarantine Inspection Service, 2007b).

The state and federal agencies maintain a watching brief on other issues. For example, frogs are frequently transported from tropical to temperate areas in banana shipments. The Melbourne markets are estimated to import around 6000 frogs of four species per year. It is believed that the fungus *Mucor amphibiorum* was introduced to Tasmanian platypii from "banana" frogs (Tasmania – Department of Primary Industries and Water, 2007).

The United States

The Agricultural Marketing Service of the United States Department of Agriculture (USDA) was inaugurated in 1915, with the aim of providing market information and common terminology for quality and the development of grade standards (USDA, 2007b). Given their experience and technical capacity, the AMS has contributed significantly to the development of international produce standards, e.g. Codex, UNECE.

The United States Inspection Service acts to apply these fruit and vegetable standards, and was established in ten of the largest wholesale markets in 1917. The service arranges for domestic inspection of fruit and vegetables, both for sellers and for buyers, to ensure that products meet specific grade standards. There are 158 grade standards for 85 fresh fruits, vegetables and nuts. Inspections are generally voluntary, made at the discretion of either the seller or buyer, and paid by user fees. However, inspections are mandatory for fruit purchased by government agencies. Clients can request a quality and condition inspection, a condition only inspection, or a container weight/count only inspection. A quality and condition inspection of a product "in quantities of 51 or more packages … unloaded from the same land or air conveyance, over half a car lot equivalent product" is priced at US $114 (USDA, 2007b).

The European Union

Pascale (1992) has reviewed the wider issue of the impact of EEC regulations on quality on trade in fresh fruit and vegetables. Since 1992 the European Community has also regulated the labeling of food by geographic or traditional origin (European Commission, 2007). Three categories are recognized: protected designation of origin (PDO), protected geographic indication (PGI) and traditional speciality guaranteed (TSG). PDO describes foodstuffs produced, processed and prepared in a given geographical area using recognized know-how. For PGI, a geographical link to one of the three stages of preparation must be demonstrated. To achieve designation, a case must be supported by the relevant national government, and approved by the European Commission, Agriculture/Food quality section. Well over 100 PDO/TSG assignments have been granted on fruit and vegetables (European Commission, 2007).

The Philippines

As a horticultural trading country, the Philippines maintain national standards on a range of fruit and vegetables. For example, the Philippine National Standard on Mandarin (ICS 065.020.20) details specifications on fruit diameter, defects, packaging, color, juice total soluble solids (or Brix), juice total acidity, juice Brix to total acidity ratio and minimum percentage juice content as a maturity requirement. These standards are informed by existing standards (e.g. the USDA–AMS and UNECE). Allowable levels of heavy metal and pesticide residues are directly referred to those set by the Codex Alimentarius Commission.

VII. Regulation within a supply chain

A given supply chain must first adopt (or circumvent) the governmental regulation imposed by its trading environment. However, there is constant "evolutionary pressure" between rival supply chains to capture market share. Large retailers will often engage at least two "produce supply managers" for each commodity. The resulting competition involves differentiation of product in terms of price, quality or some other aspect of the "offer." The successful supply chain will be disciplined in adherence to standards, and robust in its ability to deliver quantity and quality of fruit. To achieve this, a successful supply chain will impose "regulations" on its members.

Thus, a given supply chain must seek to distinguish itself in some way. For example, a supply chain may acquire exclusive marketing rights to a variety that promises increased market share or premium price. Participants agree to be bound by rules that may include the window and volume of production, the production and postharvest methods, and the marketing path. A supply chain can also seek to distinguish itself through technology. For example, the SmartFresh™ quality system, developed in the US, has been effectively and widely used by Australian producers participating in export programs to maintain consistent fruit quality (Good Fruit and Vegetables, 2007). In this system, fruit are treated with a chemical (MCP) to delay the ripening process and improve shelf life.

Another component of fresh fruit and vegetable supply chain "self" regulation involves the reduction of risk associated with chemical safety and hygiene to consumers. Proactive action by the large retailers in this area also reduces the risk of provoking government-imposed regulation. Supply chain members are required to participate in a food safety management program scheme, which typically varies somewhat between retailers. Such programs become an important feature of the import/export process if they are recognized by supply chain participants and government regulators in both source and destination countries.

There are several food safety management programs utilized within the fresh fruit and vegetable sector. The HACCP program is one such food safety management system. It is used in the US, Europe, East Asia and Australasia. This program is accessed through a project management company which designs, implements and manages the food safety program (e.g. HACCP Australia, 2007). In these programs, an analysis of what and where hazards can occur is made, and systems and procedures are implemented to minimize the risk of failure. Subsystems, such as pest control, recall protocols, hygiene and sanitation are also implemented. For example, an analysis of a packing house operation might consider the risk of using contaminated water in the fruit washing process, or the possibility of contamination of fruit from the breakage of a glass component in the packing line. Onsite operators and management are trained, and a maintenance/audit program involving HACCP personnel is implemented.

Another component of supply chain self-regulation takes the form of a specification sheet (Figure 9.4), against which produce can be assessed. Generally, this specification is written for fruit and vegetables arriving at the retailer's distribution centre.

Coles Fresh Product Control Specification
Golden Delicious Apples V1.0

Overview			
Product Title	Golden Delicious Apples		
Date	18/07/2008	**Supercedes**	
Business Supplied To	Coles Supermarkets	**Crate Weight Minimum**	12kg
State	Australian Capital Territory, National, New South Wales, Northern Territory, Queensland, South Australia, Tasmania, Victoria, Western Australia	**Order ID**	
Country of Origin	Australia	**APN/PLU**	4020, 4021
Pack Life	Packed on 7 Days		

Physical Tests	Product File>Specification>Tests
Test	**Accept / Pass Criteria**
Fresh Produce - A: Variety	Golden Delicious Apples
Fresh Produce - B: Colour	A green- yellow golden skin. A pink blush is acceptable up to 20%.
Fresh Produce - C: Appearance	Bright
Fresh Produce - D: Maturity	
Fresh Produce - E: Brix	Brix => 12.5
Fresh Produce - G: Starch	
Fresh Produce - H: Acidity	
Fresh Produce - I: Firmness	Firmness 5.5 kg (11 mm plunger)
Fresh Produce - J: Size	Count per carton: 60 - 65 – 70 – 75 – 82 - 90
Fresh Produce - K: Shape	Conical to Round
Fresh Produce - L: Defects	Minor Defects: 7 pieces of fruit or less per pack with < 1cm2 in total surface area affected. Major defects: 2 pieces of fruit or less per pack with 2cm 2 total surface area affected.
Fresh Produce - M: Presentation	A minimum of 85% fruit stickered with the PLU
Fresh Produce – N: Inner Packaging	
Fresh Produce – O: Outer Packaging	Coles B Crate - RPC
Fresh Produce – P: Treatment	Washed and polished Waxed
Fresh Produce - Q: DC Maximum Acceptance	If Australian grown produce the maximum shelf life acceptance into the DC shall be 7 days from the date of packing.
Fresh Produce - R: Pulp Temperature	0 – 12 C
Fresh Produce - S: Best Before / Use By	
Fresh Produce – T: Max Harvest to Pack Date	

Packing		Product File>Specification>Packaging
Description	**Value**	**Details**
Full Pallet Height		2 pallets of 36
Number of Layers		6 crates per layer 6 layers high
Fresh Produce - Crate Type (A,B,C,E)		B
Fresh Produce - Kilo/Units per crate		12

Figure 9.4 (Continued)

Coles Fresh Product Control Specification
Golden Delicious Apples V1.0

Variations			Product File>Specification>Variations
Temporary / Seasonal Variation			
Variation Effective From	18/07/2008	**Variation Effective To**	

Attachments	Product File>Specification>Attachments
Physical Filename	**Current Version**
Golden Delicious Apples (kg) 070408 V1 DC Acceptance Chart.pdf	1
Golden Delicious Apples (kg) 070408 v1 pic attach.pdf	1
Standard Produce Quality control Specifications.pdf	1

Printed By Andreas Klieber Date Printed 03-Nov-2008 15:16

Figure 9.4 Specification sheet for peaches from an Australian retailer.
Source: http://www.supplier.coles.com.au/quality control/specifications.asp (Accessed 26 October 2007)

Typically, assessment of fruit against at least some of the specified criteria (e.g. juice Brix) at a retailer distribution centre is haphazard. This is a function of the effort required to select a representative sample, and to measure the desired criteria of a statistically significant number of samples. Unfortunately, sometimes enforcement of specification criteria may be used within a supply chain to regulate supply, i.e. the specification may only be enforced when product is in oversupply. If enforcement is sporadic, the supply chain will largely ignore the criterion. If enforcement is consistent, a strong incentive exists for the grower/packer/supply chain agent to adopt systems to ensure that the criterion is addressed.

Valero and Ruiz-Altisent (2000) describe a quality control system on fruit quality intended for implementation at the retailer distribution centre which involves statistical sampling protocols and quantitative measures of quality attributes including fruit firmness, temperature, skin color, juice total soluble solids content and juice total titratable acidity. This system represents an "ideal."

GlobalGAP (EurepGAP)

EurepGAP, now known as GlobalGAP, was implemented by European retailers as a means of ensuring product was safe, of high quality and produced in a humane and environmentally sound way. It also requires that product be traceable from its point of origin in terms of all treatments. The specifications set in this scheme are thus, tighter (extending to eating quality determinants) and broader (extending to social and environmental issues) than those set by the CAC.

The GlobalGAP certification requirement was originally imposed onto producers wishing to access the large European retailers, but GAP certification now serves a wider purpose. The commonality of the GAP programs in different countries allows it to act as an international standard. Thus, this certification scheme is becoming a global market requirement in the fresh produce trade. GAP certification can be a tool to ensure access to global markets.

GlobalGAP certifiers can inspect conditions and product in the country of origin, or a local version can be certified by GlobalGAP, with the standard adapted to local conditions. Implementation of a local version of the standard, with certification of product undertaken by local bodies, reduces the cost of audit and inspection. For example, China and Japan have established ChinaGAP and J-GAP, respectively, and Thailand is currently in the process of developing ThaiGAP.

To achieve GAP certification on product, farmers must learn what must be done to meet standards, invest in systems to comply with the standard and pay for independent verification of compliance. The processes and documentation required by GlobalGAP thus factors against the involvement of small producers. Hey (2007) reports that by 2007 GlobalGAP accreditation in Thailand involved only 300 agricultural suppliers, and was driven by a few large private export companies. However, in Thailand fruits and vegetables are produced on 600 000 small farms, with farm personnel typically poorly educated. Hey (2007) reported that through ThaiGAP, the Thai government will provide support to eight clusters of growers across five regions, with certification documentation services supplied to grower groups, thereby greatly increasing participation rate.

Organic certification

Another area of differentiation is in organic certification. Both production and postharvest practices must be certified "organic." Thus, organic produce loses this status if quarantine provisions require it to be fumigated.

Certification agencies confirm compliance to organic standard requirements. However, there is more than one standard – a situation that has arisen as the organic industry has developed "from grass roots," forming several industry associations which have established their own standards and certifying bodies. A useful list of standards and certifying bodies can be found at http://organic.com.au/standards/, although this list is likely to be very incomplete. A plethora of multiple standards (Figure 9.5) is confusing to the marketplace and there is a trend towards standard consolidation (Lockie et al., 2006).

For example, in Australia, the domestic sector can use either the National Association for Sustainable Agriculture standard or the Biological Farmers

Organic bananas – Lady Finger		1 kg	$6.90		OGA 731A
Organic oranges		1 kg	$4.90		NASAA 10187IC
Organic mandarin	*local*	1 kg	$4.90		NASAA 4069A
Organic lemons	*local*	1 kg	$4.90		NASAA 4069A
Organic limes	*local*	Each	75c		ACO 10045
Organic pear		1 kg	$9.90		DEMETER
Organic kiwi fruit		Each	75c		BD 2016A
Organic pineapple	*local*	Each	$6.50		ACO 4256A

Figure 9.5 Excerpt from order form of "Mary's Home Delivered Organic Fresh Food." Product price list and order form, 5 June 2007 (Yeppoon, Australia). Certification column refers to organic certification.

Associations' Australian Organic Standard, while exporters must use an AQIS standard. In a bid for uniformity, Standards Australia is developing a domestic standard based on the AQIS standard.

The three major trading blocs are segregated by the use of different standards: the National Organic Program (NOP) in the US, the EU standard (regulation 2092/91), and the Japanese Agricultural Standard (JAS) (Lockie et al., 2006). For example, the JAS organic certification system requires that no chemicals be used on farms for three years prior to the start of organic production, in common with most standards. However, the JAS standard extends the definition of "chemical" to alkali humic acid, lignin sulfonate and potassium bicarbonate, items allowed in the US NOP organic certification. To export product to Japan as "certified organic," a NOP certified United States producer must, therefore, arrange for a JAS certification of his operation.

The next decade should see a movement towards uniformity of organic standards to facilitate international trade. This will probably come first through the organic movement, e.g. through the International Federation of Organic Agricultural Movements, a German based international NGO, with the setting of a private standard that is recognized by all major trading blocs (i.e. by NOP, EU and JAS), and later through adoption of such a standard by intergovernmental agencies, particularly Codex.

Tesco: greenhouse friendly?

The past half century has seen the rise of the global retailer. These retailers dominate their supply chains and therefore, can drive (regulate) change. In driving change, the retailers seek to reflect rather than influence public attitudes, with the timing of the change linked to a judgement of when a specific value-client group appears sufficiently large and cohesive. For example, public attention has swung to the issue of greenhouse gases and global warming. Tesco, the UK based trans-national retailer, is to label air freighted produce with an aeroplane symbol, and has committed to a 50% reduction of the "carbon footprint" of its existing stores and distribution centres by 2020 (Tesco, 2007). The retailer has indicated that a carbon labeling system will be introduced for all products (with this calculation to include emissions due to production, transportation, storage and packaging). The data and assumptions required for such an exercise are not to be underestimated. For example, tomatoes grown in a warm climate and shipped in bulk to the UK incur greater "food miles" than a local hydroponic grower growing in a heated greenhouse, but which has a greater "carbon footprint?" Are fresh vegetables more "greenhouse friendly" than frozen vegetables? The carbon cost of refrigeration of frozen vegetables can be estimated, but the amount of waste of fresh product up to the point of consumption should also be known to enable a comparison.

VIII. On the regulation of eating quality

Setting and maintaining eating quality standards on fresh produce

We have seen that national and international standards on fresh fruit and vegetables focus on issues of food safety and external appearance. In contrast, standards on eating quality have been sporadically enforced. Indeed, eating quality is often not considered within discussions of "fruit quality" or "vegetable quality." For example, the text *Fruit and Vegetable Quality* (2000), edited by Shewfelt and Bruckner, details a range of concepts, from breeding to economics, but it does not address the issue of measurement of internal eating quality or the setting of minimum standards. Similarly the text, *Quality Factors of Fruits and Vegetables* (1989), edited by Jen, features a broad range of topics relating to the processing of fruit and vegetables, but offers little on quantitative levels of components related to eating experience, and does not report any minimum standards. In the specific context of citrus, Fellars (1985) concedes that the words "flavor" and "flavor quality" often appear in the literature, reference to without sensory ratings for quality or palatability existing.

Defining eating quality

Setting a quality standard to deliver eating quality in a consistent fashion requires the use of quantitative, but easily measurable, characteristics that can be correlated to eating quality. The primary measurable attributes of a fruit that can be related to taste are texture (commonly indexed as firmness), total sugar content (measured as percentage of total soluble solids, TSS, or Brix, in juice extracted from the fruit), type of sugar present (fructose elicits a greater sweetness sensation than sucrose), and in certain fruit, acidity (sourness sensation). Volatiles and semivolatile organic compounds also impact the flavor and aroma of foods. However, analysis of volatiles can be a "daunting task, and obtaining useful information from such measurements can be even more challenging" (Marsili, 1997). In some fruit, starch is accumulated during maturation and converts to sugar during ripening. For these fruits, starch (or dry matter content, DM) at fruit maturity is a useful guide to fruit sugar content at ripeness and thus, to potential eating quality. In other fruit, other parameters are of importance (e.g. oil content of avocado fruit).

The importance of these various parameters will vary by fruit, but firmness, TSS and DM content are arguably the most important general criteria. TSS and DM are easily measured attributes and therefore, the logical criteria upon which to establish a quality control (QC) procedure.

Who enforces eating quality standards?

Historically, the advent of the central marketing system allowed imposition of a more formal (often government sponsored) regulatory system. For example, Smith (1988) reported that Queensland government inspectors attempted to enforce a minimum flesh TSS standard (of 12% for summer harvested fruit and 10% for winter harvested fruit), through random inspections of fruit in the Brisbane Central Market. Similarly, Greer (1990) detailed Queensland's then current legal requirement for lychee fruit, being a minimum TSS to acid ratio of 35:1. Fruit could be destroyed if they did not meet this grade. We have earlier discussed the advent in 1915 of the voluntary AMS grade standards in the US.

The emergence of "super" retailers, purchasing directly from producers, has worked to weaken the central market system and associated broad regulatory structures. For example, current Queensland Department of Primary Industries (QDPI) recommendations (Menzel et al., 2001) for these fruit exclude internal quality grade standards, and only describe external attributes. As noted earlier, however, supply chains driven by the large retailers have developed their own formalized quality control systems that extend to the setting of standards on eating quality criteria.

However, it is an observation that, except in Japan, retailers inconsistently, even rarely, enforce their internal quality specifications. Enforcement occurs only when a sufficiently large proportion of the consignment is affected by a disorder that would provoke severe consumer dissatisfaction (e.g. brown core in apples), or when the supply chain is oversupplied. In large measure this behavior can be ascribed to the relative difficulty of assessing fruit for internal attributes, and to the perceived lack of impact of these criteria on in-store consumer purchase patterns. In the following sections, specification criteria on a range of commodities are reviewed, and issues related to enforcement of such specifications are discussed.

Setting the eating quality standard

There exists a considerable body of published work on the relationship of fruit eating quality to measurable attributes such as TSS. This literature covers factors such as market differentiation (different grade standards for different market segments), and the influence of flesh firmness and acidity on perceived sweetness. However, it is possible to summarize this literature in terms of a minimum level for various attributes, by commodity, to achieve an acceptable eating quality (Table 9.2).

The human palate is able to differentiate between fruit varying by 1 to 2% TSS. To generalize, a TSS level of at least 10 is required for the fruit to taste sweet, but this value varies by commodity. As noted above, this value can also vary by consumer group (e.g. Cristoto, 1994; Cristoto et al., 2007).

The setting of official and product supply chain specifications on eating quality attributes should be informed by the scientific literature. For example, the specifications of a national body, the Australian United Fresh Fruit and Vegetable Association (AUF), and those of two international bodies, the Codex Alimentarius Commission and UNECE, show general agreement (Table 9.3). There is, however, room for greater consistency between these bodies. In particular, the Codex specifications need to be expanded, as they generally do not cover internal (eating) quality attributes.

A given distribution channel may also specify attributes associated with eating quality. Typically, such specifications are set by the retailers on advice from the supply chain manager, and by reference to the official standards. A typical product specification used in the horticultural trade covers a range of features. For example, a product specification from the retailer Woolworths for peach and nectarine covers size, pack count per box, firmness (as measured with an 8 mm diameter probe), sugar (percent TSS of extracted juice), pulp temperature, blemish incidence, skin color, skin shriveling, flesh color, split stones and foreign taints or odor. Of these 11 features, only two relate directly to internal eating quality (firmness and percent TSS).

The general level of agreement between specifications set on eating quality attributes by three major Australian retailers (Table 9.4) indicates that these retailers are not seeking differentiation on the basis of product eating quality.

Table 9.2 Examples of specifications on eating quality attributes, as recommended in the scientific literature. Attributes of dry matter (DM), juice content, total soluble solids (TSS), total acidity (TA), moisture content and firmness are reported. DM, juice content and TSS are minimum specifications, TA and firmness are maximum specifications. Units of DM, juice content, TSS, TA and firmness are %w/w, %w/w, %w/v of extracted juice, mg/L in extracted juice, and kg/f with an 8 mm diameter plunger, respectively, except were otherwise stated.

Fruit	Climacteric	Attribute	Level	Reference
Avocado	Yes	DM	21	Agrilink (2001)
		(at harvest) oil	8%FW	Seymour et al. (1993)
Banana	Yes	TSS	6.7–12.7 (unripe)	Choon and Choo (1972)
		fullness	23.0–31.0 (ripe)	Samson (1989)
		index	variable per cultivar	
Citrus	No	TSS: acid	8:1–10:1	Baldwin (1993)
		Limonin	≤6 ppm	Davies (1986)
(grapefruit)		TSS: acid	6:1	Kader (2002)
(mandarin)		TSS: acid	8:1	Kader (2002)
(orange)		TSS: acid	8:1	Kader (2002)
			10:1–16:1	Samson (1989)
			navels: 7.5:1–9.0:1	Davies (1986)
		juice content	50% FW	Samson (1989)
Grape – table	No	TSS	Ribier, Red malaga, Emperor 16; other 17	Weaver (1976)
		TSS: acid	Thompson seedless, Malaga, Ribier 25:1	Weaver (1976)
			Muscat, Emperor, Cornichon, O”hanez 30:1	Weaver (1976)
Kiwifruit	Yes	TSS	6.2	Given (1993)
		(at harvest)		
		TSS (ripe)	14	Kader (2002)
			15	Mitchell et al. (1991)
		TSS (for long-term storage)	7–9	Sale (1985)
		firmness	0.71	Cheah and Irving (1997)
		(8mm probe)		
Lychee	No	TSS: acid	35:1	Greer (1990)
			30:1–40:1	Underhill and Wong (1990)
		TA	4.4 cmoH^{+}/kg	Batten (1989)

Mango	Yes	TSS	15	Yamashita (2000)
			16	Satyan and Chaplin (1986)
			12	Samson (1989)
		DM (at harvest)	14	Bally et al. (2000)
		specific gravity	1.01–1.02	Samson (1989)
		firmness	1.75–2 kg/cm^2	Samson (1989)
Melon	Yes	TSS	10	Mutton et al. (1981)
		firmness (8 mm probe)	1–2	Mutton et al. (1981)
Papaya	Yes	TSS	11.5	Sankat and Maharaj (2001)
Pineapple	No	TSS	14	Smith (1988)
			12	Bartholomew (2003)
		TA	≤1.0%	Kader (2002)
		TSS:acid	20:1–40:1	Bartholomew (2003)
		TSS:citric acid	19:1	Bartholomew (2003)
		translucency	optimum 50–60% cross sectional area	Bowden (1969)
		specific gravity	0.960–1.004	Smith (1984)
Pome fruit	Yes			
(apple)		TSS	Jonathan 11; Delicious and Red Delicious 10	AHC (1999)
			12–14 (ripe)	Harker et al. (1997)
			Starking and Delicious 10.8–12.2	Truter and Hurndall (1988)
			high quality dessert 14–16, cooking 11–13, Delicious and Spartan: 9–11	Goodenough and Atkins (1981)
		TSS (storage)	Delicious 10; Bonza 13; Golden Delicious 12; Gala 12.5; Granny Smith 12; Fuji 13; Pink Lady 15; Sundowner 14.5; Lady Williams 14.5	AHC (1999)
		pH	high quality dessert 3.2–3.5, cooking 2.8–3.2, Delicious and Spartan 3.5–3.7	Goodenough and Atkins (1981)
		firmness	5.5 at sale, 6.5 storage	AHC (1999)
(pear)		TSS	12 (at optimal firmness, suitable TSS:acid ratio)	Harker et al. (1997)
			13	Kader (2002)
		firmness	highly liked at 0.6–1.5; optimum at sale 1.3–1.5	Harker et al. (1997)
		TSS:acid	2.85:1–3.31:1	Kappel et al. (1995)

(Continued)

Table 9.2 Continued

Fruit	Climacteric	Attribute	Level	Reference
Stone fruit	Yes			
(apricot)		TSS	10	Kader (2002)
		TA	0.8	Kader (2002)
(cherry)	No	TSS	14–16 depending on cv.	Kader (2002)
(nectarine)		TSS	10	Brady (1993)
			11	McGlasson (2001)
		TA	0.6	Kader (2002)
		firmness	0.9–1.4	Crisosto (1994)
(peach)		TSS	10	Brady (1993)
			11	McGlasson (2001)
		TA	0.6	Kader (2002)
		firmness	0.9–1.4	Crisosto (1994)
(plum)		TSS	11	McGlasson (2001)
			12	Kader (2002)
		internal breakdown/TSS	amber jewel 17% TSS for less internal breakdown	Ward and Melvin-Carter (2001)
		TA	0.8	Kader (2002)
		firmness	0.9–1.4	Crisosto (1994)
Strawberry	No	TSS	7	Kader (2002)
		TA (citric)	0.8	Kader (2002)
Tomato	Yes	moisture content	> 94%w/w	Hobson and Davies (1971)
		firmness	1.0–1.5	Kader and Morris (1976)

Agrilink (2001). Avocado Information Kit. Department of Primary Industries, Queensland Nambour.
Australian Horticultural Corporation (1999). Guide to quality management – Apples. Australian Horticultural Corporation, Sydney.
Baldwin, E.A. (1993). Citrus fruit. In: Biochemistry of Fruit Ripening, G.B. Seymour, G. Tucker (eds.). Chapman and Hall, London, pp. 107–149.
Bally, I.S.E. et al. (2000). Mango production in Australia. Acta Horticulturae, 509, 59–67.
Bartholomew, D.P. (2003). The pineapple, botany, production and uses. Cabi Publishing, New York.
Batten, D.J. (1989). Maturity criteria for litchs (lychees). Food Quality and Preference 1, 149–155.
Bowden, R.P. (1969). Further studies on ripeness in pineapples. Food Technology in Australia, 21, 160–163.
Brady, C.J. (1993). Stone Fruit. In: Biochemistry of fruit ripening, G.B. Seymour, G.A. Tucker (eds). Chapman and Hall, London.

Cheah, L.H., Irving, D.E. (1997). Kiwifruit. In: Postharvest physiology and storage of tropical and subtropical fruit, S.K. Mitra (ed.). Cab International, New York.
Choon, S.C., Choo, C.G. (1972). Comparative evaluations of some quality aspects of banana (Musa acuminata (Colla)) I. Flavour, sources and sweetness. Malaysian Journal of Agricultural Research, 1, 54–59.
Crisosto, C.H. (1994). Stone fruit maturity indices: a description review. Postharvest News and Information, 5, 65–68.
Davies, F.S. (1986). The naval orange. Horticultural Reviews, 8, 129–180.
Given, N.K. (1993). Kiwifruit. In: Biochemistry of Fruit Ripening, G.B. Seymour, G.A. Tucker (eds). Chapman and Hall, London.
Goodenough, P.W., Atkin, P.K. (1981). Quality in stored and processed vegetables and fruits. Academic Press, New York.
Greer, N. (1990). Growing lychee in South Queensland. Queensland Department of Primary Industries, Brisbane.
Harker, F.R. et al. (1997). Texture of fresh fruit. Horticultural Reviews, 20, 121–223.
Hobson, G.E., Davies, J.N. (1971). The tomato. In: The Biochemistry of Fruits and their Products, A.C. Hulme (ed.), Vol. 2. Academic Press, London, pp. 347–482.
Kader, A.A. (2002). Standardisation and inspection of fresh fruits and vegetables. In: Postharvest Technology of Horticultural Crops, A.A. Kader (ed.). University of California, Oakland, pp. 287–299.
Kader, A.A., Morris, L.L. (1976). Tomato firmness as a quality attribute. Proceedings of the second tomato quality workshop. University of California, Davis, CA.
Kappel, F. et al. (1995). Ideal pear sensory attributes and fruit characteristics. Hort Science, 30, 988–993.
McGlasson, B. (2001). Editorial. Australian Fresh Stone Fruit Quarterly, 3, 2.
Mitchell, F.G. et al. (1991). Effect of harvest maturity on storage performance of "Hayward" Kiwifruit. Proceedings of the 2nd International Symposium on Kiwifruit, I.J. Warrington et al. (eds),Vol. 297, pp. 617–625.
Mutton, L.L. et al. (1981). The objective definition of eating quality in rockmelons (*Cucumis melo*). Journal of the Science of Food and Agriculture, 32, 385–390.
Sale, P.R. (1985). In: Kiwifruit Culture, D.A. Williams (ed.). New Zealand Government Printer, Wellington, N.Z.
Samson, J.A. (1989). Tropical Fruits. Longman Scientific and Technical, Singapore.
Sankat, C. K., Maharaj, R., Papaya. In: Postharvest Physiology and Storage of Tropical and Subtropical Fruits, S.K. Mitra (ed.). CAB International, New York, pp. 167–189.
Satyan, S.H., Chaplin, A. (1986). An assessment of fruit quality of various mango cultivars. Proceedings of the First Australian Mango Research Workshop, Cairns, Queensland, pp. 324–333.
Seymour, G.B., Tucker, G.A. (1993). Avocado. In: Biochemistry of fruit ripening, G.J. Seymour et al. (eds). Chapman and Hall, London, pp. 53–81.
Smith, L.G. (1984). Pineapple specific gravity as an index of eating quality. Trop. Agric. (Trinidad), 61, 196–199.
Smith, L.G. (1988). Indices of physiological maturity and eating quality in smooth cayenne pineapples. 1. Indices of physiological maturity. Queensland Journal of Agricultural and Animal Sciences, 45, 213–218.
Truter, A.B., Hurndall, R.F. (1988). New findings on determining maturity of "Starking," "Tropical" and "Starkrimson" apples. Deciduous Fruit Grower, 38, 26–29.
Underhill, S.J.R., Wong, L.S. (1990). A maturity standard for lychee (*Litchi Chinensis* Sonn.). Proceedings of the Symposium on Tropical Fruit in International Trade, R.E. Paull (ed.), Vol. 269, pp. 181–187.
Ward, G., Melvin-Carter, E. (2001). Strategies to rescue losses from internal breakdown in plums – project SF00024. Horticulture Australia Limited, Sydney.
Weaver, J.R. (1976). Grape growing. John Wiley & Sons, New York.
Yamashita, K. (2000). Mango production in Japan. Acta Horticulturae, 509, 79–85.

Table 9.3 Official grade standards on eating quality. Attributes and units as for Table 9.2. Where a single value is presented, only two grades exist (unacceptable/acceptable). Where further values are presented, a number of grades are possible.

Fruit	Attribute	UNECE/OECD	Codex	AUF (1996)	US (California)
Avocado	DM at harvest	Hass 21 other 19	–	<21; 21–23; >23	≥18.4–21.9 depending on cv.
Banana	–	–	–	–	–
Citrus					
(grapefruit)	juice content	–	35	–	–
(lemon)	juice content	25	–	30	≥28–30 depending on cv.
(lime)	juice content	–	42	–	–
(mandarin)	TSS	–	–	8	–
	TSS:acid	–	–	8:1	6.5:1
	juice content	33	–	28	–
(orange)	TSS	–	–	7–9; 10–11; >11	–
	TSS:acid	Israeli market: pigmented 5.5:1 other 6:1; European market 6.5:1	–	Navel 8:1; other 8.1; 8:1–10.1; >10:1	8:1
	juice content	Israeli market: Navel ≥30 other ≥35; European market: ≥38	navel ≥33 other ≥35	Navel ≥30; other ≥33	–
Custard apple	–	–	–	–	–
Grape – table	TSS	–	–	–	14.0–17.5 depending on cv.
(seedless)	TSS	14	–	≤14; 15–16; 17; ≥18	
(seedless)	TSS:acid	–	–		≥20:1
(seeded)	TSS	13 (12 some cv.)	–	≤14; 15–16; 18; >18	
Kiwifruit	TSS (at harvest)	6.2	–	6	6.5
	firmness	–	–	1.0; 1.5; 2.0; 2.5	–
Lychee	–	–	–	–	–
Mango	DM	–	–	14	–

(Continued)

Table 9.3 Continued

Fruit	Attribute	UNECE/OECD	Codex	AUF (1996)	US (California)
Melon	TSS	10 Charentais; 8 other	–	honeydew	cantaloupe
				≤10; 10–12; >12	>8.0, >9.0
				rockmelon ≤9; 9–12; >12	honeydew 10
Papaya	–	–	–	–	–
Pineapple	TSS	12	12	<10; < 12; >12	–
Pome fruit (apple)	TSS	–	–	fruit for storage ≤10; 11; 12; ≥13	Jonathan 12
		–	–	immediate sale <10; 10; 11; ≥12	Red Delicious 11.0
	firmness	–	–	fruit for storage ≤5.5; 6.0; ≥6.5	Jonathan 8.6
				immediate sale ≤5.5; 6.0; ≥6.5	Red Delicious 8.2
(pear)	TSS	–	–	–	13
	firmness	–	–	–	10.4
Stone fruit (cherry)	TSS	–	–	–	≥14–16 dep cv.
Strawberry	–	–	–	–	–
Tomato	–	–	–	–	–

Sources: UNECE www.unece.org/trade/agr/standard/fresh/fresh_e.htm
Codex www.codexalimentarius.net
AUF Story, A., Martyine, A. (1996). AUF National Product Description Language. The Australian United Fresh fruit and Vegetable Association, Flemington Market, Australia.

Examples of eating quality standards

In the following section, specifications related to eating quality standards are considered for two widely traded commodities, apple and stone fruit, in terms of the scientific literature, intergovernmental and NGO standards, and retailer specifications.

Pome fruit: apple

It is generally accepted that fruit TA, TSS and firmness of flesh are important eating quality factors for apples (e.g. Chen and De Baerdemaeker, 1993; Yahia, 1994; Harker, 2001; Harker et al., 2003). Malic acid is responsible for the sour and acid taste in apple (Yahia, 1994). Harker (2001) reported on a close relationship between total acidity (TA) and acid taste in apples, although the relationship between TA and consumer acceptability was cultivar specific.

Table 9.4 Specifications on eating quality attributes of fresh fruit, except apple, as set by three Australian retailers (in 2004). Attributes and units as for Table 9.2.

Fruit	Attribute	Australia i.	Australia ii.	Australia iii.
Avocado	DM	Hass 22–26; Shepard 23	21–35	–
	firmness	–	–	–
Banana	dry matter	–	–	–
	TSS	–	–	–
Blueberry	TSS	–	10	–
Citrus				–
(grape fruit)	TSS	9	9	–
	TSS:acid	–	4.8:1	–
	juice content	35	33	–
(lemon)	juice content	30	10	–
(lime)	juice content	20	10	–
(mandarin)	TSS	Ellendale 8; Honey Murcott, Imperial 10	9	10
	TSS:acid	Ellendales 7:1, Honey Murcott, Imperial 10:1	8:1; Clementine 7:1	–
	juice content	33	33	–
(orange)	TSS	Navel 11; Valencia 7	9	10
	TSS:acid	Navel 8:1; Valencia 7.5:1	8:1; Valencia 7:1	–
	juice content	33	33; Navelina, Sevile 25	–
Custard apple	–	–	–	–
Grape – table	TSS	16; Thompson 18; Sweet White seedless 15; Muscatel White 20	16; Calmenia, Red Gum, Ribier 15; Cardmal, Italia, Marro seedless 17	15
	TSS:acid	Seedless: Sweet White 20:1; Crimson, Thompson 19:1; Stanley, Flame 18:1	18:1; Thompson 19:1	–

Sweetness in apples is related to sucrose, glucose and fructose content, with 50% of the sugar present being fructose (Yahia, 1994). Eating quality specifications are typically set in terms of TSS of extracted juice. For example, Goodenough and Atkin (1981) recommend that high-quality dessert apples should have a high TSS (14–16%) relative to Delicious and Spartan cultivars (9–11%). Harker (2001), however, contends that, while TSS is a good sweetness indicator for juices and other fruits, it is not for apple fruit. This contention is based on sensory research in which the relationship between perceived sweetness and TSS was poorer than the relationships between perceived texture and puncture force or perceived acid taste and TA, in apples. This result is suggested to be due to the level of flavor volatiles that alter the perception of sweetness. Nonetheless, apple TSS is widely specified in both official (Table 9.3) and supply chain (Table 9.5) standards, with more differentiation by cultivar than is seen

Table 9.5 Specifications on eating quality attributes for apple fruit as set by three Australian retailers (in 2004). Attributes and units as for Table 9.2. Retailer ii specified standards for some fruits in terms of in season consumption and for entry to controlled atmosphere storage (with latter values in parenthesis). Retailer iii specified standards by harvest period, February to August and September to January (with latter values in parenthesis). Sources include http://www.supplier.coles.com.au/quality_control/specifications.asp (Accessed 26 October 2007) and http:///www.woolworths.com.au/Vendors/qualityassurance/FreshFoodSpec

Retailer	TSS			Firmness		
	i	ii in season (CA)	iii	i	ii in season (CA)	iii Feb–Aug (Sept–Jan)
Apple						
Abas	–	13	–	–	5.8–6.0	–
Akane	11.5	13	–	5.6	5.8–6.0	–
Bonza	12.6	12	12	5.6	5.3–5.5	5.5 (5)
Braeburn	14	15	11.5	6.5	5.8–6.0	6 (5)
Cameo	12	12	–	–	6.8	–
Cox Orange	–	14	–	–	5.8–6.0	–
Crofton	–	14	–	–	5.8–5.8	–
Firmgold	–	12.8	–	–	5.8–6.0	–
Fuji	13	14	13	5.6	5.6–5.8	6 (5)
Golden	12.5	–	12	5.5	–	6 (5)
Golden delicious	–	12.8	–	–	5.8–6.0	–
Granny Smith	–	11	12.5	–	6.3–6.5	6.5 (5.5)
Gravensten	–	12	–	–	5.8–6.0	–
Johnagold	13.6	14	13	6	5.8–6.0	6 (5)
Jonathan	12.6	11.5	13	5.6	5.6–5.8	6 (5)
Lady William	14	12.5	14.5	6.5	6.2–6.4	6.5 (6)
Matsu	–	11	–	–	6.8–7.0	–
Pink Lady	14	13.5	14	6.3	5.8–6.0	6 (5)
Red Delicious	12	12	10	6	5.8–6.0	6.5 (6)
Royal Gala	12.6	12	12	6.5	5.8–6.0	6 (5)
Stark Blushing Gold	–	12	–	–	5.8–6.0	–
Sundowner	13	12.8	14.5	6.5	5.9–6.1	6 (5.5)
Toffee Apple	–	11	–	–	–	–
Pear						
Buerre Bosc	13	11 (12)	–	6.3–8.0	6.0–9.0 (4.0–8.0)	–
Packham	11	–	–	6.0–8.0	–	–
Packham Ripe and Ready	13	12	–	4.0–4.5	4.0–6.0 (3.0–5.0)	–
Red Sensation	11.5	–	–	6.0–8.0	–	–
Sensation	–	11	–	–	5.0–9.0 (4.5–8.0)	–
Sirrera	–	12	–	–	8.0–10.0 (5.0–10.0)	–
Sophia Pride	–	11 (12)	–	–	6.0–9.0 (4.0–8.0)	–
William	11	–	–	6.3–9.0	–	–
Ya	9	–	–	6.0–8.0	–	–
other	–	11 (12)	–	–	6.0–9.0 (4.0–8.0)	–

for any other commodity. The minimum suggested TSS for apples ranges between 12–14% (Tables 9.2–9.5).

Apple crispness and juiciness are key attributes in determining consumer preferences. Harker et al. (2002) report that penetrometer measurements are good predictors of such textural perceptions. Further, Harker et al. (2002) report that apples with a firmness level <5.0 kgf (11 mm diameter probe) are more susceptible to the development of the mealiness (texture) disorder, while fruit with a firmness value greater than 7 kgf are effectively free of the disorder.

The Australian Horticultural Corporation (Table 9.3) recommends different flesh firmness and TSS levels depending on cultivar and whether the fruit is at point-of-sale or intended for long-term controlled atmosphere storage. For example, flesh firmness (measured using an 11 mm diameter plunger) of no less than 6.5 kgf was recommended for apples for long-term storage, and less than 5.5 kgf for fruit at the point of sale. A Californian standard on Jonathan and Red Delicious apples sets a minimum TSS of 12% and 11%, respectively, and a maximum firmness of 8.6 and 8.2 kgf, respectively.

No specifications are set on apple eating quality related attributes in the UNECE or Codex guidelines. Arguably, these guidelines should contain such information, at least in the specification of premium grade fruit.

In contrast, Australian retail stores specify internal quality standards for over 20 cultivars of apples (Table 9.5). These specifications varied slightly between retail chains. For example, the minimum TSS standard required for Akane apples is 11.5% with one retailer and 13% with another retailer (Table 9.5). However, in practice, there is no evidence that the retailers are attempting to differentiate their standard product on the basis of eating quality.

Stone fruit: peaches, nectarines and plums

The eating quality of peaches, nectarines and plums is usually described in terms of flesh texture and firmness, TSS and acidity. Sucrose is the dominant sugar in peach, nectarine and plum fruit (Lill et al., 1989), and accounts for at least 80% of total sugars (Kawano et al., 1989). The predominant organic acid in peaches and nectarines is malic acid (Lill et al., 1989).

Lill et al. (1989) suggested that flesh firmness, in conjunction with background color, was a reliable indicator of the picking maturity for peaches and nectarines, with a firmness of 5–7 kgf (11 mm plunger) recommended. Further, Crisosto (1994) reported that for peach, nectarine and plum, flesh firmness was a useful indicator of postharvest ripening. Peaches with a firmness rating of 2.7–3.6 kgf were “ready to buy,” and “ready to eat” at a flesh firmness of 0.9–1.4 kgf.

As a specification on eating quality, McGlasson (2001) recommended a minimum of 11% TSS for peach, nectarine and plum fruit produced in Australia, whilst Kader (2002) suggested a minimum TSS of 10% for apricot and peach, 14–16% (depending on cultivar) for cherry, and 12% for plum fruit. As noted earlier Crisosto et al. (2007) has further differentiated consumer groups in terms of preferred TSS levels.

The commercial release of low acid lines of fruit, complementing the traditional high acid varieties, represents a comment on consumer sweetness preference, as much as a preference for low acidity. For fruit of a given TSS level, a lower acidity level increases the perceived sweetness.

Internal breakdown is a physiological disorder of stone fruit that negatively impacts eating quality. The disorder results from the abnormal ripening and early senescence of the fruit, with symptoms usually occurring during cold storage or during ripening after cold storage. Ward and Melvin-Carter (2001) reported that symptoms in plums appear as internal browning and gel breakdown. They found that for Amber Jewel plums, incidence of internal breakdown was minimized if the fruit were packed and appropriately cooled on the day of harvest. Additionally, fruit with TSS ≥17% had a significantly reduced risk of developing internal breakdown symptoms.

UNECE stone fruit specifications (Table 9.3) are subjective, e.g. "they must be sufficiently developed and display satisfactory ripeness," and have not adopted any quantitative standards for internal eating quality factors. Similarly, Codex and AUF maturity grades are based on firmness descriptors ("hard," "firm," etc.), with infrequent mention of internal quantitative measures or recommendations (Table 9.3). Thus, comprehensive official specifications on eating quality do not exist, as yet.

Of the retailers surveyed, one retailer provided comprehensive TSS and firmness standards compared to the other retailers, differentiating between cultivars differing in flesh color (Table 9.4). For example, the minimum TSS recommended for yellow flesh (10% TSS) nectarines was lower than that for white flesh (12% TSS) varieties, while the firmness standard of 5.2 kgf was common across all varieties. A second retailer gave only an "all-variety" minimum TSS of 10% and a firmness of 4 kgf, while a third retailer did not specify for TSS in stone fruit (Table 9.4). Of two European retailers surveyed (data not shown), one held a minimum standard of 9% TSS and firmness of 1.4–3.5 kgf for nectarines, while the second provided TSS grades for plums based on color (black plum: 12% TSS and 1.8–3.6 kgf; red: 10% TSS and 1.4–2.3 kgf; yellow: 14% TSS and 1.0–1.8 kgf).

Will it happen?

For two widely-traded commodities, apple and stone fruit, it is evident that specifications on eating quality are inconsistent. Further, even where such specifications exist within a supply chain, enforcement is uncertain. Thus, these specifications are not standards. This conclusion is consistent with that of Florkowski (1999) who noted that "intrinsic quality attributes are not reflected in grading systems and are excluded from fresh produce standards," and continues "(t)his gap leaves a place for government as a monitoring, regulatory or even enforcing agency."

In the last decade, a range of non-invasive technologies have become available for assessing the internal quality of fruit and vegetables (e.g. see review by Abbott et al., 1997). For example, fruit firmness can be assessed using technology based on accelerometers, acoustic frequency or acoustic velocity. Ripeness can be assessed using electronic noses or volatile "badges." Chlorophyll florescence can be used for assessment of maturity. X-ray transmission systems can be used to visualize density-related internal defects and near-infrared spectroscopy is available for assessment of carbohydrate or water content. With the advent of these technologies, there exists an opportunity to refine, adopt and enforce specifications related to eating quality.

IX. A case study: technology adoption and regulation of fruit TSS

Fruit has been traditionally graded by hand and eye on size or weight, color and defects. As supply chains set standards based on these criteria, there was incentive to develop suitable technology to mechanize the sorting process. Simple diverging belt graders allowed sorting on size, and mechanical counterweight tipping bucket graders allowed sorting by weight. With the advent of electronic grading platforms, weight grading using electronic load cells increased in accuracy. The addition of video cameras to the electronic grading platforms allowed for grading on fruit color (1970s), and later (1980s) allowed for defect detection using image classification routines.

However, as we have reviewed above, fruit eating quality is determined by other attributes. For many fruit commodities, texture and sweetness are particularly relevant. To a scientist or engineer the “problem” is thus obvious, that fruit eating quality is variable, that fruit firmness and sugar levels are a major factor in eating quality for many fruit commodities, and therefore the solution is to adopt technologies that allow for fruit grading on these attributes. It might therefore, be expected that technologies to non-invasively grade fruit firmness and sweetness would be rapidly adopted, given the link between these attributes and eating quality and the existence of criteria on these attributes in many retail specifications. Indeed, fruit firmness and sweetness grading technologies became available from the 1990s onwards but, except for Japan, have not been widely adopted.

The question of what is limiting technology adoption must be considered using a systems approach. Such an approach aids the identification of critical steps in a system and provides a tool for the integration of specific knowledge into a system (Prussia and Shewfelt, 1992).

Our research group has been involved in developing the sweetness grading technology for western agricultural conditions (lower cost, higher pack line speeds) (e.g. Subedi et al., 2007; Walsh et al., 2006). Our experience with the adoption of this technology informs the following discussion.

Sweetness grading (near-infrared spectroscopy) technology has been in extensive use in other industries, notably the cereal, sugar and dairy industries, since the 1970s. Thus, although the technology was not mature in the horticultural application, intending horticultural participants had access to technical advisors from both industry and government sectors.

In Japan, marketing of a high value “gift” line of fruit of excellent external appearance and internal quality provided an existing business model/supply chain to implement the new technology in. Sweetness grading technology was first developed (1989) out of mining/processing groups (Mistui Mining, Sumitomo Metals and Mining), and quasi-government R&D groups (Fantec), and later other groups (Eminet). These groups supplied sensors to the Japanese fruit grading equipment manufacturers. Within little more than a decade, the packing house market in Japan was saturated with this technology.

However, the available (Japanese) technology was very expensive and geared for a different market, in which speed of assessment was not as important. Further, the technical issue of compatibility of this technology with existing on-farm pack line equipment could not be resolved simply. By 2000, Colour Vision Systems (CVS) of Australia, Compac of New Zealand and Unitec of Italy offered sweetness grading technology outside of Japan. Later, by the mid-naughties, technology would become available through the major European manufacturers of fruit grading equipment (Greefa and Aweta of Holland, and MAF-Roda of France–Spain, through CVS).

Thus, the availability of the technology was not a limiting factor to its adoption. However, the cost (approximately $US30 000 per lane) and relative complexity of the technology were limiting factors, requiring adoption by a supply chain geared to achieve marketing benefits from the “guaranteed sweet” technology.

In 1999–2000, an Australian product supply manager interested in the technology commissioned focus groups with consumers (R. Gray, OneHarvest P/L, personal communication). Fruit with large “flavor gaps” (disparity between consumer taste expectation and actual experience) were identified, and the literature searched for major determinants of taste in those commodities. Commodities such as melons (all seasons), stone fruit (early season) and mangoes were identified as candidates for the sweetness grading technology. In 2000, the Australian supply chain manager negotiated exclusive access to one brand of sweetness grading equipment.

The supply chain manager then sought to contract melon and stone fruit growers to supply fruit, with growers located over a spread of geographic areas to provide constancy and security of supply. As incentive, packing houses were initially offered the technology free of charge, and growers were offered a guaranteed (above average market) price for sweet product, with the grower–packing house marketing remaining fruit through normal channels. It proved difficult, however, to attract established growers with established marketing arrangements. More success was had with the annual crop (melon) than the perennial crop (stone fruit), attracting growers that had not previously grown this crop. Further, growers typically believed they grew consistently sweet fruit. In practice, it was soon evident that pack-out rates on sweet produce were far lower than anticipated. Further, this pack-out rate was variable week-to-week (e.g. Long et al., 2004; Golic and Walsh, 2005). In an attempt to address this issue, an R&D program was implemented on agronomic practices and on choice of varieties to maximize melon sweetness.

Installation of the technology into existing pack lines was not as simple as bolting a unit above the pack line. Existing pack line electronics had to be compatible to the technology. The technology was also disruptive of packing house operations. For example, with grading to a sweetness standard, pack line sorting to five size standards would require ten pack-out points. Five pallet lines in the cold room would become ten. Further complications arose in that the sweet fruit were largely more mature fruit, and ripened at a different rate to the below TSS standard fruit.

The product supply manager introduced the technology supported sweetness guaranteed program to a major retailer, and negotiated a price premium for fruit above the retailer's specification level on TSS. However, while the retailer allowed in-store labeling of fruit in the first year of marketing, no labeling was allowed in the second year. With the fruit being offered at a higher price than standard grade fruit, this policy was obviously detrimental to sales. From the third year, the retailer required labeling of the fruit with their own quality label, a label applied to a number of lines considered to be of higher eating quality (e.g. a low acid pineapple variety).

Consumer purchasing was disrupted during the year in which in-store labeling was not permitted. In effect, the consumers could not find the fruit. In other seasons, consumer purchasing patterns were disrupted by periods of non-supply. While this was done with the best of intentions, to maintain a standard, the inconsistent supply resulted in a loss of product identity with the consumer. Further, the reallocation of produce display space during periods of non-supply was difficult to recover.

Thus, the sweetness grading technology was a great technological solution – to a problem that the supply chain did not value. Specific points in the supply chain recognized that consumer perception of eating quality should be an issue, and that TSS is a major determinant of eating quality in some commodities, but the supply chain as a whole did not value the concept, the cost of implementation was not shared, and the reward was not realized. In conclusion, use of this technology can be expected to be sporadic until such time as retailer specifications are enforced.

In contrast, the technology was adopted in Japan to support an existing market for quality "gift" fruit. In this market, the premium paid for sweet fruit is sufficient to cover the cost of the technology and to reward growers for the agronomic effort (and loss of yield) incurred in producing sweeter fruit. This "gift fruit" business model/supply chain did not exist in non-Japanese markets, and the sweetness grading technology has had limited adoption.

The technology has subsequently been adopted by other supply chains as a tool to reward growers, rather than as a tool to enforce a standard to "protect" consumers. Growers are rewarded for fruit above a specified TSS level, and penalized for fruit below this level. This creates a known incentive to support agronomic and varietal selection that results in elevated fruit TSS.

X. Regulatory issues for the future?

Common standards facilitate international trade and improve transparency to consumers. Convergence of heavy metal, chemical residue and microbiological (phytosanitary) standards has been driven by national and intergovernmental agencies such as UNECE and the OECD, with the Codex Alimentarius emerging as a global minimum standard. Common processes to deal with quarantine issues have developed under the WTO. These trends are expected to continue, with further intertwining of the UNECE, OECD and Codex standards, and increased adoption by Asian and African countries as a tool to increase export trade. Similarly, consolidation and increased adoption of the organic standards is to be expected. For example, the IFOAM organic specifications can be further mainstreamed into Codex.

This prediction is somewhat at odds with the CACs view of its own activity (http://www.fao.org/docrep/w9114e/w9114e00.htm Accessed 12 December 2007). The CAC reports that its consumer protection elements are gaining in importance, while the "compositional" or quality elements of individual commodity standards do not attract as much attention. It is noted, however, that future direction depends on community attitudes and demands.

The interpretation of standards is indispensable to application in practice, and so the availability of explanatory brochures on standards and inspection guidelines is important. Organizations like OECD and AMS can be expected to continue to inform Codex.

However, standards need to be enforced, and thus there is a need for certifying bodies. The organic movement developed through the efforts of many industry associations, leaving a legacy of many private certifying agencies. It is likely that there will be a trend in some areas to develop a national certifying agency. Official standards on food safety criteria exist, but enforcement is often ad hoc. This gap may be filled by either a government or private certifier. Given the current focus on China with respect to food safety, developments within China and within countries importing produce from China will be interesting to watch.

With the continued rise of the global retailers and global production groups, it is to be expected that private sector regulation will increase, to match consumer demand and to insure against official (government imposed) regulation. For example, the GAP program is on track to become a generic certifying body. Thus the large retailers, working through their category managers, will continue to develop as setters and enforcers of standards.

In the decades to come, new social drivers will emerge, with related regulatory pressures. The issues of an ageing population and of an increasingly sedentary lifestyle and poor diet are probable drivers. The "Two-and-Five" fruit and vegetable consumption campaigns are standard bearers in this area. The use of nutritionally and functionally enhanced fruit and vegetables will rise, e.g. the Gates Foundation has funded research into vitamin enhanced bananas for Uganda. Issues related to "food miles" or carbon cost of production will become regulated. With increasing population and increased industrialization and urbanization, competition for water increases. Some markets might require labeling for the use of recycled sewage water in irrigation. Water use efficiency may well become a point of differentiation, perhaps with fruit labeled with a water efficiency star rating (based on ML/tonne). Thus the regulatory environment of the next decade is likely to be quite different than that outlined in this chapter.

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Key words

Agricultural Marketing Service, certification, Codex Alimentarius, eating quality, fair trading, firmness, food safety, food miles, fresh fruit and vegetables. GlobalGAP, HACAAP, near-infrared spectroscopy, organic, product description language, quarantine, regulation, Total Soluble Solids, specification, standards, supply chain, UNECE, WTO.

References

Abbott, J.A., Lu, R.F., Upchurch, B.L., Stroshine, R.L. (1997). Technologies for non-destructive quality evaluation of fruits and vegetables. In: Horticultural Reviews, J. Janick (ed.), Vol. 20. John Wiley & Sons Inc., Canada, pp. 1–119.

Agricultural Marketing Service – USDA (2007a). Fruit and Vegetable Programs – History and Scope. http://www.ams.usda.gov/fv/fvhist.htm Accessed 18 September 2007.

Agricultural Marketing Service – USDA (2007b). Fruit and Vegetable Programs, Fresh product grading and quality certification: Program Overview and Inspection Fees. www.ams.usda.gov/fv/fpboverview.htm Accessed 26 October 2007.

Asia Fruit Magazine (2007a). News – Zespri profit falls as loyalty payout increases. Asia Fruit Magazine, July–August, 12.

Asia Fruit Magazine (2007b). Asia Fruit Magazine, July–August, 1–176.

Asia Fruit Magazine (2007c). Fresh Bites. Asia Fruit Magazine, July–August, 12.

Asia Fruit Magazine (2007d). News – EU delegation pressures China over trade tariffs. Asia Fruit Magazine, July–August, 10.

Asia Fruit Magazine (2007e). Retail. Asia Fruit Magazine, July–August, 17.

Australian Government – Department of Foreign Affairs and Trade (2007). Australia–United States Free Trade Agreement Chapter Three – Agriculture. http://www.dfat.gov.au/trade/negotiations/us_fta/final-text/chapter_3.html Accessed 1 November 2007.

Australian Quarantine Inspection Service (2007a). About AQIS. http://www.daffa.gov.au/aqis/about Accessed 22 November 2007.

Australian Quarantine Inspection Service (2007b). Industry Advice Notice no. 2004/12: Detection of Citrus Canker in Queensland. http://www.daff.gov.au/aqis/export/plants-grains-hort/ian/04/12 Accessed 22 November 2007.

Baker, J. (2007). Australian imports enjoy healthy growth. Asia Fruit Magazine, July–August, 81.

Balmer, B. (2007). New quarantine laws threaten to hinder market access. Asia Fruit Magazine, July–August, 50.

Bell, B., Elliott, R.E.W.E. (1993). Aspects of New Zealand's experience in agricultural reform since 1984. http://www.maf.govt.nz/mafnet/rural-nz/profitability-and-economics/structural-change/reform-of-nz-agriculture/httoc.htm Accessed 24 November 2007.

Chen, H., De Baerdemaeker, J. (1993). Effect of apple shape on acoustic measurements of firmness. Journal of Agricultural Engineering Research, 56, 253–266.

Codex Alimentarius Commission (2007a). Welcome. www.codexalimentarius.net Accessed 19 November 2007.

Codex Alimentarius Commission (2007b). Strategic Framework 2003–2007: Strategic objectives and priorities. http://www.fao.org/DOCREP/004/Y2361e/y2361e03.htm#TopOfPage Accessed 19 November 2007.

Collen, C. (2007). Mounting food safety scares spur organic demand in China. Asia Fruit Magazine, July–August, 120.

Crisosto, C.H. (1994). Stone fruit maturity indices: a description review. Postharvest News and Information, 5, 65–68.

Crisosto, C.H., Crisosto, G.M., Echeverria, G., Puy, J. (2007). Segregation of plum and pluot cultivars according to their organoleptic characteristics. Postharvest Biology and Technology, 44, 271–276.

European Commission – Agriculture and Rural Development (2007). Quality products catch the eye: PDO, PGI and TSG. http://ec.europa.eu/agriculture/foodqual/quali1_en.htm Accessed 20 October 2007.

Fellars, P.J. (1985). Citrus: Sensory Quality as Related to Rootstock, Cultivar, Maturity and Season. In: Evaluation of Quality of Fruits and Vegetables, H.E. Pattee (ed.), AVI Publishing, Westport, CT, USA.

Florkowski, W.J. (1999). Economics of Quality. In: Fruit and Vegetable Quality: An Integrated Approach, R.L. Shewfelt, B. Bruckner (eds). Technomic Publishing Co. Inc., Lancaster, PA, USA.

Food Standards Australia New Zealand (2007). Welcome to Food Standards Australia New Zealand. http://www.foodstandards.gov.au/ Accessed 17 September 2007.

Golic, M., Walsh, K.B. (2005). Robustness of calibration models based on near infrared spectroscopy to the in-line grading of stone fruit for total soluble solids. Analytica Chimica Acta, 555, 286–291.

Good Fruit and Vegetables (2007). Freshness system wins award. Good Fruit and Vegetables, 17, 5.

Goodenough, P.W., Atkin, P.K. (1981). Quality in-stored and processed vegetables and fruits. Academic Press, New York, NY, USA.

Greer, N. (1990). Growing lychee in South Queensland. Queensland Department of Primary Industries, Brisbane, Australia.

Growcom (2007). About Us. http://www.growcom.com.au/home/inner.asp?pageID=32 Accessed 26 October 2007.

HACCP Australia (2007). HACCP based food safety programs and endorsements. http://www.haccp.com.au/ Accessed 11 November 2007.

Harker, F. R. (2001). Consumer responses to apples. Washington Fruit Trees Postharvest Conference. March 13–14. Wenatchee, WA, USA.

Harker, F.R., Gunson, F.A., Brookfield, P.L., White, A. (2002). An apple a day: the influence of memory on consumer judgement and quality. Food Quality and Preference, 13, 173–179.

Harker, F.R., Gunson, F.A., Jaeger, S.R. (2003). The case for fruit quality: an interpretative review of consumer attitudes and preferences for apples. Postharvest Biology and Technology, 28, 333–347.

Hey, J. (2007). Thailand – Thailand develops globally recognized system. Asia Fruit Magazine, July–August, 30–34.

Horticulture Media Advisor (2007). Horticulture Media Advisor http://www.hortcodema.com.au Accessed 19 November 2007.

Jen, J.J. (ed.) (1989). Quality Factors of Fruit and Vegetables. American Chemical Society, Washington, DC, USA.

Kader, A.A. (2002). Standardisation and inspection of fresh fruits and vegetables. In: Postharvest Technology of Horticultural Crops, A.A. Kader (ed.). University of California, Oakland, CA, USA, pp. 287–299.

Lill, R.E., O'Donoughue, E.M., King, G.A. (1989). Postharvest physiology of peaches and nectarines. Horticultural Reviews, 11, 413–452.

Lockie, S., Lyons, K., Lawrence, G., Halpin, D. (2006). Going Organic. Mobilizing Networks for Environmentally Responsible food Production. CABI, Cambridge, MA, USA.

Long, R., Walsh, K., Rogers, G., Midmore, D. (2004). Source-sink manipulation to increase melon (*Cucumis melo* L.) fruit biomass and soluble sugar content. Australian Journal of Agricultural Research, 55, 1241–1251.

Marsili, R. (1997). Techniques for analyzing food aroma. Marcel Dekker, New York, NY, USA.

McGlasson, B. (2001). Editorial. Australian Fresh Stone Fruit Quarterly, 3, 2.

Menzel, C., Bagshaw, J., Campbell, T., Greer, N., Noller, J., Olesen, T., Waite, G., Kernot, I., Chapman, L., Rigden, P. (2001). Lychee information kit. Queensland Department of Primary Industries, Brisbane, Queensland, Australia.

OECD (2006). Guidance on objective tests to determine quality of fruits and vegetables and dry and dried produce. http://www.oecd.org/dataoecd/32/47/19515719.pdf Accessed 19 November 2007.

OECD (2007). Fruit and vegetables: standards applicable under OECD scheme. http://www.oecd.org/document/38/0,3343,en_2649_33907_1890726_1_1_1_1,00.html Accessed 25 October 2007.

Pascale, A.M. (1992). Quality in the fruit and vegetable sector: EEC regulations and influence of quality on trade and processing. Options Mediterraneennes. Seie A, Seminaires Mediterraneens, 19, 89–97.

Pineiro, M., Diaz, L.B. (2007). Improving the safety and quality of fresh fruit and vegetables (FFV): A practical approach. ISHS Acta Horticulturae 741: I International

Symposium on Fresh Food Quality Standards: Better Food by Quality and Assurance, A.N. Fardous, W. Schnitzler, M. Qaryouti (eds). ISBN 978–90–66053–28–1, http://www.actahort.org/books/741/741_1.htm

Prussia, S.E., Shewfelt, R.L. (1992). A systems approach to postharvest handling. In: Postharvest Handling. A Systems Approach, Chapter 3. Academic Press.

Scrimgeour, F., Sheppard, R. (1998). An economic analysis of the deregulation of selected Israeli, South African and South American producer boards, A Report Prepared for MAF Policy by MAF Policy Information Paper No. 20 ISSN 1171 4654 ISBN 0–478–07497–2 http://www.maf.govt.nz/mafnet/rural-nz/profitability-and-economics/trends/deregulation-analysis/dereg.htm#E11E1 Accessed 25 November 2007.

Shewfelt, R.L., Brückner, B. (eds) (2000). Fruit and Vegetable Quality. Technomic Publishing, Lancaster, PA, USA.

Smith, L.G. (1988). Indices of physiological maturity and eating quality in smooth cayenne pineapples. Indices of eating quality. Queensland Journal of Agricultural and Animal Sciences, 45, 219–228.

Story, A., Martyine, A. (1996). AUF national product description language. The Australian United Fresh fruit and Vegetable Association. Flemington Market, Victoria, Australia.

Subedi, P., Walsh, K.B., Owens, G. (2007). Prediction of mango eating quality at harvest using short wave near infrared spectroscopy. Postharvest Biology and Technology, 43, 326–334.

Tasmania – Department of Primary Industries and Water (2007). Native plants and animals – the threat of introduced tree frogs http://www.dpiw.tas.gov.au/inter.nsf/WebPages/SJON-52J3FT?open Accessed 15 November 2007.

Tesco (2007). Greener living – what we are doing. http://www.tesco.com/greenerliving/what_we_are_doing/default.page? Accessed 22 November 2007.

United Nations Economic Commission for Europe (2007a). Trade. http://www.unece.org/trade/welcome.htm Accessed 19 November 2007.

United Nations Economic Commission for Europe (2007b). Working Party on Agricultural Standards. http://www.unece.org/trade/agr/standard/fresh/fresh_e.htm Accessed 9 December 2007.

United Nations Economic and Social Council (2006). Economic Commission for Europe. Committee on Trade. Working Party on Agricultural Quality Standards. Specialized Section on Standardization of Fresh Fruit and Vegetables. Report on 1st session, 15 July 2007 (ECE/TRADE/C/WP.7/GE.1/2006/2). http://www.unece.org/trade/agr/meetings/ge.01/document/200602.pdf/ Accessed 22 November 2007.

Valero, C., Riuz-Altisent, M. (2000). Design guidelines for a quality assessment system of fresh fruits in fruit centres and hypermarkets. Agricultural Engineering International, 2, 1–20.

Walsh, K.B., Long, R., Middleton, S. (2006). Use of near infra-red spectroscopy in evaluation of source-sink manipulation to increase stone fruit soluble sugar content. Journal of Horticultural Science and Biotechnology, 82, 316–322.

Ward, G., Melvin-Carter, E. (2001). Strategies to rescue losses from internal breakdown in plums – project SF00024. Horticulture Australia Limited, Sydney, NSW, Australia.

World Trade Organization (2007). Understanding the WTO: basics – What is the World Trade Organization? http://www.wto.org/english/thewto_e/whatis_e/tif_e/fact1_e.htm Accessed 11 September 2007.
Yahia, E.M. (1994). Apple flavour. Horticultural Reviews, 16, 197–234.

10

Fresh-cut Produce Quality: Implications for a Systems Approach

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I. Introduction

Fresh-cut produce implies fruit or vegetables that have been prepared and subsequently packaged to provide convenient and safe ready-to-eat products for consumers, while maintaining their live, fresh state. Fresh and raw vegetables and fruits are subjected to minimal process operations, such as cutting, trimming, shredding, peeling, washing,

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decontamination, dipping, rinsing and packaging. Fresh-cut products, thus, are highly perishable, but also agronomically and technologically more susceptible to quality deterioration than whole vegetables. The processing operations eliminate any inedible parts, but reduce the edible product shelf life by several weeks or months, depending on the raw material. The nutritional and sensory quality should be comparable to the unprocessed product. Leafy vegetables, particularly baby leaves, are the consumers' favorite, but they are very delicate and susceptible to process manipulations. Control and innovation technology implementation needs to be pursued to optimize all fresh-cut production and processing procedures.

A fresh-cut product is physically altered from its original state during trimming, peeling, washing and cutting operations. However, it remains in a fresh state and is thus characterized by living tissues that undergo or are susceptible to enzymatic activity, texture decay, undesirable volatile compound production and microbial contamination, which reduce shelf life. In the fresh-cut industry, shelf life is the time required by a fresh-cut product to lose quality attributes, such as freshness, firmness, texture, color, aroma and nutritional value, below a level acceptable to the consumer. The relative importance of each quality factor varies according to the product and market. The final potential postharvest quality and shelf life of fresh produce are determined before harvesting. Processing practices, e.g. packaging and storage temperature, do not improve quality; they can only slow the rate at which deterioration occurs. Practices such as washing, sorting and sizing are services performed with the consumer in mind, and generally do not improve the inherent quality (Brecht et al., 2003). The first and most important aspect that affects the subsequent postharvest processing and shelf life phases is raw material quality at harvest.

Fresh produce in general, and fresh-cut produce in particular, is perishable. Once harvested, quality deterioration occurs leading to raw material losses even before the produce reaches the consumer. Fresh fruits and vegetables postharvest losses have been estimated between 2% and 20% in developed countries, and between 24% and 40% in developing countries, respectively (Sirivatanapa, 2006). High levels of waste result in higher prices for the final product. Improper handling during harvest on farms causes quality deterioration. Quality in the supply chain is crucial in terms of food safety, quality and environmental impact. Low input and efficient cultural practices, postharvest technologies and supply chain management contribute to "making the difference" in an industry that wishes to be efficient and competitive. The critical points that need to be improved in the fresh-cut sector include:

- early cold chain implementation;
- storing and shipping conditions prior to reaching the processing plant;
- logistics;
- processing inputs;
- handling in distribution.

For these reasons, innovative technologies have been developed to enhance raw material production, preserve quality, guarantee safety, prolong shelf life and diversify the fresh-cut products available to consumers.

A. Consumer trends and the fresh-cut market

Most fruit and vegetables are low-cost food that contain low levels of fat and high levels of a number of nutritionally important compounds, such as vitamins, minerals, fiber, bioactive compounds, etc., many of which cannot be synthesized by the human body. Changing eating habits such as snacking, year-round product availability and a growing trend towards vegetarianism and healthy eating have resulted in an increasing demand for convenient products that fit into the modern consumer lifestyle, while offering healthy food. Fresh-cut products, especially vegetables, have thus become very popular.

In recent years, the consumer demand for fruit and vegetables decreased in Europe. However, instead of a decrease, the ready-to-eat product sector reported an increase in sales. In the past few years, fresh-cut produce has seen an increase in sales throughout the world. Out of the total produce sales, fresh-cut sales in Europe have an estimated share of 18%, a share of 9% in the US, and Australia has a 5% share, respectively (Premier, 2007; Premier et al., 2007). Fresh-cut produce sales in the US are the highest (ca. $14 billion) with an increase of more than 50% between 2003 and 2006 (Figure 10.1). This is an indication that the fresh-cut industry is expanding faster than any other segment of the fruit and vegetable market. The fresh-cut segment supplies both the food service industry and retail outlets in the US. Approximately 60% of fresh-cut produce ends up in the food service industry, with 40% going to the retail market. Of the retail market, 62% consists of salads, 31% of vegetables and 7% of fruit (Premier, 2007). The fresh-cut industry is growing in many European countries, with the UK, France and Italy leading in terms of market share. The UK is the leader in the fresh-cut market in Europe, supplying 120 000 tons of fresh-cut salads in 2004, valued at €700 million; France follows with a volume of 77 000 tons, which includes fresh-cut and grilled/steamed vegetables (Table 10.1). In Italy, following a slow start, the sales exceeded 64 000 tons, and

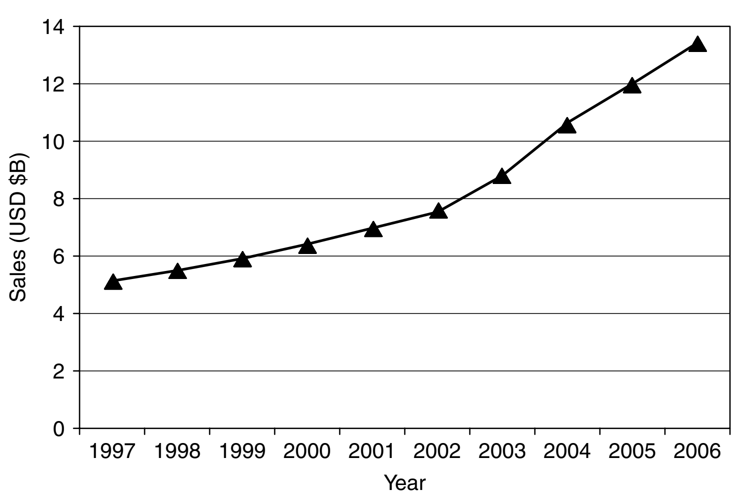

Figure 10.1 US fresh-cut produce sales from 1997 to 2006. Source: http://www.pma.com.

Table 10.1 Volume and value growth in fresh-cut production in selected European countries

Country	Fresh-cut production, tons	Year-to-year volume growth, %	Million euros	Year-to-year value growth, %
France[a]	76 940	+6.4	520.0	+2.3
UK[b]	120 000	NA	700.0	NA
Germany[c]	7642	+7.5	58.8	+12.9
Italy[d]	71 793	+34.6	510.0	+28.5
Spain[e]	20 265	NA	121.5	NA

[a]France: fresh-cut, cooked and grilled produce until September 2005.
[b]UK: fresh-cut salad retail until 2004.
[c]Germany: fresh-cut salad until June 2005.
[d]Italy: fresh-cut vegetables until August 2005.
[e]Spain: fresh-cut vegetables sold at retail until March 2005.
Source: Della Casa, R., Daltri, C. (2006). L'Informatore Agrario, 4, 63–65.

Table 10.2 The value of the Italian fresh-cut industry and annual growth rates between 2001 and 2006

Year	Million euro	Growth rate in % (preceding year = 100)	Fresh-cut production, tons	Growth rate in % (preceding year = 100)
2001	191	–	23 943	–
2002	257	+34.6	30 545	+27.6
2003	355	+38.1	40 687	+33.2
2004	397	+11.8	44 879	+10.3
2005	479	+20.7	55 748	+24.2
2006	553	+15.4	64 607	+15.9

Compiled using the following sources: Della Casa, R. (2005). In: http://www.unaproa.com.
Galassini, U. (2005). Proceedings Vegetalia, January 29, 2005, Cremona, Italy.
Gatti, G. (2006). In: http://venetoagricoltura.regione.veneto.it.
Setti, G. (2004). Terra e Vita, 7,11.
Setti, G. (2006). Colture Protette, XXI.

the corresponding value of €553 million in 2006 (Table 10.2). In recent decades, the changes in lifestyles and habits, the increase in the number of working women and an increase in single and two-person households have resulted in an increased interest in the convenience that the fresh-cut industry can offer. In Italy, 40% of consumers buy fresh-cut produce (Bernardelli, 2005).

Fresh-cut production is widespread throughout the world; in some countries it is devoted to exports aimed at western countries (e.g. Thailand to the UK, Mexico to the US). The fresh-cut market is developing in South-East Asia and Latin America. In Asia, fresh-cut product sales are driven by demand in countries like Japan, Singapore and the Republic of Korea. Sales of fresh-cut produce in Japan have grown from approximately $1 billion in 1999 to $2.6 billion in 2005, of which 89% consisted of fresh-cut vegetables and 11% of fresh-cut fruits (Kim, 2007). In the Republic of Korea, sales have grown from $0.5 billion in 2003 to $1.1 billion in 2006. These sales implied a level of production of 110 000 tons of which 33% consists of vegetable salads, 42.1% of ready-to-cook vegetables, 8.7% of wild vegetables, 15.6% of fruit and 0.3% of mushrooms. It has been reported that fresh-cut produce has been increasing in China since the late 1990s, with an annual growth rate estimated at 20%, although no exact figures are available (Zhang, 2007). Despite the opportunity that this sector can offer the overall produce industry, the lack of reliable published data makes it difficult to appreciate the importance of the fresh-cut business around the world.

B. Food safety risks in the fresh-cut chain

The success of the fresh-cut industry depends on quality and maintaining consumer confidence. The indicators of vegetable quality include color, texture, flavor and other attributes, many of which may be influenced by abiotic and biotic factors. For example, Kader et al. (1973) reported specific quality indicators for lettuce (*Lactuca sativa* L.). Fresh-cut vegetable safety is related to inherent anti-nutritional substances, such as nitrate and oxalate, which accumulate during growth (Reinink and Blom-Zanstra, 1989; Weerakkody, 2003), and external microbial and chemical contamination during postharvest (Cantwell and Ermen, 2006). These critical factors can be controlled throughout the entire chain by implementing targeted cultural techniques and observing sanitation programs. Good agricultural practices (GAPs) and good manufacturing practices (GMPs) provide recommended guidelines that guarantee a minimum safety level. The hazard analysis critical control point (HACCP), which includes good hygiene practices (GHPs), is regulated in the European Union (EU) by EU-Reg. N. 852-853-854/2004. Produce sanitation should start in the field and should encompass all growing, harvesting, handling and processing areas. One approach could be that growers should provide documentation (a logbook) of the microbial load, of fertilizer and irrigation water usage, and of the workers' hygienic practices (Zagory, 1999).

A larger volume and greater variety of fresh-cut products have become available because of the growth of the fresh-cut sector. From 1996 to 2006, 26% of all foodborne disease outbreaks caused by the consumption of fresh produce implicated fresh-cut produce (FDA, 2007). Fresh fruit and vegetables normally already contain high levels of microorganisms at harvesting before processing. Soil, water, air and insects all contribute to the microflora of vegetables, but their importance differs according to the edible part of the plant. For example, leaves are primarily exposed to water, whereas roots have more contact with the soil. The numbers and the species of microorganisms found on fresh produce, and specifically on fresh-cut product, are highly variable. The range of contamination depends on the harvest time, weather conditions at harvesting, applied fertilizer, handling by workers during harvest, sorting, and the subsequent processing, e.g. the contact with cutting knives, transport belts, boxes or water used for washing.

The difficulties involved in killing and removing microorganisms from raw material can originate from preharvest sources, such as feces, soil, sewage and sludge, irrigation water, water used to apply fungicides, insecticides and herbicides, improper manure, dust, wild and domestic animals and human handling (Beuchat, 2007). The control of these contamination sources can enhance the successful management of microbial safety risk in the fresh-cut industry. Three types of microbes are present on the surface of fresh-cut produce:

1. useful microbes, such as some lactic acid bacteria, which should not be removed or killed;
2. spoilage microbes, such as pectynolytic Gram negative bacteria belonging to *Pseudomonadaceae* or *Enterobacteriaceae* and yeasts with fermentative metabolism like *Saccharomyces* spp., found on fruit, which should be minimized during processing because they reduce shelf life;
3. pathogens (e.g. *Clostridium botulinum*, *Escherichia coli*, *Listeria monocytogenes*, *Salmonella* spp., *Staphylococcus aureus*) responsible for food-borne disease outbreaks.

The aim of the fresh-cut industry is to prevent the presence of pathogens and ensure that they are not introduced during the processing system. Because of their growth, internalization and infiltration behavior, sanitizer treatments are not effective and cannot ensure safety, thus GAPs, GMPs and HACCP are essential to prevent human pathogen contamination.

II. Cultivation management for the fresh-cut industry

A. Raw material quality for the fresh-cut industry

Any preharvest condition that stresses a plant will affect the quality and shelf life of the final product. The understanding of these conditions is crucial to assess the postharvest potential of fresh produce, especially those that will be further stressed by fresh-cutting. Some consumers wrongly assume that fresh-cut produce is a second-class product obtained from the leftovers of first-class fresh vegetables, while the raw material must actually be in a perfect state with regard to safety, physiology, extrinsic and internal quality before processing. The raw material must be suitable for fresh-cut processing, and this means that it must be clean and safe. The most important prerequisites concern:

1. the absence of insects, soil, metals and weeds, which increase the length and cost of the washing phase and jeopardize the quality;
2. a low level of microbial contamination that accelerates metabolic processes which reduce the shelf life;
3. the absence of pathogens that cannot be either controlled or eliminated during processing.

Cultivation conditions, such as the culture system, irrigation, climate and fertilization, influence the quality of the raw material and can modify its physiological behavior and suitability for fresh-cut processing. The preharvest and harvest conditions that affect vegetable quality and shelf life are related to:

- genetically controlled factors (cultivar, strain);
- climatic conditions (light, temperature, relative humidity, etc.);
- soil conditions (type of soil, pH, moisture, microflora, soil-borne diseases, etc.);
- culture systems (open field cultivation, protected cultivation, soilless systems, etc.);
- agricultural practices (use and type of fertilizers, pesticides, growth regulators, irrigation, etc.);
- harvesting (harvest time and temperature, mechanical harvest, manual harvest, etc.).

Food safety and quality begin on the farm. Fresh-cut produce, being a perishable product, is characterized by an irreversible decay in quality, and for this reason it is important to obtain the best raw material quality at harvest. Raw material variability remains a challenge: cultivars, growing conditions, climatic conditions, preprocessing handling and storage all affect the visual quality, shelf life, flavor and the compositional and textural quality (Cantwell and Ermen, 2006).

B. Cultivars

The quality of the product can be preserved and enhanced by the addition of value and broadening the product line of fresh-cut products to consumers. Quality starts in the field and is the result of cultivation standardization which combines a careful choice of varieties with the best cultural techniques, from planting to harvest. Choosing the proper cultivar is not an easy task, because various parties in fresh-cut production and distribution often have conflicting needs. Breeding selects cultivars that can solve the problems of growers and processors, reduce production costs, and optimize postharvest technology efficiency.

Growers want cultivars that are resistant to biotic and abiotic factors, while ensuring a high yield, suitability for mechanical harvesting, plant size uniformity, lower rejection rates during processing and uniform maturity. The absence of biotic and abiotic damage reduces both the metabolic processes after harvest and microbial contamination at any stage. Resistance to biotic and abiotic factors allows not only reduction of pesticide use, but also production of unblemished raw material. Breeders have selected *Cichorium intybus* L. (chicory) cultivars with high bolting tolerance and frost resistance without any variation in color. Cultivars with high bolting tolerance satisfy commercial and organoleptic maturity requirements, and lead to a reduction in discarded material, thus lowering postharvest losses. Baby leaf cultivars of lettuce have been selected because of their resistance to different *Bremia lactucae* strains, while spinach (*Spinacia oleracea* L.) cultivars have been selected because of their resistance to *Peronospora farinosa*.

Processors want cultivars with low respiration and enzymatic rates, and with tolerance to stress due to mechanical operations, such as washing, sorting, cutting and drying. Cultivars tolerant of low temperatures used in the supply chain are also preferred. For instance, head vegetables (e.g. lettuce, chicory) are preferred to baby leaves (e.g. rocket, *Eruca sativa* Mill; corn salad, *Valerianella olitoria* L.), because they are more resistant to mechanical stress and extended storage prior to processing. The latter feature improves logistic management of the produce flow. Spinach cultivars are classified according to leaf shape, i.e. smooth, savoy or semi-savoy. The smooth leaf and semi-savoy types are mainly used for processing, while the savoy type is used for the fresh market. The savoy types are preferred for shipping, because they are less likely to wilt or turn yellow before reaching the market (Mills, 2001). The smooth type spinach cultivars are suitable for canned, frozen or fresh-cut produce, because the leaves are easy to clean before processing. Cantwell and Ermen (2006) described lettuce cultivars that differed according to their enzymatic browning rate and the phenylalanine ammonia lyase (PAL) activity of the cut pieces. All types of "radicchio," a chicory cultivar famous for its color and slightly bitter flavor, have a long shelf life associated with reduced oxidation at the cutting point.

Cultivar selection is of great importance in fresh-cut fruit processing, because cultivar characteristics, such as flesh texture, skin color and browning potential, can vary a great deal. Fruit tissue softening during ripening and senescence is triggered by ethylene production, which is one of the main reasons for the relatively short post-cutting life of fresh-cut fruit. The commercial success of fresh-cut peach and nectarine slices (*Prunus persica* [L.] Batsch) has been limited, due to their short shelf life because of cut surface browning and pit cavity breakdown (Gorny et al., 1999). Their shelf life can vary from 2 to 12 days at 0°C, depending on the cultivar. The selection of appropriate cultivars, and an appropriate maturity at harvest, a proper storage temperature and relative humidity (RH), can be considered the most important factors that determine the shelf life of fresh-cut peach and nectarine slices. The shelf life of fresh-cut slices of pear cultivars (*Pyrus communis* L.) varies greatly due to their different degrees of flesh softening and surface discoloration. The shelf life of pear slices is reduced with an increased incidence of cut surface browning. Gorny et al. (2000), when comparing Bartlett, Bosc, Anjou and Red Anjou varieties, stated that Bartlett pears were the most suitable cultivars for fresh-cut processing, because they exhibited the longest post-cutting shelf life of all cultivars tested. Ethylene production can be inhibited by the use of 1-MCP. The effectiveness of 1-MCP is cultivar-specific and influenced by the maturity of the fruit. Calderon-Lopez et al. (2005) found that slices prepared from apple cultivars (*Malus* × *domestica* Borkh.) treated with 1-MCP had lower ethylene production rates, and were firmer than those of untreated fruits.

One of the main parameters considered by consumers when choosing a product is the color of the product. Consumers associate color with freshness, better taste, flavor and ripeness. In fruit, such as apples, cherries (*Prunus avium* L., *Prunus cerasus* L.) and strawberries (*Fragaria* × *ananassa* Duch.), there has been much interest in breeding fruit varieties with different color, hues, patterns, or with a total anthocyanin content. Red skinned apples are preferred to the other colored apples; furthermore, the apple skin is a source of antioxidants and may become a new quality marker for different apple cultivars (Takos et al., 2006).

Processors set the characteristics of a product with retailers, and control the microbial and nutritional quality both at harvest and after processing. The cultivars can change according to consumer demand, but it is important that they satisfy the grower and processor requirements to guarantee process and product safety and quality.

C. Growing conditions

Climatic conditions, including light and temperature, have an important influence on the chemical composition of horticultural crops. The amount and intensity of light during the growing season have a definite influence on the amount of ascorbic acid that is formed (Lee and Kader, 2000). Light intensity influences the amounts of oxalate, ascorbate and nitrate in spinach leaves (Proietti et al., 2004). Light and temperature affect anthocyanin synthesis in several species which, in many instances, is favored by UV wavelengths and low temperatures (Kleinhenz et al., 2003, and citations therein). Sunlight is the most important external factor that regulates anthocyanin synthesis in apple skin, this was found by Takos et al. (2006) who isolated a light-induced gene that encodes an *MYB* regulator of anthocyanin synthesis in apple fruit skin.

Environmental conditions influence vegetable and fruit resistance to biotic and abiotic factors. Adverse conditions that negatively stress a plant make vegetables and fruits unsuitable for processing. Research results have suggested that lettuce tissue damage incurred in the field increases the potential risk of *E. coli* contamination (University of Arizona–Cooperative Extension, 2004a). After harvesting, quality deterioration can be accelerated in produce damaged by pests, fungi, bacteria and viruses, which alter the plant metabolism and increase the risk of a second microbial contamination. Cultivation for fresh-cut processing should take place in areas far from chemical, atmospheric or animal husbandry pollutant sources, which jeopardize the safety of the raw material.

Water influences the raw material microbial quality throughout the entire processing cycle. Water used for production and harvest operations can contaminate vegetables if the edible portions have been in direct contact with water containing pathogens harmful to humans or through water-to-soil and soil-to-product contact (Solomon et al., 2003). It is important to ensure an appropriate chemical and microbial quality of the irrigation water and the water used in harvest operations. The chemical quality of water can influence plant growth. An example is salinity, which increases the susceptibility of plants to many diseases such as *Fusarium* spp. and *Verticillium* spp. wilts (Besri, 1997). The water should be periodically controlled through microbial and chemical analyses, including tests on the levels of fecal coliforms (i.e. *E. coli*) and heavy metals, whose absence is a safety indicator. However, growers may encounter difficulties in controlling water quality, because it originates from sources that could become polluted. Irrigation water comes from superficial and underground sources that can be contaminated by drift, run off or leaching of water from polluted areas (Lunati, 2001; Steele and Odumeru, 2004).

Irrigation methods (e.g. drip irrigation, overhead sprinkler, furrow, sub-irrigation systems) can be chosen according to their potential to introduce or promote the growth of pathogens on produce. Water quality, irrigation and postharvest disinfecting treatments appear to be of paramount importance in reducing the risk of *E. coli* contamination in lettuce (University of Arizona–Cooperative Extension, 2004a). Fonseca (2006) evaluated the postharvest quality and microbial population of iceberg lettuce affected by moisture at harvest. Iceberg lettuce irrigated 4 days before harvest had microbial counts over 0.4 Log cfu g^{-1} higher than lettuce irrigated 16 days before harvest. In addition, the microbial population of lettuce irrigated 4 days before harvest with overhead sprinklers was much higher than lettuce irrigated using the furrow system.

Water influences not only the microbial quality, but also the shelf life of vegetables. Recent studies suggest that in some cases "controlled" water stress during plant growth can produce beneficial effects during postharvest storage (University of Arizona–Cooperative Extension, 2004b). Moisture stress imposed on broccoli (*Brassica oleracea* L. var. *italica*) during maturity increased their shelf life from 2–3 days to as many as 13 days at 15°C. Similarly, water stress can improve the postharvest quality of carrots (*Daucus carota* L.), melons (*Cucumis melo* L.) and celery (*Apium graveolens* L.), but the positive effect of stress depends on when the plants are subject to it. Shelf life at maturity is important for the fresh-cut industry.

The soil type affects not only the nutritional quality, but also the safety of the raw material. The soil texture influences the mobility and efficiency of nitrogen and mineral uptake, which in turn has an impact on the quality of the final product. Cantaloupe melons grown in clay soil produced better-tasting fruit, in terms of sweetness and flavor, with superior fresh-cut quality, in terms of less sour taste and off-flavor, than melons grown in sandy soil (Bett-Garber et al., 2005). As fresh-cut produce is prepared from a raw material that is in contact with soil, microbial contamination can occur. GAPs and GHPs suggest that land used for grazing livestock is not suitable for growing vegetables, and it is recommended that manure and compost are avoided as fertilizers because they can be sources of microbial and heavy metal contamination.

D. Raw material production

Inherent fruit quality parameters, such as sugar and acid content, ripening and storability, and external fruit quality parameters, such as color, form, stage of growth and firmness, are closely correlated to the main nutrients: nitrogen, phosphorus, potassium, calcium and magnesium. The nutrients can be supplied to the plant through distribution on the soil surface or by fertigation. Fertigation increases the efficient use of fertilizers and nutrient availability at root level, and fertigation in particular increases the mobility of potassium and phosphorus.

In fruits, nitrogen is negatively correlated with the firmness, dry matter percentage, refractometric index, soluble sugar content and acidity. An excess of nitrogen availability causes poor fruit skin color development and increases plant susceptibility to pests and physiological disorders. In vegetables, particularly leafy vegetables, nitrogen supplied as nitrate is negatively correlated to the dry matter percentage and directly correlated to the nitrate content in the edible portion (Fontana et al., 2004; Nicola et al., 2005b). In leafy vegetables, nitrogen fertilization can be scheduled to reduce the nitrate content in leafy vegetables in order to reach acceptable threshold levels, which are generally below 2500 mg kg^{-1} f.w. In the EU, specific limitations are set for the nitrate content in the final product for lettuce and spinach (EU-Reg. N. 563/2002).

Supplementing sufficient soil potassium with additional foliar potassium applications during cantaloupe fruit development and maturation improves the fruit's marketable quality by increasing firmness and sugar content, and fruit nutritional quality by increasing ascorbic acid, beta-carotene and potassium levels (Lester et al., 2007). The preharvest nutritional status of fruit, especially with respect to calcium, is an important factor that affects potential storage life (Gąstoł and Domagała-Świątkiewicz, 2006). Fruits with a high level of calcium have lower respiration rates and longer potential storage life than fruits containing low levels of calcium. Many physiological disorders in fruits are associated with a calcium deficiency. The easiest way to maximize the calcium level in fruit is to use a foliar spray although, in many instances, the uptake and penetration of calcium into the fruit and its movement within the fruit tissues is difficult to achieve (Mengel, 2002).

Most leafy vegetables used for the fresh-cut industry in Europe are from protected cultivation, because protected cultivation leads to an increased yield, allows off-season production, controls the abiotic factors and facilitates pest management. In Italy, the protected cultivation of vegetables for the fresh-cut sector represents 75% of the total production (Daffonchio, 2007). The produce originates from different geographic areas, according to the season. Each geographic area is characterized by different environmental conditions, cultivar availability and cultural practices. These factors can influence not only the quality of the raw material at harvest, but also the efficiency of postharvest technologies, such as the choice of operational temperatures and packaging systems. Fruit and vegetables are produced both in open field and in protected cultivations (Figure 10.2a,b). Compared to the open field system, the

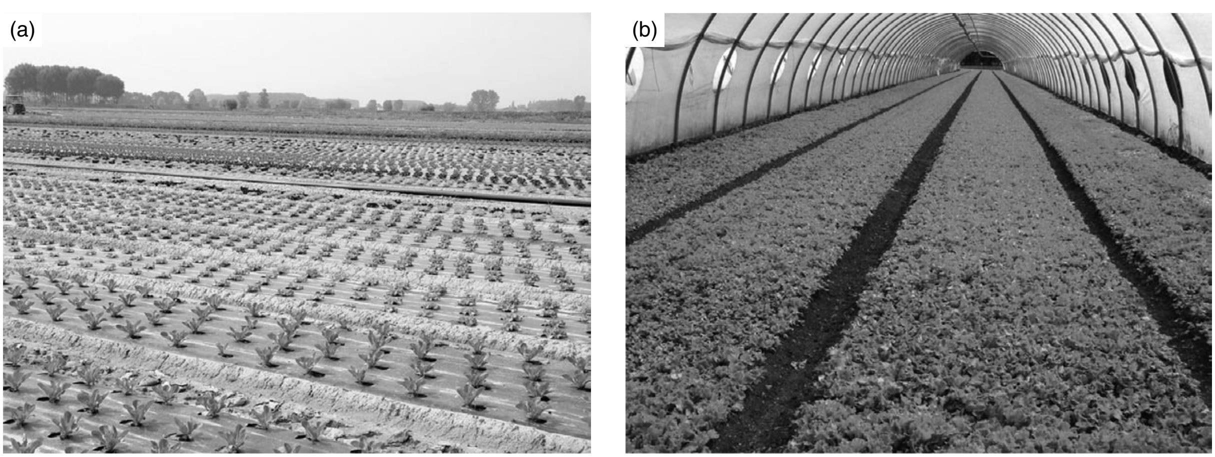

Figure 10.2 Head lettuce varieties grown in open field (a) and baby leaf lettuce under protected cultivation (b).

protected culture system offers many advantages, for example, protection from damaging winds and other adverse weather conditions, such as rain and hail, a reduction in evapotranspiration rate, an increase in photosynthesis rate, and an advance in the harvest date. The covering material of the greenhouses enhances the internal air temperature, and leads to reduced air and soil temperature excursions. All these aspects affect plant health, and improve raw material quality, yield and safety.

Voća et al. (2006) compared strawberry crops grown in open field cultivation, soil protected cultivation and soilless protected cultivation systems, and found that the cultivation system had a great influence on the color and firmness of the strawberry fruit cv. Elsanta. Better fruit coloring was obtained in the protected cultivation systems, although the soilless system gave the lowest fruit firmness. The overall chemical composition of the fruit indicated that the highest quality was reached with the soil protected cultivation.

Vegetables usually contain relatively high numbers of microorganisms at harvest, because they are in contact with soil during growth (Tournas, 2005). Not all microorganisms are capable of proliferating on vegetables. Several microbial species can break the protective cover of plants and then grow and cause spoilage; others can enter the plant tissue through wounds and then can grow and spoil the vegetable. Some fungal spores can survive for some time in the soil and contaminate plants one season after another; these organisms may cause plant disease in the field, as well as spoilage during storage. In these circumstances, field treatments with fungicides and the use of resistant cultivars are necessary in order to avoid disease development and spoilage. The avoidance of disease development and spoilage are main factors that favor the development of the soilless culture system.

The soilless protected cultivation system allows higher qualitative and quantitative standards to be obtained, cultural techniques to be standardized and both production costs and environmental impact to be reduced. The system is a valid alternative to the soil cultivation system, as it helps to avoid soil-borne diseases, and controls mineral plant nutrition in order to standardize the qualitative characteristics of the final product. The use of mineral and sterile media with a low environmental impact may be an alternative to the practice of soil disinfection. When investigating a soilless system, in order to obtain uniform produce of high quality, it is crucial to adjust the nutrient solution, moisture and water content of the growing medium, because they are the most important aspects, apart from environmental growing conditions.

The soilless protected cultivation system is highly productive, and has proved to enhance the postharvest shelf life of many fresh-cut vegetables (Fontana et al., 2003, 2004, 2006; Fontana and Nicola, 2008; Hoeberechts et al., 2004; Nicola et al., 2003, 2004, 2005a,b; Sportelli, 2003). Natalini (2005) studied the influence of cultivation techniques on melon crop growth, fruit yield and quality. Comparing soil protected cultivation to a soilless culture system (nutrient film technique, NFT) the author observed that NFT gave the highest yield, while the fruit quality was quite poor in terms of softening and loss of cellular integrity during storage.

Among the different soilless cultivation systems, the floating system (FL) is a recent growing system that has led scientists and extension specialists to consider it as a way of producing leafy vegetables with characteristics that satisfy the requirements of the entire chain. The system is suitable for raising vegetables with both short production cycle and high plant density; it can be considered an efficient system to produce leafy vegetables with high added value, for example, basil (*Ocimum basilicum* L.), rocket, corn salad, purslane (*Portulaca oleracea* L.), garden cress (*Lepidium sativum* L.), dill (*Anethum graveolens* L.), baby lettuce and spinach, among others.

The FL is a sub-irrigation system that consists of trays that continuously float on a water bed or nutrient solution (Nicola, 1993; Pimpini and Enzo, 1997; Thomas, 1993) (Figure 10.3a,b). A sub-irrigation system increases the precision of fertilizer application to plants by reducing water leaching during irrigation. This production system requires relatively low maintenance and labor costs, and results in an efficient use of water and greenhouse space (Galloway et al., 2000). The FL allows the produce quality at harvest to be improved, reduces microbial contamination, and eliminates soil and chemical residue spoilage. Normally, produce obtained from soil cultivation systems can reach a total bacterial count of 10^6 to 10^9 cfu g^{-1}, which can be reduced by 2–3 Log cfu g^{-1} after washing and sanitation practices. Garden cress grown in a FL resulted in a low total bacterial count at harvest, ranging from 10^2 to 10^5 cfu g^{-1}, with *Pseudomonas* spp. ranging from 10^0 to 10^4 cfu g^{-1}, total coliforms ranging from 10^0 to 10^3 cfu g^{-1}, and yeasts and moulds ranging from 10^2 to 10^4 cfu g^{-1} (Nicola et al., unpublished data). Consequently, soilless cultivation systems can reduce the sanitizer input, for example, in water during fresh-cut processing by providing cleaner raw material.

E. Raw material harvest and handling

Good preharvest and harvest practices are necessary to reduce commodity damage. It has been extensively reported that the quality of a raw material and the storage

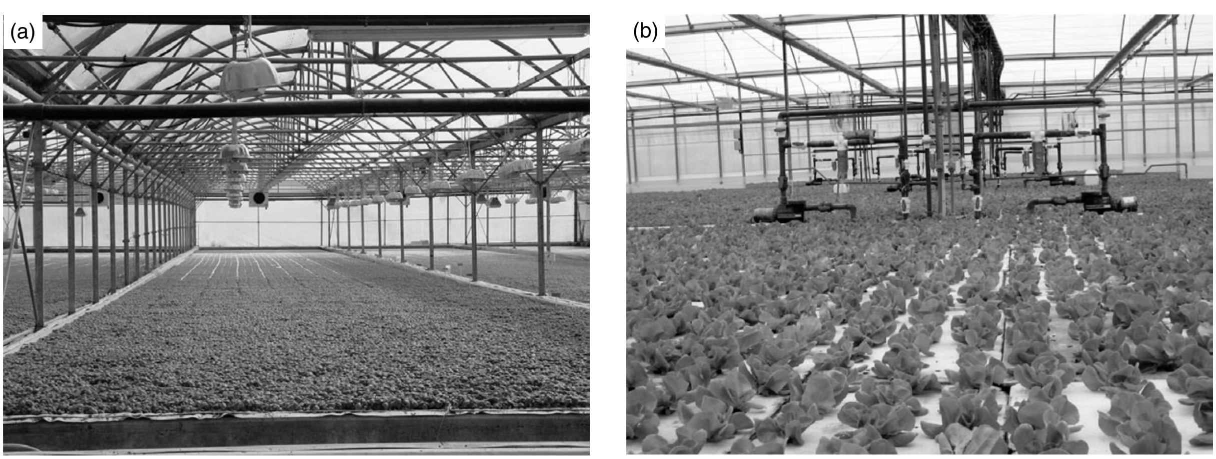

Figure 10.3 Soilless culture system with sub-irrigations: the flotation system for basil (a) and lettuce (b).

conditions before processing are very important to keep the quality of a vegetable (Wiley, 1994). The harvest, handling, shipping and storage (HHSS) before processing are stages where low temperature conditions are vital to preserve the quality of the raw material. The cold chain should, in fact, begin as early as possible, and be maintained from the field to the processing plant. Low temperatures, in the range from 0 to 10°C, depending on the species and cultivar, keep the turgor in vegetables unaltered and slow microbial contamination. However, production operations are not yet broadly organized or optimized to handle the harvest phase with a minimum lag time before implementing the cold chain.

Fresh-cut vegetable shelf life is, at the moment, ca. 6–7 days in Italy. The shelf life of fresh-cut produce in the US exceeds two weeks, depending on the species. The long shelf life is basically achieved due to, apart from the limited range of species and typology produced, prompt cooling and the maintenance of the cold chain, with temperatures generally below 4°C after harvest during processing, shipping and distribution. At present, an uninterrupted cold chain is not standard practice in Italy. Farms are not equipped for raw material conditioning in the field, and there are problems with logistics between growers and processors. Most of the processors are located in Northern Italy, while most of the raw material comes from Southern Italy (Lunati, 2003). Consequently, the maintenance of the cold chain to preserve the freshness and quality of the raw material before processing increases costs. In Italy, the cold chain is discontinuous, low temperatures are not guaranteed from harvest to the processing plant, and from there to the consumer. The cooling of produce when shipping for processing affects the final price of fresh-cut produce, which is already high for most Italian consumers.

The stage of maturity of fruit and vegetables destined for fresh-cut processing is a critical factor that helps to determine the potential quality and shelf life of the product. The eating quality and shelf life of fresh-cut fruit products are influenced by the stage of ripeness at cutting (Gorny et al., 2000). In the case of leafy vegetables, the growth stage at harvest can influence the shelf life of the baby leaves, harvested at an early growth stage due to market demand. The rate of deterioration has often been related to the metabolic processes and respiration rate, which are usually higher in younger leaves. The high respiration rate explains why it is hard to reach a commercial shelf life longer than seven days.

Harvesting directly affects the appearance and shelf life of the final product. The safety and the quality of fresh-cut produce depend not only on the cultural practices and postharvest conditioning, but also on the harvesting and handling procedures. Factors that can affect the microbial condition in the raw material include the climatic conditions which the plants are produced in, and the temperature and air conditions at which the produce is stored after harvest. Harvesting in the heat of the day causes wilting, shriveling, softness and a high respiration rate, and shortens shelf life considerably (Perkins-Veazie, 1999). Rough handling creates areas that darken, soften and make the product vulnerable to pathogen attacks. Microbes can also readily attach to cut leafy vegetable surfaces (Takeuchi and Frank, 2001) reducing the safety and nutritional quality. At harvest, appropriate measures should be taken to reduce or eliminate the potential risk of pathogen contamination through soil contact at the cut surface. The reduction or elimination of pathogens can be achieved by cleaning cutters and containers, by increasing the cutting quality, e.g. cutter sharpening, and by guaranteeing the hygiene of field workers.

The harvesting method, whether by hand or mechanical, and handling can determine the variation in maturity and physical injury, and consequently can influence the nutritional composition of vegetables. The use of good preharvest, harvest and handling practices is necessary to reduce commodity damage. Harvesting early in the morning, before plants become warm and respiration rate increases, lowers the needed cooling and often lengthens the preprocessing storage. Placing the harvested produce quickly under shade, in opaque or dark boxes, or using white tarpaulins to reflect heat from the filled bins can cut the load temperature by 30% (Perkins-Veazie, 1999). These often disregarded stages of the supply chain, harvesting and handling, should be optimized, and the cool chain implemented as early as possible to maintain product quality (Thompson et al., 2001) in order to guarantee food safety and to reduce the amount of cooling needed afterwards (Figure 10.4).

Fresh fruit and vegetables are living tissues, and subject to continual changes after harvest. Fresh produce consumes photosynthates that were stored in the product before the harvest. The consumption rate depends on the respiratory activity of a particular commodity and its temperature. Delays between harvesting and cooling or processing can result in direct losses, due to water loss and microbial contamination, and indirect losses, such as flavor and nutritional quality (Thompson et al., 2001). The rate of product deterioration is proportional to the rate of respiration, which increases exponentially with temperature (Cantwell, 2007). Shriveling and the loss of fresh, glossy appearance are two of the most noticeable effects of cooling delays, particularly for commodities that lose water quickly and show visible symptoms at low levels of water loss, such as most leafy vegetables. A correlation has been found between respiration rate and shelf life (Ninfali and Bacchiocca, 2004). Vegetables characterized by weak respiratory rates, such as carrots, have a long shelf life. Preprocessing storage conditions are fundamental to preserve raw material quality; the optimal

Figure 10.4 Harvested iceberg lettuce stored in a dark, cold room (4°C) before processing.

vegetable storage temperature should be observed to avoid chilling injuries, such as browning or pitting, and vegetable thermal shock due to the high temperature gap between the field and the storage room.

III. Processing management for the fresh-cut chain

Fresh-cut processing accelerates the color, texture, firmness, flavor and nutritional value deterioration of a product, and compromises its shelf life. Moreover, wounded surfaces provide favorable conditions for microbial growth. Therefore, adequate control strategies during the storage of fresh-cut produce should minimize nutritional and sensorial loss and microbial growth. Proper handling, the use of effective sanitizers, adequate temperature storage and packaging are the main ways of reducing rapid degradation of fresh-cut produce.

A. The postharvest quality of fresh-cut produce

It was previously stated that cultivars, environmental conditions, irrigation practices, fertilizers and pest control programs affect produce quality. Practices such as washing, sorting, sizing, cutting, blending and packaging do not change the inherent quality, but add value for the consumer, who is looking for convenience and also healthy and tasty food (Figure 10.5a,b). Like any perishable product, fresh-cut fruit and vegetables are characterized by an irreversible deterioration of quality. Therefore, the sensory quality of these types of products cannot improve during further storage; it can only be retained or deterioration can be retarded by applying optimal processing and packaging techniques, a proper storage temperature and eventually application of enzymatic browning inhibitors (Watada and Qi, 1999) and ethylene or oxygen absorbers (Markarian, 2004).

Fresh products are susceptible to deterioration between harvest and consumption and this may reach very high values after harvest, depending on the species, harvesting and handling methods, processing, length and temperature of storage and distribution, market conditions, etc. A longer shelf life, therefore, depends on a combination of correct cooling storage throughout the entire chain, modified atmosphere packaging conditions and good manufacturing and handling practices (Kader, 2002a). The main objectives of postharvest technology concern quality and safety assurance, and loss reduction in the postharvest chain.

B. Cutting

Producing fresh-cut fruit and vegetables involves substantial mechanical injury due to peeling, slicing, dicing, shredding or chopping (Portela and Cantwell, 2001) (Figure 10.6a–d). Thus, the physiology of minimally processed fruit and vegetables is essentially the physiology of wounded tissues, which are subjected to an increase in respiration rate and ethylene production, membrane degradation leading to cellular

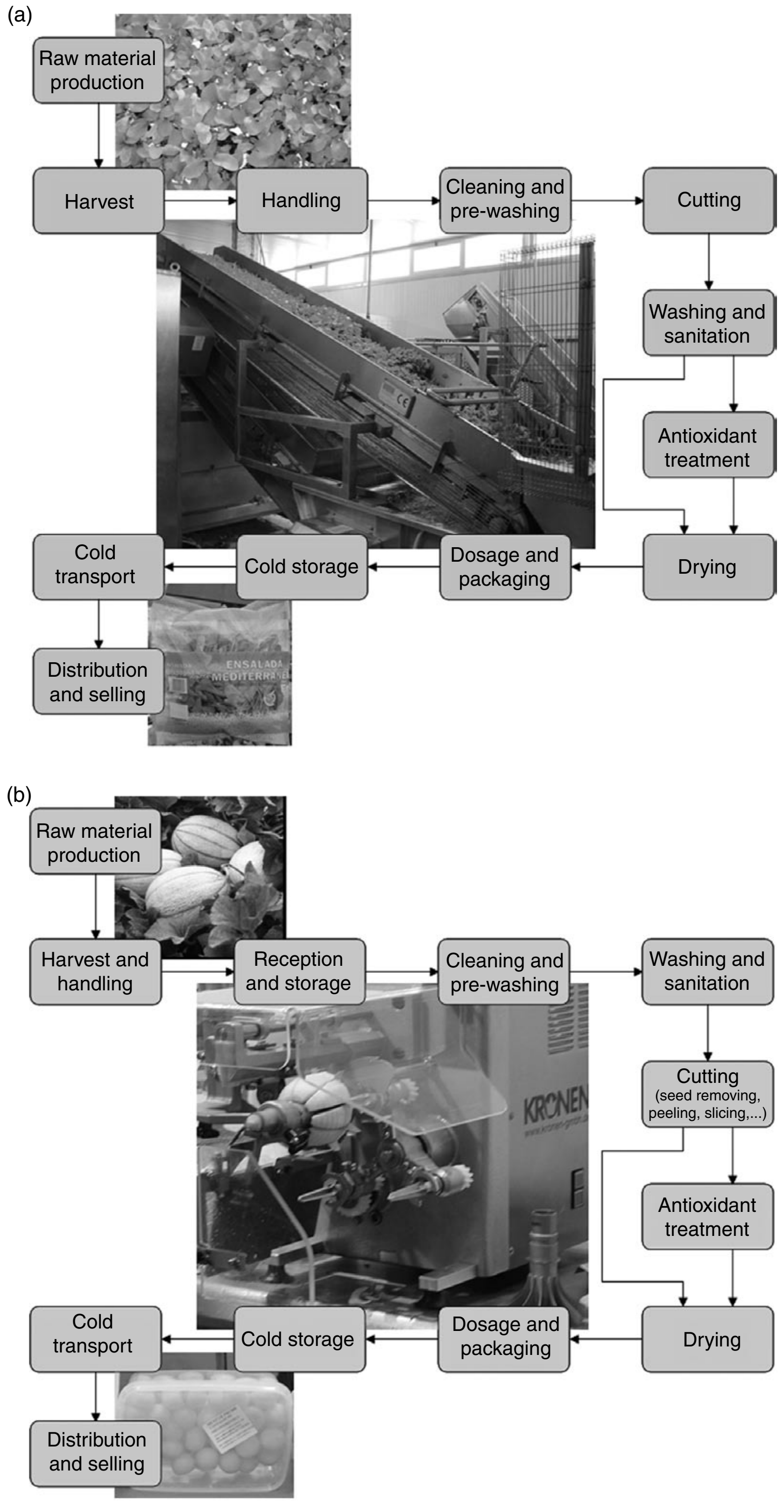

Figure 10.5 General diagram flows of processing operations for leafy vegetables (a) and fruit (b).

Figure 10.6 (a) slicing onions; (b) trimming asparagus; (c) peeling carrots; (d) slicing tomatoes in fresh-cut processing plants.

disruption and decompartmentalization of enzymes and substrates, and accumulation of secondary metabolites. All these biochemical reactions are responsible for changes in quality characteristics, such as texture, color, flavor and nutritional value (Portela and Cantwell, 2001, and citations therein). Many factors affect the intensity of the wound response in fresh-cut tissues. These factors include species and cultivar, stage of physiological maturity, temperature, O_2 and CO_2 concentrations, water vapor pressure, various inhibitors and the severity of wounding (Cantwell, 1992; Brecht, 1995).

The severity of wounding depends on the type of cutting, cutting area size and cutting shape. The response of the tissue to processing wounds usually increases as the severity of the injury increases. Peeling and cutting increase the respiration rate from one-fold to seven-fold compared with the same fresh whole produce (Rivera-Lopez et al., 2005). Del Aguila et al. (2006) measured the differences in respiration rate, ethylene production and soluble solids between whole and shredded radish (*Raphanus sativus* L. cv. Crimson Gigante), and between shredded and sliced radish.

During cold storage, the respiration rate of whole radish remained stable, while oscillations in fresh-cut radish were observed, with a generally higher respiration rate in shredded radish. After nine hours of processing, ethylene production was higher in the shredded and sliced radish than in the whole radish, and the shredded radish lost more soluble solids than the sliced or whole radish. The decrease in soluble solids was partially attributed to the consumption of carbohydrates during respiration related to the repair of injury, and the higher injured area of shredded radish may have caused an amplification of the response to injury.

Cutting and shredding should be performed with the sharpest possible knives or blades made from stainless steel (Allende et al., 2006). Saltveit (1997) considered that very sharp cutting tools could limit the number of injured cells. Barry-Ryan and O'Beirne (1998) observed that carrot slices prepared using a sharp blade had a reduced microbial load and off-odor development, and were characterized by a higher microscopic cellular integrity and a longer shelf life than slices prepared using a blunt blade. Portela and Cantwell (2001) evaluated the consequences of blade sharpness and thereby, the degree of wounding on the appearance and physiology of fresh-cut cantaloupe melon. Pieces prepared using a sharp borer maintained marketable visual quality for at least six days, while those prepared using a blunt borer were unacceptable at six days, due to surface translucency and color changes. Borer sharpness did not affect the changes in decay, firmness, sugar content, or aroma, while blunt-cut pieces had increased ethanol concentrations, off-odor and electrolyte leakage compared to sharp-cut pieces.

Cutting technique quality can influence microbial growth. Gleeson and O'Beirne (2005) evaluated the effects of different slicing methods on the subsequent growth and survival of *E. coli*, *L. innocua*, and background microflora during storage at 8°C on modified atmosphere packaged vegetables (sliced carrots, and sliced iceberg and butterhead lettuce). In general, the slicing method had no significant effect on the initial inoculation levels. *L. innocua* grew better and *E. coli* survived better on vegetables sliced with blades that caused the most damage to cut surfaces. Slicing manually with a blunt knife or with machine blades gave consistently higher *E. coli* and *L. innocua* counts during storage than slicing manually with a razor blade. The effects of hand tearing were similar to slicing with a razor blade. The slicing method also affected the growth of the total background microflora; razor sliced vegetables tended to have lower counts than other treatments. Product respiration was also affected by the slicing method; the use of a razor blade resulted in lower respiration rates.

Different new solutions have been tested to prevent the acceleration of decay due to peeling, cutting or slicing, e.g. the "immersion therapy," which consists of cutting a fruit while it is submerged in water. The cutting of a submerged fruit controls turgor pressure, due to the formation of a water barrier that prevents movement of fruit fluids while the product is being cut (Allende et al., 2006). Additionally, the watery environment helps to flush potentially damaging enzymes away from plant tissues. Another technique is the cutting operation performed under ultraviolet-C (UV-C) radiation. Lamikanra et al. (2005) observed that post-cut application of UV improved shelf life of cut cantaloupe melon, while cutting fruit under UV-C radiation further improved product quality. More specifically, the study found that UV-C radiation during processing reduced rancidity and improved firmness retention in the stored fruit. The UV-C radiation also reduced spoilage microorganisms, such as mesophilic and lactic acid bacteria.

Finally, the "water-jet cutting" method which is successfully used for e.g. meat, poultry, and vegetables (McGlynn et al., 2003), can also be used in the fresh-cut industry. This is a "non-contact" cutting method (Allende et al., 2006) which slices fresh fruit and vegetables utilizing a high pressure fluid jet that minimizes bruising in the cut pieces and tissue damage in the vicinity of the cut surface (http://www.freepatentsonline.com/4751094.html). This method reduces the excessive tissue damage caused by compression and tearing the piece along the cut surfaces. It has been found that in fruit and vegetables sliced with a high pressure fluid jet, the cell tissue damage is minimized so that when the fruit or vegetable is subsequently eaten, it provides essentially the same sensory qualities, odor, texture and taste as the freshly harvested fruit or vegetable. This type of slicing, together with proper storage conditions, allows produce shelf life to be prolonged in comparison to other conventional cutting methods, such as regular kitchen paring knives, commercial rotary blade cutters, razor sharp, or thin blade knives. The vegetables particularly adapted to being cut by this method are fresh root vegetables, leafy vegetables and fruit and vegetables with firm tissue. The efficiency of this cutting method depends on the orifice size, water pressure and standoff distance, which must be tuned according to the inherent characteristics of the species and cultivar (Bansal and Walker, 1999). McGlynn et al. (2003) assessed the effect of water-jet cutting on the shelf life of cut watermelon (*Citrullus lanatus* cv. Sangria). A comparison of pieces cut with a water jet with those cut with a knife showed that the former were firmer than the latter after seven and ten days of storage, and this should be due to weight loss. The experiment showed that water-jet-cut watermelon pieces tended to lose less moisture during storage than knife-cut pieces. The decrease in weight loss due to the loss of liquid during storage could have a significant impact on the consumer perception of freshness and texture, and could influence microbial control strategies.

C. Washing systems

The processing operations of fresh-cut produce include washing treatments to make the product ready-to-eat. The produce has to be clean, free of soil residue, insects, metals and weeds, and safe. The raw material should be carefully cleaned before processing, because fresh-cut produce is prepared from material grown mostly in contact with soil and without any strong antimicrobial treatments, such as pasteurization or sterilization. Even healthy looking products from the field can harbor large populations of pathogens, particularly during warm weather.

Washing raw material before cutting and during fresh-cut processing is the most effective way of minimizing the risk of the presence of pathogens and of any residue left on the produce from harvest and handling conditions. When fruit and vegetables are exposed to water containing pathogens, they often become infected and subsequently decay during shipping and handling. Pathogens present on freshly-harvested products accumulate in recirculated water handling systems and greatly reduce sanitation efficiency. Fresh-cut produce is highly susceptible to microbial contamination, because microbial cross-contamination can occur through shredders and slicers and the inner tissues can be exposed to microbial attachment and growth after cutting. Many postharvest decay problems result from the ineffective sanitizing of dump tanks, flumes and hydrocoolers (Figure 10.7a,b). Moreover, the operations should be conducted at a low temperature to reduce microbial growth. A delay between pre-washing and subsequent operations without product refrigeration can allow microbial growth and a subsequent shortening of the shelf life, as reported by Sinigaglia et al. (1999) concerning cut lettuce salad and shredded carrots.

The washing after cutting reduces microbial contamination levels and enzymatic oxidation during further storage. The effectiveness of washing to remove soil impurities and microbial contaminations is related to numerous factors, such as raw material spoilage, the duration of the washing treatment, the washing water temperature, the method of washing (dipping, rinsing, or dipping/blowing), the type and concentration of the sanitizer and the type of fresh-cut fruit or vegetable. At the moment, the disinfection agents that are used and tested for water sanitation are chlorine, ozone, organic acids, hydrogen peroxide, alcohols, phosphoric acids, UV-C light radiation, ultrasound and others, including combinations of some of them for synergistic effects (Weyer et al., 1993; Zhuang and Beuchat, 1996; Beuchat et al., 1998; Sapers and Simmons, 1998; Day, 2001; Seymour et al., 2002; Allende et al., 2006 and citations therein; Artés et al., 2007). Essential oils have also been studied as natural disinfectants (Roller and Seedhar, 2002 and citations therein). Ozone reduces the amount of wastewater, lowers the refrigeration costs of chilled water because of the less frequent flume water changing, and it can be combined with chlorine, whose use can be reduced by 25% leaving less residual odor on the product (Strickland et al., 2007). Organic acid dippings have a much more residual antimicrobial effect than an ozone and chlorine treatment on the microflora of lettuce during storage (Akbas and Ölmez, 2007). The antimicrobial action of organic acids depends on several factors, such as a reduction in pH, the ratio of the undissociated fraction of the acid, chain length, cell physiology and metabolism. Organic acid with only one carboxylic group, such as lactic acid, has been found to be

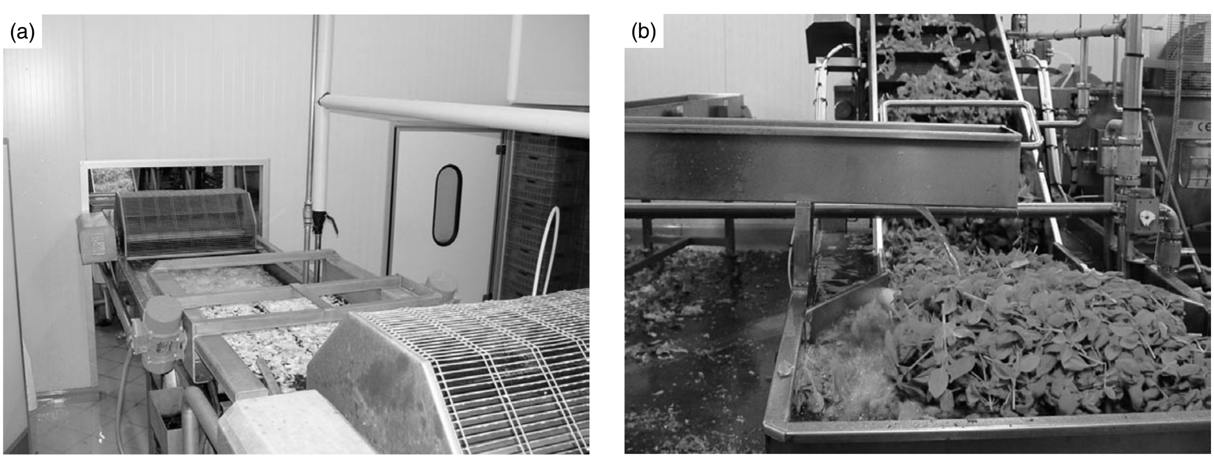

Figure 10.7 Washing of fresh-cut lettuce (a) and basil (b) in processing plants.

less active than citric acid which has more carboxylic groups. A calcium lactate treatment has been reported to have potent antibacterial properties (Saftner et al., 2003). Martín-Diana et al. (2005) compared calcium lactate with chlorine as a washing treatment for fresh-cut lettuce and carrots. Calcium lactate was not significantly different from chlorine treatment in terms of maintaining color and texture during the entire storage period. Furthermore, carotenoid levels were higher in calcium lactate-treated carrots than chlorine-treated samples after ten days of storage at 4°C. Ultimately, the mesophilic, psychrotropic and lactic acid bacteria counts were not significantly different for the calcium lactate and chlorine treatments for either vegetable. Thus, calcium lactate appears to be a suitable washing treatment, which has no post-treatment bleaching effect on fresh-cut lettuce, and does not cause the appearance of whiteness on the surface of sliced carrots. At present, chlorination is used primarily in processing plants, although there have been many attempts to find alternative washing treatments to chlorine because of the formation of carcinogenic chlorinated compounds (chloroamines and trihalomethanes) in water. Furthermore, chlorine compounds can burn the skin and release dangerous chlorine gas into the work environment (Martín-Diana et al., 2005; Page et al., 1976; Parish et al., 2003; Suslow, 2006; Wei et al., 1995). However, a sure and certain disinfection system that is able to remove dirt, weeds, pesticide residues and microorganisms, while at the same time not negatively affecting the intrinsic and extrinsic quality of the product, has yet to be found.

Lu et al. (2007) studied a predictive model through a response surface methodology to evaluate the effect of three selected factors (i.e. chlorine concentration, washing time and water-to-lettuce ratio) on reducing aerobic mesophilic bacteria in fresh-cut lettuce. Chlorine concentrations of 0, 75 or 150 μg L^{-1}, washing times of two, five or eight minutes, and water-to-lettuce ratios of 25, 30 or 35 L kg^{-1} were tested. According to the model, the efficacy in reducing aerobic mesophilic bacteria was largely influenced by the hypochlorite concentration, moderately by the washing time and only slightly by the water-to-lettuce ratio. The model predictions indicated that washing with a 75 μg L^{-1} chlorine concentration for 6.5 minutes reduced aerobic mesophilic bacteria in fresh-cut lettuce by about 2 Log cfu g^{-1}. The same reduction in aerobic mesophilic bacteria could be obtained through adjusting the washing time and water-to-lettuce ratio.

When planning the concentration of chlorine to be used, one should consider its reaction to organic matter. When the chlorinated solution comes in contact with cut produce, the sanitizer will react with the organic matter (such as vegetable tissue, cellular juices, soil particles, microbes) and the available (free) chlorine will be depleted. The difference between total chlorine and available chlorine depends on the amount of organic matter and inorganic compounds that react with the free chlorine (resulting in combined chlorine) during washing (Pirovani et al., 2004). The smaller the amount of organic cellular compounds released by cutting the produce, the smaller the difference between the total and available chlorine. Consequently, the proper concentration of chlorine to be used during sanitation should also be modeled according to the type of produce, cut size and type (e.g. slice, shred, whole leaf).

The chlorine concentrations and washing times vary to a great extent from processor to processor, and these differences are mainly related to the different operational temperatures and the resulting bleaching effects that are tolerated by the consumers in any given market. Chlorine lethal effect increases with temperature, and its affect on microbial removal occurs when there is a positive temperature differential between the water and the produce, that is, when the water is warmer than the produce (Beuchat, 2007; Hernandez-Brenes, 2002). According to Beuchat (2007), the lethal effect of chlorine occurs within the first few seconds of treatment, and the population of microorganisms decreases as the concentration of chlorine increases to about 300 $\mu g\ ml^{-1}$, above which its effectiveness is not proportional to the increased concentration. Treatments with 50–200 $\mu g\ ml^{-1}$ chlorine and a washing time of 1–2 minutes can reduce the number of microorganisms by 1–2 Log cfu g^{-1} in some instances, but can at the same time be completely ineffective in others (Hernandez-Brenes, 2002; Roller and Seedhar, 2002). Most fresh-cut processors in the Mediterranean use a concentration of chlorine of between 30 and 50 $\mu g\ ml^{-1}$, to avoid bleaching and fading effects on the products, with operational water temperatures close to 12°C.

Raw material is generally washed in cold water, because low temperatures slow down plant respiration, transpiration, warming and microbial activity. Water temperatures range between 4°C and 12°C, although washing hot raw material (e.g. summer in the Mediterranean) with colder water could cause the vegetable tissues to absorb any chemical contaminants present in water (Hernandez-Brenes, 2002, and citations therein). Maintaining the water temperature 5°C above the internal temperature of the produce can prevent this "suction" effect. One precaution could be an initial air-cooling step before washing, to minimize the temperature gap between the produce and the water temperature.

D. Drying systems

An important factor for the stability of fresh-cut product is moisture control. After washing, the excess water should be removed from the fresh-cut product before packaging, to prevent rapid microbial development and enzymatic processes that lead to product quality deterioration. Various methods exist to remove washing water, including centrifugation, passing the produce over vibrating screens with air blasts, or blotting. Water remaining on the product is a critical issue.

The duration and speed of centrifugation need to be adjusted for each product (Figure 10.8). Minimal centrifugation can leave residual water on the produce surface, thus favoring microbial growth, while excessive centrifugation can result in cellular damage and cause cellular leakage. Fresh-cut products are often left with too much moisture, which causes rapid deterioration. Pirovani et al. (2003) evaluated the effect of speed (from 0 rpm to 1080 rpm) and operation duration (from 1 minute to 9 minutes) of spin drying on the excess water remaining on washed, fresh-cut spinach, as well as the microbial growth and sensory deterioration during storage of fresh-cut packaged spinach. The combination of the centrifugation speed and operation duration affected the water removal. According to their results, it is necessary to reach higher centrifugal speeds than 600–700 rpm and duration longer than four minutes to obtain an optimal drying level of spinach (i.e. 0.1–0.3% of excess water).

Luo and Tao (2003) used imaging technology to determine the tissue damage of fresh-cut iceberg lettuce and baby spinach during a centrifuge drying process. Large

Figure 10.8 Iceberg lettuce after drying centrifugation.

differences in damage were found for fresh-cut iceberg lettuce between the two centrifuge-drying speeds of 150 rpm and 750 rpm. Furthermore, a significant difference was found at 750 rpm depending on the location of the samples in the centrifuge drying basket; the tissues of samples located near the side of the drying basket were more damaged than those located at the top, in the center, or at the bottom. For baby spinach, the damage due to the centrifugal force was similar to the results for iceberg lettuce, the samples at the bottom of the basket, in addition to those near the side of the basket, suffered from severe tissue damage. The damage to the spinach tissues was possibly influenced by both the centrifuge speed and the weight of the product in the drying basket.

Drying tunnels with continuous air flows are also used, especially for more delicate vegetables (Donati, 2003). The critical points when using air drying tunnels are the optimal adjustment of the air temperature to avoid possible raw material fading, the thermal shock between air temperature flow and raw material temperature, and the residual water on the raw material, all of which are factors that could reduce shelf life quality. Some companies have recently introduced cool-drying tunnels, which are very efficient but incur additional cost.

At present, a wide range of moisture levels are found in fresh-cut products. Fine tuning has to be related to how much water can be left to maintain tissue turgor without compromising food safety. A low microbial load on the raw material or an efficient sanitation treatment are the driving forces that can lead to less tissue damage during a long drying phase and to higher tissue turgor, ultimately leading to high-value commercial products and extended shelf life.

E. Packaging

Packaging is not only the final operation of fresh-cut processing that allows the products to be distributed and safely reach the consumers, but also the tool which, together with the cold chain maintenance, allows the quality of fresh-cut product to

Figure 10.9 Packages for fresh-cut produce.

be preserved and prolongs its shelf life (Figure 10.9). The most studied packaging method is modified atmosphere packaging (MAP). Low O_2 concentrations reduce the respiration rate, chlorophyll degradation and ethylene biosynthesis, while high CO_2 concentrations reduce the respiration rate and slow plant metabolism. The aim of packaging is to create an atmosphere that slows produce respiration, so that the minimal necessary O_2 concentration or maximum tolerated CO_2 concentration of the packaged produce is not exceeded, and both fermentation and other metabolic disorders are avoided (Jacxsens, 2002).

A modified atmosphere (MA) is generated by respiration of fresh-cut produce (passive MAP) or attained by a gas flushing (active MAP) (Bolin and Huxsoll, 1991;

King et al., 1991; Artés, 2000a,b; Kader, 2002a). The latter is preferred for fresh-cut vegetables, whose shelf life is relatively short. Passive MAP is applied to fresh-cut vegetables sealed within bags of semi-permeable films, harnessing the naturally occurring respiration of the living vegetable tissues, which will obviously modify the atmospheric conditions (Thomas and O'Beirne, 2000). One of the most important factors of this technique is the gas permeability of the selected film that must allow an adequate O_2 and CO_2 exchange between the product and the atmosphere, in order to establish the desired gas composition inside the bag. Due to the perishability of freshly processed produce, the MA is often actively established either by flushing with the desired atmosphere or by creating a slight vacuum and replacing the package atmosphere with the desired gas mixture (Artés, 2000a; Kader, 2002a).

The choice of packaging film depends on the permeability of the film to O_2 and CO_2 that must be adapted to the O_2 consumption rate and CO_2 production rate of the produce. If the permeability for O_2 and CO_2 is perfectly matched to the respiration rate of the produce, an ideal equilibrium modified atmosphere (EMA) can be established inside the package. For most produce this atmosphere is between 1–5% O_2 and 3–10% CO_2, balanced by N_2 (Kader et al., 1989; Day, 1993). The EMA depends on many factors: the product respiration rate, respiring surface area, storage temperature, packaging film permeability and equipment, RH, filling weight, pack volume, film surface area, degree and kind of illumination of the display in the retail store, as well as the initial microbial load (Artés and Martínez, 1996; Jacxsens et al., 1999; Day, 2000; Kader, 2002a,b). It was previously mentioned that the biological agents that limit the shelf life of vegetables differ because of a number of factors. Thus, it is expected that the range of recommended atmosphere composition varies according to the different kinds of products, as well as the success of the atmosphere modification (Saltveit, 1997). The subsequent maintenance of the optimum atmosphere during storage is, therefore, effective in delaying quality deterioration, as well as deterioration during shipping. It has also been observed that when shipping fresh-cut products by air, the volume of the packages increases with decreasing external air pressure; the packages can open and thus become unmarketable (Emond, 2007).

The most difficult task during packaging of fresh-cut produce is to reach the optimal EMA conditions inside the package. The main problem is that only a few packaging materials present on the market are sufficiently permeable to compensate for produce respiration. Most films are not optimal in O_2 and CO_2 conditions when the produce has a high respiration rate (Jacxsens et al., 2002). At present, oriented and bi-oriented polypropylene films are the most commonly used packaging films, even though they only give results for fruit and vegetables with a slow to moderate respiration rate stored at low temperatures. Thus, they are not suitable, for example, for baby leaves or berries. Furthermore, the difference in temperature sensitivity of the respiration rate of the produce and the film permeability can create an unbalanced atmosphere. A film permeability increase should be proportional to the temperature increase and the respiration rate increase in order to avoid anaerobic conditions. Exhaustive reviews on different packaging systems for fresh-cut vegetables have been published by Exama et al. (1993), Lange (2000) and Ahvenainen (2000). The reviews consider the different permeability ratios of O_2 and CO_2, as well as the mechanical properties and the composition of the films. In general, an optimal package film and EMA or MAP should be chosen according to the operational and shelf life temperatures of the product, the product type, i.e. single or mix, growth stage and maturity degree, the season and geographic area of raw material production, and water excess on the cut produce after drying operations. The complexity and diversity of processing make it difficult to define recommendations specifically targeted at each fresh-cut company.

Packaged fruit and vegetables are usually exposed to different surrounding temperatures during shipping from the processing plant to the consumer, storage and display at retail; MAP is not a substitute for good cold chain management, but it can help extend the shelf life. A change in the environmental temperature creates a specific problem in EMA establishment, because the respiration rate is influenced more by temperature changes than film permeability to O_2 and CO_2 (Jacxsens et al., 2002).

F. Storage temperature and cold chain

Fresh-cut packaged products need to be stored at low temperatures (<7°C) with 95% RH to slow the respiration rate, enzymatic processes and microbial activity. Storage conditioning generally refers to the storage or holding temperature, the time/temperature and the RH which the fresh-cut products may encounter. However, other factors can play a role during storage, such as the effectiveness of the packaging material to preserve food safety and quality, the technical characteristics of the storage in the processing plant, and the cold chain implementation from the processing plant to the consumer. The storage temperature required by fresh-cut products needs to be adjusted not only according to their metabolic and microbial activities, but also according to the species/cultivar and applied processing techniques (Table 10.3).

Several authors have studied the effects of storage temperature and storage time on quality and microbial growth. Lamikanra and Watson (2003) evaluated the effects of storage time and temperature (4°C or 15°C) on esterase activity in fresh-cut cantaloupe melon. The enzymatic activity, after 24 hours in storage, was reduced by 40% and 10% in fruit stored at 4°C and 15°C, respectively. Pectin methyl esterase activity in cut fruit also decreased by about 25% at both temperatures after 24 hours, but

Table 10.3 Shelf life of selected fresh, prepared vegetables in days

Product	Days
Baby carrots, peeled onion, peeled garlic	>21
Lettuce salads, lettuce mixes, spinach leaves	14–18
Broccoli and cauliflower florets, shredded cabbage, celery and carrot sticks	10–14
Pepper and tomato dices, cucumber slices, squash slices, mushroom slices	4–9

Source: Cantwell, M. (2007).

greatly increased after 72 hours in fruit stored at 15°C. Fontana and Nicola (2007) studied the effect of storage temperature (4°C, 8°C or 16°C) on the freshness of fresh-cut garden cress stored from seven to ten days. The fresh weight loss increased linearly with increasing temperature, reaching a maximum value of 1.9% at 16°C after eight days of storage. An optimal temperature was defined as 4°C, to guarantee microbial and sensory quality. Ukuku and Sapers (2007) investigated the effects of a waiting period at room temperature (ca. 22°C) before refrigerating fresh-cut watermelon, cantaloupe and honeydew melon pieces contaminated with *Salmonella*. The *Salmonella* populations in the fresh-cut watermelon and honeydew pieces declined by 1 Log cfu g^{-1} when stored immediately at 5°C for 12 days, while the populations in the fresh-cut cantaloupe did not show any significant changes. The *Salmonella* populations in the fresh-cut melons stored immediately at 10°C for 12 days increased significantly from 10^2 to 10^3 cfu g^{-1} in the watermelon, $10^{1.9}$ to 10^3 cfu g^{-1} in the honeydew and 10^2 to $10^{3.6}$ cfu g^{-1} in the cantaloupe pieces. Keeping freshly prepared, contaminated fresh-cut melon pieces at 22°C for three hours or more prior to refrigerated storage could increase the chances of *Salmonella* growth, especially if the fresh-cut melons were subsequently stored at an improper temperature.

Storage temperature is found to be of paramount importance for evolution of microbial and visual quality of fresh-cut products. Knowledge of temperature oscillations of fresh-cut product in the cold chain is necessary to determine the influence of the temperature on the loss of quality and shelf life. Many European countries lack specific regulation concerning temperature control for fresh-cut products. Fresh-cut products are classified as refrigerated products, whose storage temperature must be kept at a maximum of 7°C, with a tolerance of up to 10°C in the warmest conditions (Jacxsens et al., 2002).

The time/temperature conditions at harvest and during postharvest handling are an essential critical control point and should be monitored. The air temperature during sorting and preparation must be lower than 12°C, while during washing, cutting and packaging, the air temperature should be maintained at between 4°C to 6°C. Temperature ranges ($\geq$10°C) can be found in a fresh-cut product cold chain during shipping and unloading at the supermarket, storage and display at retail, and in domestic refrigerators. During transport in refrigerated vehicles, the main problem is to maintain the cold chain as the door may be opened and closed frequently and the doors may be left open for variable periods of time, while orders are prepared and delivered. A rapid increase in product temperature can occur on transfer from temperature-controlled vehicles to ambient conditions during unloading at the distributor. The control of temperature performance and display units in supermarkets is rather poor, and the temperature of the fresh-cut product depends on its location on the chilled display shelf. The temperature distribution in the display environment is critical. The temperature is usually not optimal (8–10°C), and may accelerate fermentation inside packages and reduce both the shelf life and the packaging effectiveness (Emond, 2007). Finally, improper cold chain management continues in domestic refrigerators. Temperature abuse, such as storage at ambient temperature and improper cooling, has been identified as the main cause of microbial and quality deterioration.

IV. Concluding remarks

Cultivation is still a fundamental part of the supply chain, but the complex market dynamics require detailed knowledge of all stages in the supply chain. In the last ten years, the fruit and vegetable market has developed a rich array of new products. At the same time, consumers have become more concerned about health and a proper diet, and have increased the demand for healthy fruit and vegetables, and product certification.

Globalization has shown that production systems need a new approach that should focus on safety and quality rather than quantity, and has shown that a fully-integrated and complex supply chain must be able to fulfill the consumers' needs. This chapter has considered the critical points concerning the safety and quality of produce that should be controlled by growers, who represent the first stage in the fresh-cut supply chain, and the technologies used by processors to maintain quality and guarantee safety.

An optimal cultivation management on the farm, an efficient and rapid harvesting, proper postharvest handling and storage are key factors that favor the quality of the raw material. Quality raw material enhances processing and final product quality, leading to increased competitiveness in the market for the fresh-cut producer. This, in turn, leads to increased bargaining power of, in particular, processors and retailers. GAPs, GMPs and GHPs are tools that can improve product quality and enhance safety, regardless of the yield, thus their implementation is recommended. Additional information and increased awareness of the sometimes potentially deadly consequences of poor handling on consumer health could encourage growers to implement food safety and quality guidelines on the farms, and favor improvements in processing and product quality management along the entire supply chain, starting from the field.

The preharvest and postharvest issues described in this chapter highlight the research efforts that are being made to test and implement innovations in order to increase fresh-cut sector competitiveness in terms of safety and quality. A continuous exchange between scientists and the fresh-cut industry is necessary to guarantee the success of the fresh-cut system.

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Ready-to-eat, minimally processed, safety, raw material production, cultivation systems, HACCP, Good Agricultural Practices, Good Manufacturing Practices, shelf life, shelf-quality.

Bibliography

Ahvenainen, R. (2000). Minimally processing of fresh produce. In: Minimally processed fruits and vegetables (fundamental aspects and applications), S. Alzamora, M. Tapia, A. Lopez-Malo (eds). Aspen Publication, Gaithersburg, MA, USA, pp. 277–290.

Akbas, M.Y., Ölmez, H. (2007). Effectiveness of organic acid, ozonated water and chlorine dippings on microbial reduction and storage quality of fresh-cut iceberg lettuce. J. Sci. Food Agr., DOI:10.1002/jsfa.3016.

Allende, A., Tomás-Barberán, F.A., Gil, M.I. (2006). Minimal processing for healthy traditional foods. Trends Food Sci. Tech., 17, 513–519.

Artés, F. (2000a). Conservación de los productos vegetales en atmósfera modificada. In: Aplicación del frío a los alimentos, M. Lamúa (ed.). AMV-Mundi Prensa, Madrid, Spain, pp. 105–125.

Artés, F. (2000b). Productos vegetales procesados en fresco. In: Aplicación del frío a los alimentos, M. Lamúa (ed.). AMV-Mundi Prensa, Madrid, Spain, pp. 127–141.

Artés, F., Martínez, J.A. (1996). Influence of packaging treatments on the keeping quality of "Salinas" lettuce. Lebensm.-Wiss. u.-Technol., 29, 664–668.

Artés, F., Gómez, P., Artés-Hernández, F., Aguayo, E., Escalona, V. (2007). Improved strategies for keeping overall quality of fresh-cut produce. Acta Hort., 746, 245–258.

Bansal, R.K., Walker, J.T. (1999). A study of high pressure water jets for cutting chicken breast meat. J. Food Process Eng., 22, 307–318.

Barry-Ryan, C., O'Beirne, D. (1998). Quality and shelf life of fresh cut carrot slices as affected by slicing method. J. Food Sci., 63(5), 851–856.

Bernardelli, M. (2005). La crisi? Non coinvolge la IV gamma. Terra e Vita, 8, 8–10.

Besri, M. (1997). Alternatives to methyl bromide for preplant protected cultivation of vegetables in the Mediterranean developing countries. Proceedings of Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, November 3–5. San Diego, CA, USA. http://www.epa.gov/ozone/mbr/airc/1997/015besri.pdf. Accessed 12 September 2007.

Bett-Garber, K.L., Lamikanra, O., Lester, G.E., Ingram, D.A., Watson, M.A. (2005). Influence of soil type and storage conditions on sensory qualities of fresh-cut cantaloupe (*Cucumis melo*). J. Sci. Food Agr., 85, 825–830.

Beuchat, L.R. (2007). Managing food safety risks in the fresh-cut industry. Acta Hort., 746, 103–111.

Beuchat, L.R., Nail, B.V., Adler, B.B., Clavero, M.R.S. (1998). Efficacy of spray application of chlorinated water in killing pathogenic bacteria on raw apples, tomatoes and lettuce. J. Food Protect., 61, 1305–1311.

Bolin, H.R., Huxsoll, C.C. (1991). Control of minimally processed carrot (Daucus carota) surface discoloration caused by abrasion peeling. J. Food Sci., 56, 416–418.

Brecht, J.K. (1995). Physiology of lightly processed fruits and vegetables. HortScience, 30(1), 18–22.

Brecht, J.K., Ritenour, M., Sargent, S.A. (2003). Preharvest nutrition impacts postharvest quality. American Vegetable Grower, April, 36–38.

Calderon-Lopez, B., Bartsch, J.A., Lee, C.Y., Watkins, C.B. (2005). Cultivar effects on quality of fresh cut apple slices from 1-methylcyclopropene (1-MCP)-treated apple fruit. J. Food Sci., 70(3), S221–S227.

Cantwell, M. (1992). Postharvest handling systems: minimally processed fruits and vegetables. In: Postharvest technology of horticultural crops, A.A. Kader (ed.), 2nd edn, Publ. 3311. University of California, Division of Agriculture and Natural Resources, Oakland, CA, USA, pp. 277–281.

Cantwell, M. (2007). Biology of fresh-cut products. Proceedings of European short course on quality and safety of fresh-cut produce. March 12–14, 2007, Bari, Italy.

Cantwell, M., Ermen, H. (2006). Causes of quality and postharvest losses. http://postharvest.ucdavis.edu/datastorefiles/234-688.pdf. Accessed 12 September 07.

Daffonchio, R. (2007). Produzione e vendita dei prodotti ortofrutticoli in Regione Lombardia. Conference on EurepGAP e Agricoltura Sostenibile, June 13. Milan, Italy. http://certification.bureauveritas.it/webapp/servlet/FileServlet?mode=preview&downloadfile=/13_06_07_Daffonchio.pdf. Accessed 13 September 07.

Day, B. (1993). Fruit and vegetables. In: Principles and applications of modified atmosphere packaging of food, R.T. Parry (ed.). Blackie Academic and Professional, Glasgow, UK, pp. 114–133.

Day, B. (2000). Novel MAP for freshly prepared fruit and vegetable products. Postharv. News Inform., 11, 27–31.

Day, B. (2001). Fresh prepared produce: GMP for high oxygen MAP and non-sulphite dipping. Campden & Chorleywood Food Research Association Group, Chipping Campden, Gloucester, UK Guideline No. 31, pp. 1–76.

del Aguila, J.S., Fumi Sasaki, F., Sichmann Heiffig, L., Ortega, E.M.M., Jacomino, A.P., Kluge, R.A. (2006). Fresh-cut radish using different cut types and storage temperatures. Postharvest Biol. Tec., 40, 149–154.

Donati, V. (2003). Solo se si mantiene la catena del freddo. Colture Protette, 8, 39–43.

Emond, J.P. (2007). Modified atmosphere packaging: plastic film technology and selection. Proceedings of European short course on quality and safety of fresh-cut produce, March, 12–14. Bari, Italy.

Exama, A., Arul, J., Lencki, R.W., Lee, L.Z., Toupin, C. (1993). Suitability of plastic films for modified atmosphere packaging of fruits and vegetables. J. Food Sci., 58, 1365–1370.

FDA (2007). Fresh-cut fruits and vegetables draft final guidance. March 12, 2007, FDA press office. http://www.fda.gov/oc/factsheets/foodsafety2007.html. Accessed 12 September 2007.

Fonseca, J.M. (2006). Postharvest quality and microbial population of head lettuce as affected by moisture at harvest. J. Food Sci., 71(2), M45–M49.

Fontana, E., Nicola, S. (2008). Producing garden cress (*Lepidium sativum* L.) for the fresh-cut chain using a soilless culture system. J. Hortic. Sci. Biotech., 83(1x), 23–32.

Fontana, E., Nicola, S., Hoeberechts, J., Saglietti, D. (2003). Soilless culture systems produce ready-to-eat corn salad (*Valerianella olitoria* L.) of high quality. Acta Hort., 604, 505–509.

Fontana, E., Torassa, C., Hoeberechts, J., Nicola, S. (2006). Il crescione per la IV gamma: aspetti di coltivazione fuori suolo e post-raccolta. Italus Hortus, 13(5), 151–154.

Fontana, E., Nicola, S., Hoeberechts, J., Saglietti, D., Piovano, G. (2004). Managing traditional and soilless culture system to produce corn salad (*Valerianella olitoria*) with low nitrate content and lasting postharvest shelf life. Acta Hort., 659, 763–768.

Galloway, B.A., Monks, D.W., Schultheis, J.R. (2000). Effect of herbicides on pepper (*Capsicum annuum*) stand establishment and yield from transplants produced using various irrigation systems. Weed Technol., 14(2), 241–245.

Gąstoł, M., Domagła-Świątkiewicz, I. (2006). Effect of foliar sprays on potassium, magnesium and calcium distribution in fruits of the pear. Journal of Fruit and Ornamental Plant Research, 14(2), 169–176.

Gleeson, E., O'Beirne, D. (2005). Effects of process severity on survival and growth of *Escherichia coli* and *Listeria innocua* on minimally processed vegetables. Food Control, 16, 677–685.

Gorny, J.R., Hess-Pierce, B., Kader, A.A. (1999). Quality changes in fresh-cut peach and nectarine slices as affected by cultivar, storage atmosphere and chemical treatments. J. Food Sci., 64(3), 429–432.

Gorny, J.R., Cifuentes, R.A., Hess-Pierce, B., Kader, A.A. (2000). Quality changes in fresh-cut pear slices as affected by cultivar, ripeness stage, fruit size, and storage regime. J. Food Sci., 65(3), 541–544.

Hernandez-Brenes, C. (2002). Good manufacturing practices for handling, packing, storage and transportation of fresh produce. In: Improving the safety and quality of fresh fruits and vegetables: a training manual for trainers, Chapter 3. Joint Institute for Food Safety and Applied Nutrition, University of Maryland, College Park, MA, USA, pp. 1–34.

Hoeberechts, J., Nicola, S., Fontana, E., Saglietti, D., Piovano, G. (2004). Medium, cultivar and plant density influenced production and postharvest shelf life of *Raphanus sativus* grown in a soilless culture system. Acta Hort., 659, 791–798.

Jacxsens, L. (2002). Literature review. In: Influence of preservation parameters on the quality of fresh-cut vegetables, Chapter 1. Doctoral dissertation. Universiteit Gent, Gent, Belgium, pp. 1–69.

Jacxsens, L., Devlieghere, F., Debevere, J. (1999). Validation of a systematic approach to design equilibrium modified atmosphere packages for fresh-cut produce. Lebensm.-Wiss. u.-Technol., 32, 425–432.

Jacxsens, L., Devlieghere, F., Debevere, J. (2002). Predictive modelling for packaging design: equilibrium modified atmosphere package of fresh-cut vegetables subjected to a simulated distribution chain. Int. J. Food Microbiol., 73, 331–341.

Kader, A.A. (2002a). Postharvest biology and technology: an overview. In: Postharvest technology of horticultural crops, A.A. Kader (ed.), 3rd edn, Publ. 3311. University of California, Division of Agriculture and Natural Resources, Oakland, CA, USA, pp. 39–47.

Kader, A.A. (2002b). Quality and safety factors: definition and evaluation for fresh horticultural crops. In: Postharvest technology of horticultural crops, A.A. Kader (ed.), 3rd edn, Publ. 3311. University of California, Division of Agriculture and Natural Resources, Oakland, CA, USA, pp. 279–286.

Kader, A.A., Lipton, W.J., Morris, L.L. (1973). Systems for scoring quality of harvested lettuce. HortScience, 8, 408–409.

Kader, A.A., Zagory, D., Kerbel, E.L. (1989). Modified atmosphere packaging of fruits and vegetables. Crit. Rev. Food Sci., 28(1), 1–30.

Kim, J.G. (2007). Fresh-cut market potential and challenges in far-east Asia. Acta Hort., 746, 33–38.

King, A.D., Jr., Magnuson, J.A., Török, T., Goodman, N. (1991). Microbial flora and storage quality of partially processed lettuce. J. Food Sci., 56(2), 459–461.

Kleinhenz, M.D., French, D.G., Gazula, A., Scheerens, J.C. (2003). Variety, shading, and growth stage effects on pigment concentrations in lettuce grown under contrasting temperature regimes. HortTechnology, 13(4), 677–683.

Lamikanra, O., Watson, M.A. (2003). Temperature and storage duration effects on esterase activity in fresh-cut cantaloupe melon. J. Food Sci., 68(3), 703–790.

Lamikanra, O., Kueneman, D., Ukuku, D., Bett-Garber, K.L. (2005). Effect of processing under ultraviolet light on the shelf life of fresh-cut cantaloupe melon. J. Food Sci., 70(9), C534–C539.

Lange, D. (2000). New film technologies for horticultural products. HortTechnology, 10, 487–490.

Lee, S.K., Kader, A.A. (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biol. Tec., 20, 207–220.

Lester, G.E., Jifon, J.L., Stewart, W.M. (2007). Foliar potassium improves cantaloupe marketable and nutritional quality. Better Crops, 91, 24–25.

Lu, Z.X., Lu, F.X., Zhang, L.K., Bie, X.M., Zou, X.K. (2007). Predictive modeling and growth models of aerobic mesophilic bacteria on fresh-cut lettuce by hypochlorite-washing. J. Food Safety, 27(2), 157–168.

Lunati, F. (2001). Linee guida tecniche ed agronomiche per i prodotti di IV gamma. Technical report, Nomisma. http://venetoagricoltura.regione.veneto.it/archive/00000177/01/La_IV_gamma_prodotti_ad_alto_valore_aggiunto.pdf. Accessed 13 September 2007.

Lunati, F. (2003). Non solo le insalate per i mix pronti all'uso. Colture Protette, 8, 23–24.

Luo, Y., Tao, Y. (2003). Determining tissue damage of fresh-cut vegetables using imaging technology. Acta Hort., 628, 97–102.

Markarian, J. (2004). Packaging gets active: additives lead the way. Plastic Additives & Compounding, March–April, 22–25.

Martín-Diana, A.B., Rico, D., Barry-Ryan, C., Frías, J.M., Mulcahy, J., Henehan, G.T.M. (2005). Comparison of calcium lactate with chlorine as a washing treatment for fresh-cut lettuce and carrots: quality and nutritional parameters. J. Sci. Food Agr., 85, 2260–2268.

McGlynn, W.G., Bellmer, D.D., Reilly, S.S. (2003). Effect of precut sanitizing dip and water jet cutting on quality and shelf-life of fresh-cut watermelon. J. Food Quality, 26(6), 489–498.

Mengel, K. (2002). Alternative or complementary role of foliar supply in mineral nutrition. Acta Hort., 594, 365–373.

Mills, H.A. (2001). Spinach. *Spinacia oleracea*. http://www.uga.edu/vegetable/spinach.html. Accessed 13 September 2007.

Natalini, A. (2005). Il melone come prodotto di IV gamma: effetto della tecnica colturale in serra su alcuni aspetti fisiologici e biochimici della conservazione post-raccolta. MSc. Thesis. Università di Pisa, Pisa, Italy, p. 127.

Nicola, S. (1993). Il vivaismo orticolo nel pianeta Florida (USA). Colture Protette XXII, 11, 45–47.

Nicola, S., Hoeberechts, J., Fontana, E. (2004). Rocket (*Eruca sativa* Mill.) and corn salad (*Valerianella olitoria* L.): production and shelf-life of two leafy vegetables grown in a soilless culture system. Acta Hort., 633, 509–516.

Nicola, S., Hoeberechts, J., Fontana, E. (2005a). Comparison between traditional and soilless culture systems to produce rocket (*Eruca sativa*) with low nitrate content. Acta Hort., 697, 549–555.

Nicola, S., Fontana, E., Hoeberechts, J., Saglietti, D. (2005b). *Raphanus sativus* production in soilless or traditional culture systems and postharvest packaging. Acta Hort., 682, 1303–1310.

Nicola, S., Hoeberechts, J., Fontana, E., Saglietti, D. (2003). Cultural technique influences on post-harvest quality of rocket (*Eruca sativa* Mill.). Acta Hort., 604, 685–690.

Ninfali, P., Bacchiocca, M. (2004). Parameters for the detection of post-harvest quality in fresh or transformed horticultural crops. J. Food Agri. Environ., 2(1), 122–127.

Page, T., Harris, R.H., Epstein, S.S. (1976). Drinking water and cancer mortality in Louisiana. Science, 193, 55–57.

Parish, M.E., Beuchat, L.R., Suslow, T.V., Harris, L.J., Garrett, E.H., Farber, J.N., Busta, F.F. (2003). Methods to reduce/eliminate pathogens from fresh and fresh-cut produce. Compr. Rev. Food Sci. Safety, 2, 161–173.

Perkins-Veazie, P. (1999). Enhancing fruit and vegetable quality for small farm systems in the South. In: 1999 Agricultural Marketing Outreach Workshop Training Manual. http://marketingoutreach.usda.gov/info/99Manual/southfruit.htm. Accessed 13 September 2007.

Pimpini, F., Enzo, M. (1997). La coltura della rucola negli ambienti veneti. Colture Protette, 4, 21–32.

Pirovani, M.E., Güemes, D.R., Piagentini, A.M. (2003). Fresh-cut spinach quality as influenced by spin drying parameters. J. Food Quality, 26(3), 231–242.

Pirovani, M., Piagentini, A., Güemes, D., Arkwright, S. (2004). Reduction of chlorine concentration and microbial load during washing-disinfection of shredded lettuce. Int. J. Food Sci. Tech., 39, 341–347.

Portela, S.I., Cantwell, M.I. (2001). Cutting blade sharpness affects appearance and other quality attributes of fresh-cut cantaloupe melon. J. Food Sci., 66, 1265–1270.

Premier, R. (2007). Microbiological quality consideration for the ready-to-eat fresh produce industry. In: The International Conference on Quality Management of Fresh Cut Produce, August 6–8. Bangkok, Thailand, Keynote presentation.

Premier, R., Jeager, J., Tomkins, B. (2007). Microbiological quality consideration for the ready-to-eat fresh produce industry. Acta Hort., 746, 25–32.

Proietti, S., Moscatello, S., Leccese, A., Colla, G., Battistelli, A. (2004). The effect of growing spinach (*Spinacia oleracea* L.) at two light intensities on the amounts of oxalate, ascorbate and nitrate in their leaves. J. Hortic. Sci. Biotech., 79(4), 606–609.

Reinink, K., Blom-Zanstra, M. (1989). The relation between cell size, ploidy level and nitrate concentration in lettuce. Physiol. Plantarum, 76(4), 575–580.

Rivera-López, J., Vázquez-Ortiz, F.A., Ayala-Zavala, F., Sotelo-Mundo, R.R., González-Aguilar, G.A. (2005). Cutting shape and storage temperature affect overall quality of fresh-cut papaya cv. "Maradol". J. Food Sci., 70(7), S482–S489.

Roller, S., Seedhar, P. (2002). Carvacrol and cinnamic acid inhibit microbial growth in fresh-cut melon and kiwifruit at 4° and 8°C. Lett. Appl. Microbiol., 35(5), 390–394.

Saftner, R.A., Bai, J., Abbott, J.A., Lee, Y.S. (2003). Sanitary dips with calcium propionate, calcium chloride, or a calcium amino acid chelate maintain quality and shelf stability of honeydew chunks. Postharvest Biol. Tec., 29, 257–269.

Saltveit, M.E. (1997). Physical and physiological changes in minimally processed fruits and vegetables. In: Phytochemistry of fruit and vegetables, F.A. Tomás-Barberán, R. J. Robins (eds). Oxford University Press, New York, NY, USA, pp. 205–220.

Sapers, G.M., Simmons, G.F. (1998). Hydrogen peroxide disinfection of minimally processed fruits and vegetables. Food Technol., 52(2), 48–52.

Seymour, I.J., Burfoot, D., Smith, R.L., Cox, L.A., Lockwood, A. (2002). Ultrasound decontamination of minimally processed fruits and vegetables. Int. J. Food Sci. Tech., 37, 547–557.

Sinigaglia, M., Albenzio, M., Corbo, M.R. (1999). Influence of process operations on shelf-life and microbial population of fresh-cut vegetables. J. Ind. Microbiol. Biot., 23, 484–488.

Sirivatanapa, S. (2006). Packaging and transportation of fruits and vegetables for better marketing. In: Postharvest management of fruit and vegetables in the Asia-Pacific Region, Asian Productivity Organization (ed.). Asian Productivity Organization, Tokyo, Japan, pp. 43–48.

Solomon, E.B., Pang, H.J., Matthews, K.R. (2003). Persistence of *Escherichia coli* O157: H7 on lettuce plants following spray irrigation with contaminated water. J. Food Protect., 66(12), 2198–2202.

Sportelli, G.F. (2003). Ortive in fuori suolo, risultati ottimi per qualità e quantità. Colture Protette, 2, 29–38.

Steele, M., Odumeru, J. (2004). Irrigation water as source of foodborne pathogens on fruit and vegetables. J. Food Protect., 67(12), 2839–2849.

Strickland, W., Sopher, C.D., Rice, R.G., Battles, G.T. (2007). Six years of ozone processing of fresh cut salad mixes. International Water Technology and Ozone V Conference, April 2–4. Fresno, CA, USA. http://www.icwt.net/conference/presentations.htm. Accessed 10 September 2007.

Suslow, T. (2006). Making sense of rules governing chlorine contact in postharvest handling of organic produce. ANR Publication 8198. http://anrcatalog.ucdavis.edu/pdf/8198.pdf. Accessed 13 September 2007.

Takeuchi, K., Frank, J.F. (2001). Expression of red-shifted green fluorescent protein by *Escherichia coli* O157:H7 as a marker for the detection of cells on fresh produce. J. Food Protect., 64(3), 298–304.

Takos, A.M., Jaffé, F.W., Jacob, S.R., Bogs, J., Robinson, S.P., Walker, A.R. (2006). Light-induced expression of a *MYB* gene regulates anthocyanin biosynthesis in red apples. Plant Physiol., 142(3), 1216–1232.

Thomas, B.M. (1993). Overview of the Speedling, Incorporated, transplant industry operation. HortTechnology, 3(4), 406–408.

Thomas, C., O'Beirne, D. (2000). Evolution of the impact of short-term temperature abuse on the microbiology and shelf-life of a model ready-to-use vegetable combination product. Int. J. Food Microbiol., 59, 47–57.

Thompson, J., Cantwell, M., Kader, A.A. (2001). Effect of cooling delays on fruit and vegetable quality. Perishables Handling Quarterly Issue 105, 1–4.

Tournas, V.H. (2005). Spoilage of vegetable crops by bacteria and fungi and related health hazards. Crit. Rev. Microbiol., 31, 33–44.

Ukuku, D.O., Sapers, G.M. (2007). Effect of time before storage and storage temperature on survival of *Salmonella* inoculated on fresh-cut melons. Food Microbiol., 24(3), 288–295.

University of Arizona–Cooperative Extension (2004a). More studies indicate *E. coli* O157:H7 can contaminate lettuce in the field. Western Vegetable Newsletter, 2(1).

University of Arizona–Cooperative Extension (2004b). Water stress may extend shelf-life of vegetables. Western Vegetable Newsletter, 2(2).

Voća, S., Duralija, B., Družić, J., Skendrović Babojelić, M., Dobričević, N., Čmelik, Z. (2006). Influence of cultivation systems on physical and chemical composition of strawberry fruits cv. Elsanta. Agriculturae Conspectus Scientificus, 71(4), 171–174.

Watada, A.E., Qi, L. (1999). Quality of fresh-cut produce. Postharvest Biol. Tec., 15, 201–205.

Weerakkody, W.A.P. (2003). Nutritional value of fresh leafy vegetables as affected by pre-harvest factors. Acta Hort., 604, 511–515.

Wei, C.I., Huang, T.S., Kim, J.M., Lin, W.F., Tamplin, M.L., Bartz, J.A. (1995). Growth and survival of *Salmonella montevideo* on tomatoes and disinfection with chlorinated water. J. Food Protect., 58, 829–836.

Weyer, A., van de Devleeschouwer, M.J., Dony, J. (1993). Bactericidal activity of disinfectants on *Listeria*. J. Appl. Bacteriol., 74, 480–483.

Wiley, R.C. (1994). Introduction to minimally processed fruits and vegetables. In: Minimally processed refrigerated fruits and vegetables, R.C. Wiley (ed.). Chapman and Hall, New York, NY, USA, pp. 1–14.

Zagory, D. (1999). Sanitation concerns in the fresh-cut fruit and vegetable industry. http://www.davisfreshtech.com/articles_freshcut.pdf. Accessed 13 September 2007.

Zhang, X. (2007). New approaches on improving the quality and safety of fresh cut fruits and vegetables. Acta Hort., 746, 97–102.

Zhuang, R.Y., Beuchat, L.R. (1996). Effectiveness of trisodium phosphate for killing *Salmonella montevideo* on tomatoes. Lett. Appl. Microbiol., 22, 97–100.

11

Logistics and Postharvest Handling of Locally Grown Produce

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I. Introduction

There is no single clear definition of "local food," and there are very few definitions presently in use which refer to the marketing or sale of goods (DEFRA, 2003). Wikipedia describes local food (also regional food or food patriotism) or the local food movement as a "collaborative effort to build more locally-based, self-reliant food economies – in which sustainable food production, processing, distribution and consumption is integrated to enhance the economic, environmental and social health of a particular place" (Wikipedia, 2008). Local food also includes locally grown produce (Hinrichs, 2000).

The definition of "local" is flexible. A farm may see this as the area reachable within a day's drive, because this is where the product can be moved efficiently. Some see "local" as a very small area, such as a city and its surroundings, others suggest a bioregion, while yet other groups refer to the borders of a nation or state (DEFRA, 2003). Some farmers' markets have a rule that its vendors must farm within an 80 kilometer (50 mile) radius (Grimsbo Jewett et al., 2007).

Locally grown produce falls into the category of environmentally identified products (EIPs). EIPs are types of food which have been obtained in such a way that their growth, processing, or distribution have a smaller environmental impact than conventionally-grown, processed and distributed food. Some examples of EIPs include organically grown and processed food, and locally-grown and processed foods (Harris et al., 2000). Local food supply chains with fewer intermediaries between the producer and the end-consumer are widely described as a way to promote more sustainable consumption systems (Sirieix et al., 2007).

A. Consumer and farmer awareness of locally-grown produce quality attributes

The quality of locally-grown produce is made up of many attributes, both intrinsic and extrinsic. The intrinsic feature of a product includes its key external attributes such as color, shape, size and lack of defects. In addition, internal attributes include texture, sweetness, acidity, aroma, flavor, shelf life, food safety and nutritional value. The extrinsic factors cover production and distribution systems and includes the use of chemicals, sustainability of production and distribution in relation to energy utilization (Hewett, 2006). Individual differences require consideration of diverse consumer segments (Brückner, 2006; Shewfelt, 2006), and it is also necessary to assess quality in an objective way, in order to address real customers' needs and perceptions (Brückner, 2006).

Some studies were carried out to evaluate farmer and consumer awareness of the quality attributes of locally-grown produce. For example, a study at Slippery Rocks University discovered that for consumers the main quality attributes in order of importance were: taste, freshness, healthiness, price and shelf life. For the farmers the order was: taste, healthiness, freshness and being locally-grown. Other aspects, such as seasonality and agronomic practices, were also of great concern to farmers (Borsari, 2003; Borsari and Liller, 2005).

Studies carried out in Italy and France demonstrated that consumers are also interested in the "local" attribute. However, the larger the physical distance between producers and consumers, the more difficult it is to create links and to provide accurate information to consumers about origin, production methods and quality characteristics. It is also more difficult for consumers to determine the definition of good quality, and influence the structure of the production and logistic process according to their wishes (Van Der Meulen and Ventura, 1993; Sirieix et al., 2007).

A study carried out in Yorkshire on produce from local orchards discovered that the term "local" supplanted "organic" in the mind of the consumer, meaning that local was more valuable than organic. Most of the orchards surveyed were essentially "untreated," a condition which has no formal status, but which nevertheless appears to have credibility for the consumers (Borrie and Potter, 2005).

An investigation into the distribution of locally-grown produce in one supermarket chain in Northern Italy showed that 40% of the consumers chose local produce due to its known origin, 30% linked this attribute to higher quality, 13% to convenient price and 14% to product safety. Freshness and impact on the local economy were reasons to buy local produce for 3%, while 78% of the consumers were willing to pay more for local produce (Piccarolo, 2006).

II. Potential benefits

Consumers are increasingly concerned about the freshness, safety and nutritional attributes of the fruits and vegetables they purchase, as well as the environmental and social implications of the production, packaging and distribution systems used in processing the fresh produce (Hewett, 2006). The potential advantages of local fresh fruits and vegetables (FFVs) are mainly related to the coexistence of production and consumption in the same area. The growing uncertainty in global markets, due to an increased threat of regional conflicts, provides an incentive to produce food locally in order to reduce dependence on imports. By taking advantage of the shorter, but highly efficient supply chains, quality will become associated with products grown in the proximity of consumers (Shewfelt and Henderson, 2003).

Quality

The common explanation that customers give for shopping at community farmers' markets is the quality of produce. Consumers are frequently looking for produce that can only be grown locally and is picked at its peak, most desirable, stage for sale (Ernst and Woods, 2005a). Postharvest research efforts have often focused on extending the shelf life of fresh produce, although the extension of shelf life frequently results in lower consumer satisfaction, even when the produce is eaten soon after it is harvested. Therefore, it is necessary to focus on ways of improving the quality of fruit and vegetables when eaten, rather than simply increasing shelf life (Prussia and Mosqueta, 2006). By lowering the lead time between production and consumption, local production, offers an alternative to extending the shelf life of produce. This is even more important for perishable produce (Busato and Berruto, 2006). Shorter transport and storage times also help to provide high-quality local FFVs, because products can be harvested at a more mature stage, while maintaining current shelf life levels. Small local producers generally provide a broad range and variety of local FFVs compared to large-scale producers. Small local producers are also of benefit to consumers, who may have access to a greater volume and variety of fresh fruits and vegetables (Gregoire and Strohbehn, 2002).

Safety and health

Agricultural practices and hygienic conditions vary greatly between growing regions around the world, and increased global sourcing raises consumers' exposure to diverse endemic microflora carried on FFVs. Global sourcing also means longer transportation and handling times, giving pathogenic microorganisms more time to proliferate and reach levels which can cause illnesses (Gorny and Zagory, 2004). Food that travels long distances often passes through many handlers, trucks or storage spaces, and has an increased risk of cross-contamination (DHHS, 2007).

Produce that is harvested, delivered and/or purchased on the same day has far fewer food safety or contamination risks. The shorter time between harvesting and the sale of the produce reduces the risk of microbial and fungi growth, while it extends the shelf life at the retail outlet for the consumer, given the same storage conditions (Berruto et al., 2003). From a health perspective, the promotion of locally-grown food complies well with several health concerns. There is a reduced risk of diet-related chronic diseases and dietary change that complement the seasonal availability of foods produced and processed by the local food and agriculture system (Wilkins and Eames-Sheavly, 2001). Reducing diesel fuel emissions by limiting the long hauling of FFVs can help reduce asthma attacks. There is also some concern about endocrine disruptors and other toxic substances leaking into food from plastic packaging (Cohen et al., 2004). Locally-grown produce usually minimizes the use of packaging material.

Traceability

An essential feature of modern food quality management systems is the ability to trace fresh or processed, food products back to their raw materials, the producer and/or previous handlers in the supply chain (Opara, 2003; Bollen et al., 2006; see also Chapter 12). Traceability has a key role in ensuring product quality and safety (Bollen et al., 2006). Well-publicized food safety concerns have forced consumers to become interested in the origin of their food. This depends heavily on shortening the distance between producers and consumers (Halweil, 2002). In terms of food safety control, local authorities can control locally-grown produce more easily than produce shipped over long distances by a large number of producers (McGarry, 2007; Roth et al., 2008). Local produce is also relatively easy to trace since, often, the only links in the supply chain are the producer and the consumer. In particular, it is easier to trace the source of a problem when customers are dealing one-on-one with a farmer. Under these circumstances, any problem can be quickly identified and resolved (Dargan, 2006). The difficulties are much greater when the supplier buys produce from great distances and accumulates products from many farmers (McGarry, 2007).

Environment

Most produce travels long distances before being eaten. A weighted average source distance (WASD) can be used to calculate a single distance figure that combines information on the distances from producers to consumers and the amount of food product transported. A WASD was calculated for a sampling of data from three Iowa local food projects where farmers sold to institutional markets such as hospitals, restaurants and conference centers. The food traveled an average of 44.6 miles (72 kilometres) to reach its destination, compared with an estimated 1546 miles (2487 kilometres) if these food items had arrived from conventional national sources (Pirog et al., 2001). In addition to cost, transporting food also has a direct and detrimental impact on the environment, and an indirect impact on human health. In 2002, a study concluded by the Leopold Center for Sustainable Agriculture (Leopold Center, 2005) indicated that transportation of local foods would save 79–94% of the CO_2 emissions, as compared to non-locally sourced foods. Researchers in Great Britain estimated that pollution and other damage associated with transport of food could be reduced by 90% if all food was grown within 12 miles (19 kilometres) of where it was eaten (Grimsbo Jewett et al., 2007). The savings depend on the means of transportation. Some studies claim that transport is an important factor, but is not the only relevant issue concerning food production and its environmental impact. To make fair assessments and comparisons, all factors and resources used throughout the lifecycle of the product have to be taken into account: production, processing, transport, retail and consumption (Sonesson, 2005; Bhaskaran et al., 2006). Despite the reduction in energy consumption, preliminary findings suggest that consumers may be more interested in the concept if it is related to how food miles may affect product freshness, quality and taste, rather than the amount of energy consumed (Pirog, 2004). Environmental decision-makers assume that the "food miles" concept can be used as a communication signal to consumers (Smith et al., 2005). Food miles, along with the mode of transportation (e.g. truck, plane, rail and ship), should be considered to provide consumers with a relative indicator of fuel use and CO_2 emissions (Pirog and Schuh, 2002). Short supply chains could reduce postharvest losses, reducing transit time for local produce. Since the environmental impact in the production phase is often high, wasting raw material later in the chain is, of course, costly from an environmental viewpoint. The use of local products with a potentially longer shelf life could reduce the amount of waste resulting from discarding spoiled produce (Berruto and Busato, 2006). Waste reduction lowers the amount of energy used per unit of consumed produce, increasing energy efficiency.

Local community

Additionally, to keep farmers in the business of farming, the benefit of strengthening local food systems is often cited (Bryant and Johnston, 1992; Mazereeuw, 2005). The local FFV supply chain could improve the circulation of money within the region and the local economy, thus helping to break the poverty cycle. Also, urban communities where fresh, nutritious foods are scarce will be able to gain easy access to food (Casey et al., 2003). Farmers' markets also promote nutritional education, wholesome eating habits, improved food preparation, and boost the community's economy. Diversified farms which sell locally are also less vulnerable to energy cost fluctuations or export regulations. Promoting local FFVs results in good public relations for the producer, and increases consumer awareness about FFV sources and production practices. Institutions can also adopt policies that encourage purchases from local sources to promote local food production (Wilkins and Eames-Sheavly, 2001; Strohbehn and Gregoire, 2003).

Economic benefit for small-scale farmers

When produce is processed or sold fresh at grocery stores, it must pass through many links of the supply chain. However, when a farmer sells produce directly to retailers or customers, many of these links are eliminated. This makes the farmer both a producer, the first handler (he checks for imperfections personally), the processor (he prepares the produce for sale) and the distributor (he contacts and supplies the retailer with the produce) (Buck, 2007). By incorporating the above-mentioned activities, the farmer's share of consumer payments increases and affects his income positively (Gregoire and Strohbehn, 2002). Often, high-quality local produce allows farmers to raise prices. The direct sale of fresh fruits and vegetables to local caterers may provide an important source of income generation for small farms, without the need for additional investment in infrastructures and equipment (Tropp and Olowolayemo, 2000).

For developing countries, the production of FFVs for local markets can contribute to the reduction of rural poverty. Local production may also reduce imports and dependence on foreign supplies (Birthal and Joshi, 2007). While large-scale operations may benefit from investing in costly equipment and high-technology postharvest treatments, these options are impractical for small-scale handlers, especially in developing countries. Instead, simple, low-cost technological solutions are often more appropriate for small volume, limited resource, commercial operations and farmers who sell locally-grown produce. In addition, the growing demand for organic FFVs offers new opportunities for small-scale producers and marketers (Kitinoja and Kader, 2002).

III. Barriers to expansion

Despite the potential advantages of locally-grown produce, there are barriers to the expansion of the short supply chain which mainly influence small, low-income farmers. Poor handling, unsuitable containers, improper packaging and transportation can easily cause bruising, cutting, breaking and other injuries to the produce. With a high moisture content and tender exterior, FFVs are very susceptible to mechanical injury (Liu, 1999). The hygienic condition of FFVs is also an issue, because fresh produce is often eaten without prior washing (Connecticut Department of Agriculture, 2007).

The lack of storage facilities for small production units could lower the quality of the product. Adverse weather, such as high humidity or extreme temperatures, could accelerate produce respiration and deterioration. High postharvest losses could be caused by the invasion of fungi, bacteria, insects and other organisms. Physiological deterioration can also occur spontaneously due to enzymatic action, and lead to over ripeness or senescence (Liu, 1999; Kader, 2005).

The small producer's lack of technical knowledge and lack of grading equipment, results in high variability in the size and maturity of FFVs grown locally (Borrie and Potter, 2005). Even if growers and handlers of local FFVs are convinced of the merits of using proper tools or equipment during harvest and in postharvest handling, they will most likely not be able to afford them due to their cost.

The lack of production coordination between small producers could lead to oversupply and shortages within a single growing season, and generate complaints from customers. Consumers generally have a favorable attitude towards locally-grown produce. Lack of availability and information about local FFVs are the most significant barriers to consumption (Harris et al., 2000). For supermarket chains, the main obstacle appears to be a combination of a lack of supply and a lack of knowledge of where to obtain local produce (Piccarolo, 2006). The lack of communication between producers and customers/receivers and the lack of market information, results in poor planning or inadequate production volumes. Businesses tend to make unilateral changes, without fully understanding the consequences of the changes either in their own business or in other links in the supply chain (Prussia et al., 2001). An overproduction of FFVs which cannot be sold in time can lead to significant postharvest losses. This problem exists not only in many developing countries, but also in developed countries (Liu, 1999; Kader, 2005). Alternative distribution systems, such as direct sales (e.g. roadside stands, produce markets in cities, farmers' markets in the countryside) should be encouraged (Kader, 2005).

Logistic problems for the food service industry include the following obstacles involving local FFV purchases: reliability, seasonality, year-round availability, product safety, cost, familiarity of sources, as well as an increase in order receiving, product processing and payment procedures (Gregoire and Strohbehn, 2002; Strohbehn and Gregoire, 2002b, 2003). Quality is also perceived differently in each link of the supply chain (Borsari, 2003). The perception of quality, the lack of information on the location of FFV production, and the complex logistic procedures (i.e. ordering, payment, relationship, approval of new goods, low-volume suppliers) are key obstacles that hinder the development of a relationship between food service buyers and farmers (Borrie and Potter, 2005).

Overall, there is a great deal of enthusiasm for local markets, though farmers are skeptical of potential profits. The incentive to harvest and market FFVs is therefore not great when set against the general objectives of farm businesses. The biggest disincentive is the amount of time, effort and labor needed to harvest, sort and distribute the fruit during a very busy time on many farms (Borrie and Potter, 2005).

The implementation of the short, local supply chain in developing countries poses other problems. Most handlers and farmers involved directly in harvesting, packaging, transporting and marketing in developing countries have a limited or complete lack of appreciation of the need for quality, or they lack knowledge of how to maintain it (Kader, 2005). Issues that currently impede the smallholders' access to markets include a weak legal, regulatory and institutional framework; poor-quality agricultural products; inadequate entrepreneurial skills; poor facilities for processing agricultural products; poor quality of the agricultural marketing infrastructure; and limited access to market information and intelligence (ActionAid, 2006). Local conditions for small-scale handlers include labor surplus, lack of investment credit for postharvest technology, unreliable electricity supply, lack of transportation options, lack of transport infrastructure, and a shortage of storage and packaging materials, among others. An investment in locally grown produce is frequently not feasible, however, it may be possible to implement some postharvesting practices to improve produce quality (Kitinoja and Kader, 2002; Heyes, 2003). The emerging local and global urbanization and agro-industrialization patterns and the rise of supermarkets and trade liberalization require synergies rather than divisions between rural and urban areas, in order for farmers in poor countries to benefit. Institutions have a key role in promoting links between rural and urban areas (Chowdhury et al., 2005).

IV. Distribution systems

The local produce supply chain handles highly perishable produce with a short shelf life characterized by seasonal production and local appreciation. Some of this produce includes a geographic indication of origin (Pirog and Paskiet, 2004). A detailed view of the many available channels for distributing locally-grown FFVs is presented in Jett and Hendrickson (2006). Consumer awareness of local FFVs is different if they are purchasing produce, compared to when they are eating it in food service outlets. The money spent for locally-grown produce in direct marketing distributions represents only a small percentage of the total spending in other distribution channels (CTIFL, 2007c). However, interest is growing in the supply of local produce to food service outlets. Serving "sustainable" food in schools, hospitals and public institutions is becoming popular (Gregoire and Strohbehn, 2002; Strohbehn and Gregoire, 2003; Cottingham, 2007).

A. Farmers' markets

Farmers' markets are defined as fixed locations where several farmers gather to sell their own products at recurring times (Jett and Hendrickson, 2006). These are often located in the middle of cities and towns. Some markets are open seasonally, while others are open on weekends or daily, especially those located in big cities.

Throughout the year, farmers take advantage of a common space, and gather on a regular basis for the convenience of consumers. This distribution channel brings about local economic stability, contributes to a sustainable environment and is a place for information exchange and social gatherings. Farmers' markets also give consumers an element of control within the food system, and provide them with a unique opportunity to learn where the food comes from and how it is produced.

Markets are classified by different factors, such as their location or structure (open air markets, market halls and market districts) or are defined by what is sold at the market, through terms such as "grower only," "green," or "organic." Farmers' markets have rules and regulations concerning how the items are sold and who can sell them. Some markets allow vendors to sell only what they have produced on their farm, and others allow for the purchasing and reselling of FFVs (Phillips, 2007). Farmers' markets require that growers spend a significant amount of time on the marketing of their produce and, for some this may represent an inefficient use of time. Due to the relatively small sales volume, the growers need to differentiate their FFVs in order to increase their volume sold and therefore, do extra work.

In continental Europe street markets, as well as "marketplaces" (covered places where merchants have stands, but not entire stores) are commonplace. Both retailers and producers sell their wares to the public (Wikipedia, 2008). In particular locally-grown produce is sold in these markets by farmers.

Local fruits and vegetable sales in the US occupy only a small percentage of the entire distribution channel. However, over the past 10 years, the number of farmers' markets has increased by over 100%. In 2006, the directory listed 4385 farmers' markets. With total sales estimated at about $1 billion for 2005 (Shaffer and Cox, 2006). It is estimated that more than three million consumers shop at these markets, and about 30 000 small farms and food entrepreneurs earn a partial or full income selling their products at farmers' markets.

In France, 5000 farmers sell locally-grown produce directly to consumers. With €800 million in sales, these markets represent 7% of the FFVs sold (CTIFL, 2007c). Although the markets account for 15–20% of lettuce and small perishable fruits (e.g. strawberries) sales, the share of other less-perishable produce (e.g. potatoes, tomatoes) is negligible (3%). For growers, shorter channels offer an additional outlet and an opportunity to capture the margin traditionally left to the middle-men. Most consumers shop at farmers' markets for freshness, convenience and proximity to their homes (CTIFL, 2007a). For consumers, the freshness of the produce and the responsiveness of these grower–suppliers are a plus (CTIFL, 2007b).

In Italy, the phenomenon of locally-grown produce sold directly to the consumer in street markets is losing market share to supermarket chains, despite the fact that on average the markets offer FFVs at lower prices. However, in 2005 the share of highly perishable produce was still high, accounting for 34% and 47% for strawberries and nectarines, respectively, compared to 28% and 20% for the same produce sold at supermarkets (Macchi, 2006).

Another important element concerns the impact of policies and laws on farmers' markets. Hamilton (2005) described relevant policies in the US. In Italy, new regulations approved in 2007 are expected to boost farmers' markets. Approximately 400–500 new farmers' markets will be established within the next few years. The promotion of farmers' markets by regional agencies could also play an important role (Benocci, 2005).

B. Community supported agriculture

Community supported agriculture farms (CSAs) started in Missouri in the mid-1990s, after being adopted from Europe and Japan to the Northeast in the mid-1980s (Van En et al., 2007). In January 2005, there were over 1500 CSA farms across the US and Canada. CSAs are community farms where consumers interested in healthy, safe food join in an economic partnership with growers seeking stable markets (Jett and Hendrickson, 2006). Often, CSAs include a variety of community members, including low-income families, homeless people, senior citizens and differently-abled individuals (Van En et al., 2007). CSAs are also beneficial for creating loyal customers and friends, resulting in important community partnerships. The greatest benefit of CSAs however, is the financing available from anticipated membership fees, which enable the growers to pay for seeds, supplies and labor.

CSA programs may take many forms and can be initiated either by consumers (shareholding or participatory CSAs) or by farmers (subscription-based CSAs). The subscription-based CSA is the most common form. It is similar to a contractual agreement, and the level of consumer participation and involvement in the farm operations is much less significant than in the first type (Lobo and Takele, 2003). Consumers pay a membership fee based on the size of their share. CSAs may either charge an advance fee for the entire season or growers may collect a nominal membership fee with weekly or monthly invoices for the supplied goods. One share is usually designed to provide the weekly vegetable needs for a family of four. In return, members receive a supply of fruits and vegetables on a weekly basis during the growing season. By charging weekly or monthly fees based on the market value of supplied vegetables, the subscription CSAs exert less pressure on growers to supply a weekly variety compared to traditional CSA arrangements (Lobo and Takele, 2003).

At times, the CSAs provide direct delivery to members for an additional fee. The harvest risk is shared with members, who know they may receive reduced volumes or varieties depending on weather conditions or other problems. While cooperative partnerships can take a great deal of time to plan and manage, much of this can be done during the off-season. Generally CSAs have medium to high marketing costs, but they can help to stabilize farm incomes, minimize risk from specific crop failures, and provide outlets for extra produce. CSAs are almost always used in conjunction with wholesale or farmers' market outlets to diversify funding sources.

C. Food service

Food service is a growing sector in the distribution of locally-grown produce. Due to increased consumer awareness of local sustainable production, the food service sector is willing to make some local produce available on their menus (Johnson and Stevenson, 1998; Gregoire and Strohbehn, 2002; Sanders and Ancev, 2003; Starr et al., 2003; Strohbehn and Gregoire, 2003; Ringsberg, 2005). Food service is a very feasible new market for producers to consider. Several projects have focused on the distribution of locally-grown produce through a local food service. Due to the peculiarities of locally-grown produce and arrangements between farmers and the school food service, government incentives and consumer awareness, the extension of this distribution channel has ranged from pilot projects in selected cities (Ringsberg, 2005) to a vast program involving 11 000 schools in the US (http://www.farmtoschool.org/) (Buzby et al., 2003).

Successful local food projects were implemented in Iowa in several sectors of the food service industry including schools, hospitals and long-term healthcare facilities (Strohbehn and Gregoire, 2003). Also, many universities have started their own projects. For example, Cornell University pioneered a project to bring local produce to its cafeterias, and has a website with resources and pointers to other resources for promoting local food and sustainability (http://farmtoschool.cce.cornell.edu). At the University of Wisconsin, a project to encourage the purchase of food from local farms and farm cooperatives was in place on six of its campuses (Strohbehn and Gregoire, 2003). These projects gathered empirical data from the food service decision-makers to determine the perceived benefits and disadvantages of purchasing local FFVs (Gregoire and Strohbehn, 2002; Strohbehn and Gregoire, 2003). Discussions with the staff at the receiving points revealed a number of problems with the present system, which were basically caused by excessive deliveries and deliveries at unsuitable times. Ordering and receiving orders were regarded as too time-consuming because there were many low-volume suppliers. The lack of consistency and seasonality of local suppliers was also identified as a problem. Some projects indicated the necessity to establish some kind of coordination point between the suppliers and the receivers (Johnson and Stevenson, 1998; Starr et al., 2003; Strohbehn and Gregoire, 2003; Ringsberg, 2005). Small producers have difficulties providing reliable transport. Cooperative organization among small farmers could be one way to address many of these problems. Competitive pricing and the assurance of safe produce are also important.

Another issue is the complexity of the food service purchasing process which could be troublesome for small farmers. An example of procurement process simplification was carried out in Kentucky (Robbins, 2005). The state legislature amended the procurement code to allow local agricultural products to be bought without the competitive bidding process. Prices were established, based on the average sales price of several wholesale companies, and resulted in lower prices for the food service procurement and higher prices for farmers. Consumer satisfaction increased, due to the fresher produce, and it was estimated that the program generated approximately $2 million in sales of Kentucky-grown FFVs.

To promote the consumption of fresh, locally-grown FFVs among students, some pilot projects in Italy include the distribution of such foods in vending machines in schools. The sales price was lower or equal to the previously offered snacks. The vending machines were replenished daily with single packaged, local fruits, and were connected via GSM network with the supplier to avoid a lack of produce. Traceability was very simple because the produce was packaged individually, with an expiration date on the label. A single cooperative managed the service (Valentini, 2007). The pilot project involved 41 schools (i.e. 50%) of one district in Emilia-Romagna for a total of 23 500 students (Nasolini et al., 2007). Both students and teachers were informed about the project before the vending machine installation. The distribution of locally grown fruits was of interest to 46% of the students, and resulted in an increased consumption of the same produce at home (i.e. 34% of those interviewed).

Some pilot projects in London hospitals aimed at increasing the amount of local or organic food served in hospitals to 10% of the routine catering provision, to improve health by providing fresher food for patients, staff and visitors and also to support local farms and food businesses (Cairncross, 2004). Some examples of farm-to-hospital program elements include the purchasing of locally-grown products such as fruit, vegetables, meat and dairy for use in the cafeteria and patient-served meals, and hosting farmers' markets or CSA programs on hospital grounds (Cottingham, 2007). The projects increased customer satisfaction in hospitals, which are often perceived as serving low-quality food. Using high-quality, locally-grown produce in a percentage of their meals is considered important for the customers, as well as for the institutions that are responsible for promoting health by serving wholesome food (Cottingham, 2007).

D. Restaurants

Today's food consumption trends pressure many chefs to source local, high-quality products (Jett and Hendrickson, 2006). The most likely market targets are independently owned and operated restaurants that change menus frequently (Strohbehn and Gregoire, 2003). Many are high-end restaurants that depend on high-quality ingredients. Such restaurants use a limited amount of a single product and need multiple deliveries throughout the week (Nakamoto, 2003). Less pricey, high-volume restaurants could also be potential buyers of local produce, in particular highly perishable FFVs that do not withstand long shipping distances (Grimsbo Jewett et al., 2007).

Farmers should consider the following positive aspects of food service marketing: higher price, larger sales volume than retail sales, lower marketing costs and time requirements, and a buyer for unique and highly perishable products (Jett and Hendrickson, 2006). The feedback that growers receive from chefs on their product, who may recommend various solutions such as earlier harvesting or different postharvest treatments, is also important. In order to sell to chefs, growers must apply suitable postharvest handling, sorting, grading and packaging.

Restaurant sales are also an opportunity for farmers in developing countries. An investigation into the mango market in Bali examined the restaurants' acquisition of fruit directly from the fresh farmers' markets (Batt and Parining, 2000). The reason for the high rate of acquisition from local markets was due to the freshness of local vegetables (95%), although lower prices (86%), greater availability (76%) and ease of purchasing (76%) were also considered important. The lack of production during the peak tourism demand was a problem. Often, however, the product was dirty, poorly graded and its quality was too variable. While even high-class restaurants indicated a preference for locally-grown produce, it is apparent that the quality of local produce could improve significantly through the implementation of postharvest practices.

E. Supermarkets

Locally-grown produce can also be sold at supermarkets, since they cannot be purchased through traditional wholesale channels (Jett and Hendrickson, 2006). Geographic indication of origin, or very well-known locally-grown produce are accepted by supermarkets, and do not compete with the same kind of produce from outside the region (Piccarolo, 2006). By selling to a supermarket, growers can market large quantities of produce. In some cases, direct marketing to supermarkets eliminates the need for a broker, and allows the farmer to label his produce. In other cases, the supermarket is responsible for choosing a label for the product (Piccarolo, 2006).

Most supermarkets require produce of a consistent quality and quantity, which is difficult for a single producer to provide. To cope with this problem, small-scale farmers can join cooperatives for marketing purposes. A cooperative is a business organization owned by grower-members. Cooperatives offer a wide variety of crops, and serve a larger number of customers that could not have been reached by individual or small producers. Cooperative marketing offers many benefits to growers, including:

- marketing a larger volume of product and therefore reducing the marketing costs per product;
- access to new markets such as wholesale distributors or supermarkets;
- exchange of technology and skills relative to packing, labeling, grading, and other postharvest treatments;
- a decrease in the cost of postharvest handling of fresh produce;
- possible time saving in sales and payments being carried out by a single manager in the cooperative; and
- transportation and delivery to stores or customers (Jett and Hendrickson, 2006).

In some cases, a cooperative of local producers could deal exclusively with the paperwork and information management, which includes orders, delivery schedules and payments (Piccarolo, 2006). A greater involvement of cooperatives encompasses the distribution of the product and all the aspects related to postharvest treatments. A cooperative may even deal with the planning of planting and production.

F. Local fresh fruit and vegetable (FFV) distribution in developing countries

Consumers in developing countries are ready for locally-grown, fresh produce. The lack of roads and infrastructure is an important factor in local market development, which has ultimately empowered local communities. Such development is advantageous because less investment is required in postharvest facilities and in grading and packing equipment for farmers. Training packages and a forum on postharvest research (PhAction) have been designed and established by the FAO in an effort to strengthen the capacities of both public and private institutions in the development and implementation of comprehensive quality assurance and food safety programs for FFVs (Heyes and Bycroft, 2002; Kitinoja and Kader, 2002; Heyes, 2003; López Camelo, 2004; Pinero and Diaz, 2007).

Results from the implementation of direct sales of locally-grown produce in developing countries are mixed. Only a few examples are presented here. Generally, the produce has considerable postharvest losses (up to 50%) (Liu, 1999; Heyes, 2003; Kader, 2005). The main factors responsible for postharvest losses in, for example, Nepal were inappropriate packaging, transportation and grading systems (Udas et al., 2005). To rectify this problem, an attempt was made to increase farmers' and vegetable traders' awareness of postharvest handling systems. The response was encouraging.

A project carried out in Brazil was successful (ActionAid, 2006). Apart from increasing individual income, the program had a positive impact on the collective organization of farmers and on the increased participation of grassroots associations in local NGO associations. The income generated by selling fruits and vegetables to the institutional market allowed family farmers to pay for electricity which helps in pumping water from the traditional tanks of the community. With permanent access to water, vegetable production could continue through all the seasons – even the dry season – and the families now have diversified food on their table and extra income.

Postharvest losses due to parasitic diseases increase with an increase in time between harvest and consumption (Skende, 1999). In Albania, delays are either a result of an insufficient demand, or the distance from the production site to markets which require extended transportation time. Apart from the logistic and postharvest factors, the lack of financing, regulation and training were the main reasons for the failure of projects that aimed at starting or improving local, short supply chains (ActionAid, 2006). There is a need for additional research and training to overcome postharvest losses in fruits and vegetables. The adoption of low-cost technologies, which are appropriate and affordable to farmers and traders may offer a solution.

G. Protection and regulation of unique locally produced foods and vegetables

The European Union (EU) countries market highly-differentiated, quality-assured foods based on historical, cultural, social, climatic and ecological factors that make products unique. In response to growing consumer interest in regional food, producer demand and policies supporting small farmers, the EU adopted two European Council (EC) regulations (2081/92 and 2082/92) for the development and protection of foodstuffs in 1992 (Tellström et al., 2003). The EU documents and protects these food products through the use of geographic indications (GIs). The purpose of GIs is to identify the link between the locally-grown produce and the region or locality where its quality, reputation, or other characteristics are clearly attributable to its geographic origin (Pirog and Paskiet, 2004). EC regulation No. 2081/92 deals with protected geographical indications (PGI) and protected designations of origin (PDO) for agricultural products and foodstuffs. This has been replaced by regulation No. 510/2006.

To receive a PGI product designation, a geographical link must exist in at least one of the production, processing, or preparation stages. PDO is a term used to describe foodstuffs which are produced, processed and prepared in a given geographical area using recognized know-how. To achieve PDO-status, the quality or characteristics of the product must be essentially or exclusively relative to the particular geographical environment of the place of origin. The production and processing of raw materials must take place in the defined geographical area from which the product bears its name. There are currently over 300 PDO-protected food products in Europe, and over 100 of these are FFVs. The register of protected products is available at http://ec.europa.eu/agriculture/foodqual/quali1_en.htm.

Small producers prepare their product in different ways, with different results. The differentiation causes problems for some customers, such as restaurants and food service outlets. Often the PDO specifies both the region in which the product was cultivated and the postharvest handling techniques in the production manual, a document which describes each part of the process, from planting to distribution. All farmers who wish to have their produce labeled as PDO must sign a contract which specifies the procedures listed in the production manual. Such an approach standardizes and raises the quality of locally-grown FFVs. GIs are highly-differentiated products, and do not compete in the same markets as undifferentiated commodities (Pirog and Paskiet, 2004). The EU countries also prosecute the misuse of product names. In the US, GIs are protected with certification marks that certify geographical origin, the type of materials used, product quality and the manufacturing or processing method.

V. Postharvest handling

The aim of the postharvest handling of locally grown produce is to deliver quality produce to the consumer. Quality cannot be improved after harvesting, therefore it is important to harvest fruits and vegetables at the proper stage, size and at optimal quality (Bachmann and Earles, 2000). Postharvest life, however, can be maintained and extended by optimized handling and reducing damage through the application of correct postharvesting techniques (Pineiro and Diaz, 2007).

Quality is difficult to define (see also Chapters 3, 8, 9 and 18). It is the result of the interaction among many factors including produce, consumer perceptions, distribution and postharvest handling systems (Shewfelt, 2006). The legislation and regulations applied to the quality and safety assurance of FFVs also have an impact on produce quality at sales points (Batt, 2006). The main issues for consumers are what product the consumer wants, and how much he is willing to pay for it. Consumer expectations should be met through the implementation of adequate logistic and postharvest handling techniques. Although it is tempting to meet the needs of all consumers in a market, an effective strategy identifies those characteristics important to a distinct segment (Shewfelt, 2006). This also applies to locally-grown FFVs.

However, the logistic question remains: is it possible to provide the volume requested at the right time, in the right place, in the right quality, and at the right price? The adequate postharvest handling of FFVs must account for the cultural, economic, technological, environmental, administrative and legal context of the target market (Pineiro and Diaz, 2007).

However, the objectives of efficient postharvest processes and of quality improvement and safety programs must conform to the needs of the various links in the FFV supply chain. To take into account both consumer and supplier objectives, postharvest handling and logistics have to be approached using the systems approach. The application of this method enables the effects of individual actions on the final quality and quantity delivered to the customers and the performance of the supply chain to be predicted (Busato and Berruto, 2006; Prussia and Mosqueta, 2006). The systems approach (Prussia, 2005) considers all the objectives of the locally-grown FFV supply chain (quality, quantity, safety and sustainability), the diversity of FFVs handled from production to consumption, the local destination of the produce (e.g. farmers' markets, CSA, food service, supermarket chains), and finally, the logistic improvement essential for reaching the overall objectives (Berruto et al., 2003; Hendrickson, 2004; Pineiro and Diaz, 2007). An example of the systems approach applied to the use of a peach wagon prototype with suspension showed advantages in the reduction of mechanical damage to the product, one of several causes of bruising in packing houses. Therefore, the solution was not adopted by the industry (Nguyen et al., 2004; Prussia and Mosqueta, 2006).

Quality assurance and safety also involves, among other factors, the systematic organization of people, products, production systems/procedures, logistics, the market and the postharvest infrastructure available. The following steps, derived from HACCP analysis, are valuable for establishing both a postharvest handling and a logistic plan (see also Chapter 8), the assembly of a team to develop the plan and assist in its implementation; the design of a flow chart of the distribution channel and postharvesting activities; the identification of hazards that may result in loss of quality; the establishment of control measures; and the prioritizing of control points and acceptance levels. Once the plan is ready, it is necessary to establish a system to follow the activities with control measures and indexes, as well as to periodically check how the plan is working. Flexibility is necessary to meet changes in customer requests or changes in production (Pineiro and Diaz, 2007).

The production of FFVs and quality maintenance in postharvest and distribution operations is associated with the attentive application of technology throughout the production, harvesting and postharvesting phases. Hygiene problems at any point in the local produce supply chain could also lower the safety of the FFVs for consumers. Although locally-grown produce should allow for shorter lead time compared to produce shipped from major production centers, microbial growth could still pose a threat, because the FFVs could come in contact with microbes or be cross-contaminated. Therefore, the handling area for harvested produce should be used solely for the purpose of eliminating the possibility of cross-contamination. Sustained efforts must be made to avoid recontaminating the cleaned produce.

The postharvest handling activities considered in this section are: harvesting, pre-cooling, grading, packing, storage and transport (see also Chapters 9, 14, 15 and 19).

These related technologies are crucial for ensuring quality and safety. For small-scale producers, the principle is not to use sophisticated technologies, but to handle the produce efficiently throughout the supply chain. Only in this way will quality and safety be maintained, and postharvest losses reduced (Enachescu Dauthy, 1995).

A. Harvesting

Harvesting is the first step in ensuring quality. Harvesting at optimum maturity is best for consumption quality. Locally-grown FFVs can often be harvested at advanced maturity, although small farmers may lack the technology to cool the produce immediately following harvesting. For this reason, harvest techniques are of special importance to many local producers.

Early morning harvesting is therefore, important because these are typically the coolest hours of the day, and allow for lower temperatures and respiration rates. It is cheaper to keep the produce cool at this time, rather than to cool it when its temperature rises (López Camelo, 2004; Cantwell, 2007). There are some exceptions, for example, some citrus fruits are damaged if handled when they are turgid in the morning (Eckert and Eaks, 1989) or when produce is harvested in the late afternoon to be transported to a local market during the cooler night hours (Thompson, 2004).

Harvesting techniques should cause minimal mechanical damage if possible. It is important to avoid unnecessary wounding, bruising, crushing or damaging of produce by equipment or containerizing (Suslow, 1997a), because more mature produce is sometimes more susceptible to mechanical damage (Cantwell, 2007). Bruises are more common, yet less noticeable at harvesting. Gentle digging, picking and handling will help to reduce crop losses, especially for produce that must be stored (Kitinoja and Kader, 2002). Damage can be prevented by handling each fruit or vegetable as little as possible and by field packing wherever possible (Wilson et al., 1995; Bachmann and Earles, 2000). Compression can crush produce, so attention should be paid when loading containers, regardless of their dimensions. Damaged produce can easily be detected, and is usually removed during grading and packing (López Camelo, 2004).

It is recommended that harvest bins or containers be covered with a reflective pad or placed in a shaded area to reduce solar heating, water loss and premature senescence (Suslow, 1997a). Some FFVs are more susceptible than others. For berries, tender greens and leafy herbs, an hour of exposure to sun is too long.

B. Pre-cooling

It is often critical that fresh produce should rapidly reach the optimal temperature for short-term storage or shipping in order to maintain the highest quality, flavor, texture and nutritional content. The cooler should be in close proximity to the field to reduce delays from harvesting to cooling. Several methods and techniques of pre-cooling are available, primarily to meet the requirements of large producers and markets (Kienholz and Edeogu, 2002). These differ in terms of time required for the treatment, energy requirements for the movement of equipment, cost, produce weight loss, batch or continuous process, and the potential for produce contamination. Not all cooling methods are suitable for every type of FFV, or for all types of packaging (Kienholz and Edeogu, 2002; Thompson, 2004). The most feasible cooling methods for small farmers are described below.

Room cooling consists of an insulated room or a mobile container equipped with refrigeration units. It is a slow method, because the cold air circulates only around the produce, but common storage rooms can be used for this purpose. Having a cooler in the field, e.g. by buying a used refrigerated highway trailer, is a simple way to cool produce (Thompson and Spinoglio, 1996; Suslow, 1997a). Room cooling is only appropriate for small quantities of produce, or produce that does not deteriorate rapidly (Kienholz and Edeogu, 2002).

Top icing is an effective method to cool tolerant produce adaptable to small-scale operations. Ice has characteristics that make it very effective for pre-cooling fruits and vegetables, especially for small-scale farmers. These characteristics include its versatility as a cold source for several pre-cooling methods, its thermal storage capacity and its portability. The ice should be made from clean water, free of chemical, physical and biological hazards (Kienholz and Edeogu, 2002).

Again, harvesting time is crucial. Simply harvesting in the early morning or at night helps supply a high-quality product at a desired temperature. Such harvest timing is especially useful when pre-cooling facilities are unavailable.

C. Sorting and grading

Many activities are performed in the field during field packaging, and each step is executed either manually or mechanically (see also Chapter 14). When the produce is packed and graded in the field, and must then be washed, the packaging should preserve its mechanical characteristics both during and after washing in order to protect the produce from mechanical damage (Kitinoja and Kader, 2002). The water for washing produce should be potable water (Macsuga, 2007). Details on the use of chlorine and other sanitizers are presented by Suslow (1997b) (see also Chapter 10).

The first operation is to remove rejects. This involves the removal of overly mature, inferior sized, severely damaged, deformed or rotten produce (López Camelo, 2004). Locally-grown distribution channels may not use written grade standards, but the products are sorted and sized to some extent. In small-scale packing operations, one or a few grading tables may suffice (Liu, 1999). In such operations, the sorting and grading are performed manually by skilled workers. The tables and equipment should have a smooth, soft surface, and the dumping and grading operations should be gentle to minimize injury. Unnecessary drops, bumping and abrasion should be avoided (López Camelo, 2004). Sorting and grading may be carried out in the field in a permanent temporary, or mobile structure or in a protected area. The two systems are not mutually exclusive. In many cases partial field preparation may be completed later at the farm (López Camelo, 2004).

D. Packaging and packing

The packaging of FFVs should satisfy three basic objectives: the standardization of the number of units or weight inside the package; the protection of the product from injuries, poor environmental conditions or unsanitary conditions during transport; and the placement of produce in a clean area. Packaging should also ensure identification, and provide information including variety, weight, number of units, selection or quality grade, producer's name, country, area of origin, handling instructions, and appropriate storage temperature for product display (Boyette et al., 1996; López Camelo, 2004). Packaging is a cost to farmers which alters if the container may be recycled or reused (Liu, 1999).

If produce is packed for handling, waxed cartons, wooden crates or rigid plastic crates are preferable to bags or open baskets, because bags and baskets do not protect the produce when stacked (Kitinoja and Kader, 2002). For domestic marketing, plastic crates provide excellent protection for produce and adequate ventilation during handling, cooling, transport and storage. Some plastic crates are collapsible or can be nested when stacked for easier handling when empty (Kitinoja and Kader, 2002; Suslow, 1997a).

New forms of packaging, which meet consumer requirements in terms of sustainability, are on the market. It is very important to reduce or avoid the overuse of non-biodegradable plastic trays and wrapping materials whenever possible, because packaging creates an extra burden of waste disposal and damages the environment. Environmentally safe packaging is made of biodegradable materials, such as plant starch and fibers. These have the strength and features of plastic material, but are biodegradable. This type of packaging is more expensive, but for high-quality, sustainable FFVs, this could be a plus for consumers. Instead of packaged produce, some retailers are moving towards a greater use of bulk bins in order to reduce the amount of packaging used (Ritenour et al., 2008; Sharrock, 2008).

Supermarkets and food services specify packaging requisites for produce. The direct sales of locally-grown produce at farmers' markets reduce the amount of packaging needed, and to this extent it is more sustainable compared to other distribution channels. Often products at farm stands are displayed without packaging, because packaging is only used for transport purposes. However, this method requires more attention to hygienic conditions of the produce at every stage. The less packaging used, the greater the perception by consumers that the produce has been grown locally.

Packing methods can affect the stability of products during shipping, and influence how well the container protects their quality. For best results, containers should be neither too loosely, nor too tightly filled with produce. Loose products may vibrate against others and cause bruising, while over-packing results in compression bruising (Kitinoja and Kader, 2002). Adding a simple cardboard liner to a crate will make it less likely to cause abrasion to produce. Delicate and high-priced produce are often packed in trays, while other products are simply boxed together.

E. Field packaging

Field packing has considerable economic advantages when it is practiced, in that it reduces physical structures, labor and equipment costs, and results in lower levels of crop damage (Enachescu Dauthy, 1995). Many tasks are combined in field packaging.

Through this, products may be prepared directly for the market in the field in a single step (López Camelo, 2004).

Strawberries are generally field packed, since even a small amount of handling will damage these soft fruits. When lettuce is field packed, several wrapper leaves are left on the head to help cushion the produce during transport (Kitinoja and Kader, 2002). During field packaging, different types of carts may be used to provide room for more than one tray, to improve working positions and to provide shading for the produce in the field.

Particular attention should be paid to grading the produce in order to avoid the mixture of damaged, decayed, or decay-prone products in bulk or packed units (Suslow, 1997a). The main benefit of hand harvesting compared to mechanized harvesting is that skilled workers are able to select the produce at its correct stage of ripeness, and grade the product gently. This results in less damaged products and fewer postharvest losses. If workers are hired for the harvest season, training is necessary to improve their grading and harvesting skills (López Camelo, 2004).

F. Storage and transport

Local produce, often characterized by seasonal production, its small volume and short transport distances, could require less storage facilities and technology. In this case, the lead time between harvesting and customer sales could be limited to less than a day. It is important to note that the effective distribution of the produce is more important than its preservation in storage. However, storage is a strategy for achieving higher returns. Produce can be held temporarily to overcome fluctuations in supply and demand (López Camelo, 2004). Cold storage involves the use of an insulated room that ensures low temperatures by using refrigeration equipment and various air-moving systems. Storage time and type of storage condition depends on the intrinsic characteristics and perishability of the product. Shelf life ranges from short (particularly raspberries and other berries) to extended storage periods for onions, potato, garlic, pumpkins, etc. (Bachmann and Earles, 2000; Boyhan et al., 2004; Gross et al., 2004; López Camelo, 2004).

The ideal storage temperature often depends on the geographic origin of the product. Tropical plants have evolved in warmer climates, and therefore cannot tolerate low temperatures during storage. These must be stored at temperatures above 12°C. Plants which have evolved in temperate, cooler climates, on the other hand, can be stored at 0°C. Fruits and vegetables are divided into three groups in terms of temperature and RH requirements: Group 1 (0–2°C, 90–98% RH), Group 2 (7–10°C, 85–95% RH) and Group 3 (16–18°C, 85–95% RH) (Thompson and Spinoglio, 1996; Boyhan et al., 2004). Temperature, the primary means of lowering the respiration rates of FFVs, has an important relationship with vapor pressure and thus directly affects the product's rate of water loss (Suslow, 1997a). Water loss may result in wilting, shriveling, softening, browning, stem separation or other defects. It may also, of course, result in the reduction of saleable quantities (Suslow, 1997a; Berruto et al., 2003). High RH is needed to reduce product moisture losses.

The principal design constraints for produce storage are to uniformly maintain desired temperature and RH levels. The airflow must be distributed uniformly throughout the cooler in order to minimize temperature variability (Thompson and Spinoglio, 1996; Thompson, 2004). The packaging also influences the time required to cool off the produce, and energy requirements. Vent openings in the package should allow air to flow through the produce, and thus determine a way to fill the cooler. Fresh horticultural products should be cooled after harvesting and during transport. In the absence of a pre-cooling system, which is quite a common situation for many small farms, it is important to consider that room cooling is only appropriate for small amounts of produce or produce that does not deteriorate rapidly. For some produce, the use of top icing is effective for pre-cooling (Kienholz and Edeogu, 2002). Another cheap way to store products without the full temperature and RH of coolers is to take advantage of environmental conditions. At night, air temperatures tend to be low, and the cool night air can ventilate the produce. Soil temperature at a depth of two meters below the surface is equal to the average annual air temperature (Thompson, 2004). Underground or cave storage in the right season, using natural cold air, could also work for short-term storage purposes. Here, storage RH could be regulated by controlled ventilation and dehumidifiers. Well-water temperature is also usually equal to average annual air temperatures and can sometimes be used to cool FFVs. Unfortunately, few of the above alternatives work well in humid, tropical climates.

Once the FFVs have been cooled, they must stay cool. It is very important that the cold chain is continuous (see also Chapter 19). Trucks used for road transport may be refrigerated or may sometimes just be insulated for short transport distances, as in the case of locally-grown FFVs.

Transport to roadside stands and product display at roadside stands or farmers' markets can often result in the produce being exposed to direct sunlight, warm or even high temperatures, and low RH levels. Rapid water loss under these conditions can cause fruits and vegetables to deteriorate (Suslow, 1997a). By providing postharvest cooling before and during transport and a shading structure during display, the produce will last longer.

For direct marketing (in-store, roadside stand) farmers should make sure their products are fresh by misting them with water regularly or by storing them in insulated cartons prior to display. Some of these cartons can be converted into display cartons by removing the tops. Some highly perishable items may only be offered for sale if displayed in ice or water containers (Marr and Gast, 1995).

VI. Logistics

There are different definitions of logistics, each of which differs in the extent to which this matter is considered. The Council of Supply Chain Management Professionals (CSCMP) defines logistics management as "that part of the supply chain which plans, implements and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption, in order to meet customers' requirements" (CSCMP, 2008). The goal of logistic services is to ensure the availability of the right product, in the right quantity, at the right time, in the right conditions, right place, to the right customer and at the right cost. The supply chains of locally-grown FFVs are classified in direct marketing distributions (farmers' markets, CSAs, roadside stands, on-farm stores) and indirect marketing distributions (restaurants, food service, supermarkets). Each supply chain is characterized by different factors that influence logistic design and operations, described below (see also Chapters 6 and 7).

A. Product quality and availability

Quality and availability must be considered when a farmer chooses FFV supply chains (Jett and Hendrickson, 2006). Suitable FFVs for short supply chain are products which are difficult to ship over long distances, due to their perishability (e.g. some berries) or products that have strong local or regional appeal, but that may not have enough widespread appeal to be part of the standard inventory of a large-scale food distribution company (Rowell et al., 1999; Tropp and Olowolayemo, 2000; Jett and Hendrickson, 2006). Many examples of locally grown produce also include organic FFVs, and these could have a positive impact on the market (Kidwell and Thompson, 1995; Lobo and Takele, 2003; Cottingham, 2007; Grimsbo Jewett et al., 2007). Protected FFV names, such as PDO and PGI, are also important in some cases (Tellström et al., 2003; Pirog and Paskiet, 2004; MacLeod and Scott, 2007).

Farmers' markets have no constraints as to the availability of produce. Some farmers simply sell their produce at farmers' markets, while others make use of two or more distribution channels. In order to satisfy the seasonal availability requested by some distribution channels (e.g. food service, CSAs), farmers overproduce FFVs. First they provide food to the restaurant or food service, and then sell the surplus at farmers' market (Nakamoto, 2003). FFV variety is often associated with farmers' market stands. Customers expect variety, and the farmer should manage this in the production and postharvest plan, considering the special aspects of each single crop.

For farm **roadside stands** and **on-farm stores**, producing a high-quality product is a prerequisite when dealing with a high-end, high-priced product. However, this is a niche market, and sometimes overproduction can occur. A resolution to this problem can be found by selling through other distribution channels. Selling high-quality produce requires special attention to the customer (Nakamoto and Fleming, 2003). Product availability and variety is a means of increasing customer service and customer loyalty (Grimsbo Jewett et al., 2007).

In **CSA**s, consumers buy agricultural products directly from the farmer, paying for the products in advance at the beginning of the season. Under these circumstances, consumers not only support the farmers' growing operation, but also share in the risks associated with crop production. The farmer, in turn, makes a commitment to produce a diverse and sufficient quantity of high-quality FFVs in order to satisfy the demands and expectations of the consumers (Lobo and Takele, 2003). CSAs require excellent management skills, and planning is essential to provide customers with the expected variety and quantity of crops throughout a 20–24 week season. Produce variety and quality is a key issue for CSAs and all other forms of direct marketing (Grimsbo Jewett et al., 2007).

Produce growers have a considerable amount of success in marketing specialty fruits and vegetables with strong regional appeal to local institutional **food services** (Tropp and Olowolayemo, 2000). For restaurants and food services, season-long quality and availability is a key factor (Nakamoto, 2003). The overall demand for food items in school food service operations is considerably stronger during the fall, winter and early spring months, compared to late spring and summer (Helliot, 2004). Thus, when approaching clients in the food service market, it is critically important for farmers to consider which items they will be able to supply to customers. Consumers need to know which products are available and when, and want to be assured that the produce will be safe. It is common for food service buyers to face multiple responsibilities therefore; producers must understand the many requirements, as well as the various compliance regulations (Strohbehn and Gregoire, 2003). Members of small farm cooperatives can usually make greater commitments to food service in terms of guaranteed volume and availability, and can usually offer a greater volume of processed farm products than most individual small producers (Tropp and Olowolayemo, 2000; Bellows et al., 2003; Ernst and Woods, 2005b). To facilitate the work with food services, it is important to plan planting in order to offer the quantity of produce necessary during the growing season (Strohbehn, 2002; Grimsbo Jewett et al., 2007). This involves planting more than required, in order to deal with shortages within the season. Overproduction in other periods has to be sold through alternative distribution channels, such as farmers' markets (Nakamoto, 2003). Cold storage could help to cope with temporary shortages.

Top-quality for **restaurants** requires consistency of supply and means harvesting shortly before delivery. If the product is unavailable, farmers should consider purchasing from a neighbor. However, this option can lengthen lead times. Planned overproduction can be a useful risk management tool; it ensures an adequate supply of product, and enhances quality. The surplus must be sold through alternative distribution channels, such as farmers' markets (Nakamoto, 2003). A greater challenge may be posed by the need for adequate volumes of produce when marketing directly to larger restaurants. It is particularly challenging to produce a volume sufficient to meet the restaurant's needs and to have produce ready for harvest when the restaurant requires it. It is recommended that producers consult with the restaurant to determine which products are sufficient in volume to meet the needs. Meeting with the manager or chef prior to planting each year is useful, because gaining familiarity with the products that a restaurant will use may assist in planning (Tropp and Olowolayemo, 2000).

Medium-sized **supermarkets** and local grocery stores expand the market for locally-produced FFVs, and differentiate themselves from large retail chains (Hendrickson, 2004). Large retail chains could also be interested in local food, in order to attract farmers and to provide a better image to their customers (Piccarolo, 2006). Traditionally, there is an intermediary between farmers and supermarkets, e.g. a broker, called a forager. This intermediary is paid to find local produce suppliers for supermarkets or for special events. Usually, the forager does all the logistics, finds the suppliers, places orders, collects the produce and delivers it to the grocery store or other outlet. He works for the customer, and therefore is not involved in the sale of the entire output of the farm (Grimsbo Jewett et al., 2007). Product availability and volume are not a concern, because the distributor can smooth seasonality problems out by buying from local farmers in season, and by sourcing products from elsewhere when local FFVs are not available.

B. Traceability and food safety

The demand for traceability has increased, due to safety concerns (Rangarajan et al., 2000a; Carvajal et al., 2005; Bignebat and Codron, 2006; Bollen et al., 2006; Codron et al., 2006, 2007; Peeters, 2007). Food safety regulations (Rangarajan et al., 2000b; Batt, 2006; Bollen et al., 2006; Codron et al., 2006, 2007) and the geographic traceability of produce are regulated by state and national entities (Tellström, et al., 2003; Pirog and Paskiet, 2004; Hamilton, 2005). Although food safety is necessary for all produce, liability and the requested procedures for tracing production systems and postharvest techniques range from very simple to very complex activities. The traceability of produce must be guaranteed, even if produce is sold without packaging (see Chapter 12). Mandatory traceability rules usually have fewer requirements than voluntary traceability schemes. In the case of voluntary regulations (see also Chapters 8 and 9), some chains require the implementation of good agricultural practices (GAPs), the registration of all operations and an inspection of the production process. The Euro Retailer Produce Working Group – Good Agricultural Practices (EurepGAP), and the British Retail Council practices (BRC) are the well-known voluntary traceability schemes. These schemes are references for good agricultural practices, with the primary objective of reducing health risks and the assurance of product compliance through due diligence (Bignebat and Codron, 2006; Batt, 2006; Codron et al., 2006; Peeters, 2007). Farmers must satisfy these voluntary protocols in order to sell locally-grown FFVs to local supermarkets or food services. For postharvest operators, increased transparency and enhanced traceability allow improvements in supply chain management systems to be implemented. For growers, improved traceability offers the potential for improved feedback on the performance of their product in the market (Bollen et al., 2006).

In relation to farmers' markets, on-farm stores and roadside stands, despite the fact that the produce should be traceable, the above-mentioned requirements are mandatory, but at much lower levels than with indirect marketing. To sell to food services, farmers or farmer groups must obtain product liability insurance. Some farm insurance policies include coverage for products sold from the farm location, but this is inadequate for produce destined to be sold to food services. Fresh, raw fruits and vegetables are considered low risk, and insurance for these products may be minor (Grimsbo Jewett et al., 2007).

Supermarkets require food traceability because they are responsible for the products sold on their shelves. This has led to the development of private standards of good agricultural practice by some distributors (EurepGAP, BRC, Nature's Choice, etc.). Not every country has the same criminal accountability policies (Bignebat et al., 2006). Fortunately, local FFVs have fewer potential problems than meat-based products. For local FFVs, the main problems concern pesticide residues. Organic crops need other types of certification, and each country has its way to deal with the issues and the associated costs. Some of these costs are very high for the single farmer (Lobo and Takele, 2003; Tronstad, 2003).

C. Processing, packaging and labeling

Despite many advantages for handling and transportation, the customers of farmers' markets associate packaging with industrial, large-volume traditional produce and therefore it is important not to overuse packaging. Since farmers' markets often do not require packaging, marketing locally-grown produce is quite simple, because it is only necessary to wash the produce, and to clean and sanitize the package (Suslow, 1997a). Some produce requires little packaging (e.g. berries), because they have little mechanical resistance. Since some protected food names are mentioned in public procurement processes, such produce requires labeling (MacLeod and Scott, 2007). Direct sales to supermarkets and food services require farmers to package, grade or process, because they cannot depend on middle-men to perform these functions.

Food services could request cold storage on the farm or during transportation. If farmers do not assure the cold chain, they risk rejection by food services (Tropp and Olowolayemo, 2000). Catering to the clients' specific preferences in terms of product and packaging, has been instrumental for some successful cooperatives which supply to schools. This is not related to product quality itself, but complies with regulation, traceability and easy handling of produce. Product packaging and labeling pertain to compliance with government (state and national) food safety regulations and ease of ordering for managers. The ability to tailor the product packaging to meet the specific needs of individual schools can exert considerable influence on the food service director's decision to use or retain the services of a local vendor (Tropp and Olowolayemo, 2000). School food services usually have limited labor resources for produce preparation. Schools are oriented towards pre-cut, prepared FFVs. However, prepared FFVs require skills and investment that are easy to implement in a cooperative form. Labeling packages with a trademark or a geographic indication of produce origin also helps customers to recognize the product (Tropp and Olowolayemo, 2000). It is important to remember that the standard size and cleaning of FFVs for food service requirements may be different from those for market sales at times, e.g. small-sized apples compared to top grade apples at markets or supermarkets (Grimsbo Jewett et al., 2007). Packaging, when requested, has to meet sustainability requirements and calls for investment or fine-tuning of processing and packaging methods (Tropp and Olowolayemo, 2000; Ritenour et al., 2008).

Restaurant buyers prefer to have a set number or weight in each package in order to facilitate purchasing, receiving and product inventory control. To protect the quality, particularly of fresh produce, sturdy containers with appropriate packing and proper transportation must be used. Plastic bags should be approved for food storage (Strohbehn, 2002; Strohbehn and Gregoire, 2003).

Products for supermarkets are offered to the distributor's customers in standard sizes, and farmers need to package products accordingly. Farmers may have to store their product until the distributor requires it, or simply lower delivery frequency

(Grimsbo Jewett et al., 2007). Often labels are required listing weight, producer code or other information. The package could be provided by the distributor. If the produce has a geographic indication of origin, this should be placed either on the label or on the packaging.

D. Customer service

Some logistic studies claim that the effort necessary to acquire a new customer is six times greater than maintaining an existing one. Area consumer demand is an important factor for directing the logistics and sales of locally-grown produce. The distribution of locally-grown produce is the link with customers. The key to success in produce marketing has always been the establishment of good relationships with buyers over time (Rowell et al., 1999). The Internet is increasingly important for this objective. An online website which describes the farmer's activity and produce availability is crucial, and should be updated frequently. Communications should focus on hours, produce availability, updated address and other contact information, and list events. Because SMSs allow for relatively few characters, they can be used to provide simple messages which refer to details on the web page. A prompt response to e-mails is important if the farmer provides his e-mail address. The willingness, time and ability to deal directly with customers are all important for customer service (Tronstad, 2003; McKelvey et al., 2007). However, customer service requirements are related to the type of customer (consumers at farmer market, members of CSAs, local food service, etc.).

Farmers' market vendors who reduce customer waiting time improve customer service. This can be done by providing timely service, by serving customers on a first-in, first-out (FIFO) basis, by providing a pre-weighed package during the peak of the season in order to reduce the delays inline, and by speeding up the serving process (McKelvey et al., 2007). The type of payment method is also important in attracting customers. Examples of payments include: cash, checks, credit cards, use of WIC or Senior Farmer's Market vouchers, and Electronic Benefits Transfer cards for the Secure Supplemental Nutrition Assistance Program (DHHS, 2007). The use of credit cards is more frequent, and people usually tend to spend more than when they pay by cash (Tronstad, 1995). Besides price competition, the extra services (e.g. keeping produce bought by customers in a shaded area until they leave the market, giving free samples or discount coupons for the next purchase, providing printed materials) could help to increase customer demand. Farmers should obey regular market schedules, and have an adequate volume of produce.

For CSAs, keeping in touch with consumers is critical, and allows businesses to respond to changing needs or seasonal trends, or keep consumers–subscribers informed and involved with farm activities. A stable base of satisfied customers should be maintained. Satisfied customers can also bring new customers. The diversity of the products grown and sold by the farm, and the variety of value-added and customer service activities (e.g. direct delivery) will keep customer service levels high (Lobo and Takele, 2003).

For food services, customer service includes timely deliveries of the right kind of produce, in the desired quantity and of reliable quality. Food service requirements for products (size, packaging, quality, price) are particular, and farmers must pay attention to the needs of managers (Nakamoto, 2003; Tropp and Olowolayemo, 2000). The ability to cultivate close relationships with food service customers and to respond quickly to any problems is an advantage. Large-scale food distribution firms are not able to match such a service.

For restaurants, the reliability of quality and volume and communication with customers are key ways to establish and maintain a market presence (Ernst and Woods, 2005b). Again, farmers should remember that "it is easier to keep an existing customer than to create a new one," and also consider "make it easy for new customers to stick." The firm's good name and reputation are powerful assets that must be protected, and these are built through customer service (Nakamoto and Fleming, 2003).

E. Information flow

In an ideal situation, the business links in the chain are connected through cash and information flow from the consumer to the grower and by produce and value flows from the grower to the consumer. This information is not often collected and shared effectively and in a timely manner. Due to a lack of information exchange, every stakeholder tends to make unilateral decisions, without fully understanding the consequences of his or her actions on the supply chain (Prussia et al., 2001; Collins, 2006). Information exchanges provide more knowledge along the supply chain and allow for creation, delivery and share value (Collins, 2006). It is important to streamline and expedite the exchange of information, even for locally grown FFVs, because it is less expensive to invest in the exchange of information than in distribution infrastructures (Busato and Berruto, 2006; Prussia and Mosqueta, 2006). Traceability could help to streamline the information flow in both directions along the supply chain (Bollen et al., 2006).

Customers need information on production availability, site location, product price, production techniques and product traceability. It is also important to gather information from customers, and to understand their interests in terms of produce quality (Brückner, 2006; Shewfelt, 2006; McKelvey et al., 2007). This is relevant in farmers' markets and food service (Gregoire and Strohbehn, 2002). Farmers often do not pay attention to customers or provide information about product availability or shortages, or if they do so they do not provide it in time. In the traditional supply chain, such tasks are carried out by retailers and distributors (Shewfelt, 2006). Timely information is very important, especially for food services and restaurants (Tropp and Olowolayemo, 2000; Nakamoto, 2003).

Consumers at farmers' markets appreciate exchange of information on produce and free samples. Customers are often interested in the nutritional value of different FFVs, how they are grown or processed, or what makes offers special. They also appreciate hearing about how products are used by other satisfied customers. Farmers should inform customers about the farm, and should be aware of news about locally-grown products (McKelvey et al., 2007). This information, along with lessons learned directly from customers, can be used to adjust product selection to better suit customers' needs.

CSAs are sensitive to the feedback from their members who request information about on-farm activities (Grimsbo Jewett et al., 2007). The use of the Internet and e-mail helps to handle information efficiently, yields good returns on investment, and provides excellent potential for promoting the business and expanding marketing opportunities. Computers greatly enhance the work of a CSA member, not only in scheduling crop production and harvesting, but also in keeping track of the content of the weekly (or bi-weekly) basket, whole shares and half shares, workdays, and the division of available produce into equitable shares. Members can stay informed by receiving a newsletter, recipes, workday notices, schedule changes and personal notes (Adam, 2006).

The streaming of information for food services should focus on reducing transaction and procurement time (Michael, 2006). A simple way of delivering invoices could be by issuing an invoice for each delivery when a single local grower supplies to the food service. Orders could also be placed by phone (Grimsbo Jewett et al., 2007). The marketing and distribution strategies for farmers participating in a cooperative with multiple food products could allow restaurants, stores and food services to lower transaction costs involved in obtaining local FFVs, thus reducing the number of deliveries and procurement procedures (Hendrickson, 2004). Expediting the procurement process and payments is easy for cooperatives, since they can invest in the information technology to aid streamlining ordering, receiving and payment processes (Strohbehn and Gregoire, 2003). Some cooperatives provide Internet-based ordering systems. Timely communication with managers when a shortage of produce occurs is also very important.

For farmers who wish to sell to restaurants, the logistic information needed when concluding a contract with a local restaurant or supermarket pertains to: products available for sale; volume and forms of sales; availability period; frequency of deliveries and prices. The grower should be familiar with other essential information pertaining to restaurant menu needs, and his ability to satisfy these needs by customizing production (Nakamoto, 2003; Strohbehn and Gregoire, 2002a).

Information flow and order processing for supermarkets is the distributor's responsibility. The distributor handles all sales, sends invoices and is remunerated by the supermarket. In some cases the distributor simply collects the orders, distributes the sales among farmers, provides invoices, is remunerated by the supermarkets and then pays the farmers.

F. Location

Location is important for direct marketing. Every place of consumption near the place where production occurs has the potential of distributing locally-grown produce (Hendrickson, 2004). However, proximity to the city does not always favor farm direct marketing. For people who live in the city, the perception of the farm location is a few miles away from the city center (Tronstad, 2003). The optimal location however, depends on the customer base, on whether they buy produce on a daily or weekly basis or whether they visit the farm only occasionally. There is also the possibility to establish new places to sell locally-grown produce at worksites (Granger and

Cheung, 2007a,b). It is a rule of thumb that people are attracted to a shop at a location proportional to the square root of the shopping area, and inversely proportional to the distance traveled to a location. The further away the location is from customers, the bigger the area and the offered activities should be.

The location of the farmers' market is crucial. For the farmers' market, compliance with the concept of customer proximity (e.g. the distance between place of residence and place of purchase), is important. An area reachable by car, bicycle or walk within 2 to 15 minutes is considered close. The availability of parking for loading and unloading produce is also important in order to avoid long distance transportation. In most cases, it is not practical for farmers to transport their produce beyond where they park (CTIFL, 2006; DHHS, 2007). To some extent, farmers are unwilling to travel every day to reach consumers (Jett and Hendrickson, 2006). Therefore, the farmer's proximity to the market is also very important for daily farmers' markets (Concaro and Capurro, 2006; CTIFL, 2006; Jett and Hendrickson, 2006). Markets may be located on college campuses, in hospital facilities, on federal and state land, in parking lots of malls or stores, in parks, community centers, church parking lots or closed city streets. Important points to consider before joining a farmers' market are: visibility from streets and walkways; electricity availability and placement; shaded space for customers and farmers (DHHS, 2007); potable water; bathroom access; customer parking and public transportation access (Grimsbo Jewett et al., 2007).

The display layout is important in selling produce (Lloyd et al., 1995). The use of contrasting colors and the display of different colored commodities together, make a stand very appealing. The produce should be clean, neatly arranged, and regularly inspected for defective items. The display table should be full, because customers are encouraged to buy when displays show abundance. Prices have to be visible, but should not interfere with viewing of the produce. Having the products at a height and distance reachable by customers is important. Shading keeps the temperature of products low, and allows the produce to last longer under open air conditions (Suslow, 1997a).

The location of a roadside stand or on-farm store can greatly influence its profitability. Roadside stands and on-farm stores are most successful in areas of high traffic volume (Jett and Hendrickson, 2006). A visible location is usually a prerequisite for a successful farm or roadside stand. Direct marketing can also work in more remote locations, but it will require more advertising and promotion. Many urban consumers consider visits to farms or farmers' markets recreational activities, because their families enjoy seeing farms and talking with farmers (Rowell et al., 1999). Some variables to consider when evaluating sites are the street traffic, the area population density, the per capita income, the required travel distance, the location of competitors and the type of produce offered. The location should be within 15 minutes' travel time, and should provide enough parking spaces for all potential customers (Lloyd et al., 1995). Roadside stands should be visible from the road, and are more efficient if they are located near a road with an average speed lower than 80 km h^{-1}. Signs should be large enough, and should be placed at the market site and also at least 400 meters from the stand in both directions. Roadside stands or farm stores should be near the farm, orchard or field in order to create a farm atmosphere.

A survey of a horticultural district in Italy, located just 46 to 60 miles (50 to 75 kilometers) away from three major cities, showed that the development of locally-grown produce and direct marketing will be profitable only in specific areas linked to tourist attractions or other activities, and cannot become a large-scale phenomena. Farmers were not interested in daily travel over an extended period of time to sell their produce (Concaro and Capurro, 2006). Many CSAs allow the collection of shares from the farm, but also have one or more drop sites in locations convenient for their members. Some CSAs cooperate with local food cooperatives, churches, office parks or other similar locations. CSA members must collect their shares within a specified time frame. Some members may even be willing to use their home as a drop site for others in their area (Grimsbo Jewett et al., 2007).

G. Distribution and schedule

Small farms generally lack cold storage (Tropp and Olowolayemo, 2000). However, due to short distances, both freshness and shelf life are still high for locally-grown produce. With the use of information technology it is possible to reduce lead time for information flow and therefore, limit the total lead times for delivery of FFVs (Busato and Berruto, 2006), providing longer shelf life for the product at the consumer point (Prussia and Mosqueta, 2006). For growers that participate in farmers' markets, the customers must be served on a FIFO basis. At peak season a pre-weighed package reduces the time spent in line and accelerates servicing customers (McKelvey et al., 2007). Some logistic studies have shown that a short reduction in service time significantly reduces customer waiting time. For example, when ten customers are in line, saving one minute per customer allows each customer on the average to save five-and-a-half minutes (Berruto, 2004). The layout of the stand should be carefully planned. Farmers should avoid too much movement of people at the stand, because workers will lose time and confuse customers. Adjusting the seasonal flow of customers by providing an adequate number of people working at the farm stand is also important, in order to provide timely service to customers.

For roadside stands and on-farm stores, the logistic problem is the opening hours in which customers may buy the produce. Opening hours range from eight to ten hours per day. Harvesting can proceed during the store opening hours and provide fresh produce to the stand throughout the day. This helps to distribute the daily work among personnel, and preserves product freshness, but is not feasible in all weather conditions. If cold storage is available, the produce should be placed in storage until displayed. Other activities, such as on-farm tours for schools, require extra personnel and should also be scheduled.

The distribution of CSA shares is less restrictive than for supermarkets, although it is very important for farmers and members. It is easy to plan, because consumers receive products once a week and it is less constraining than in the case of food service or restaurant deliveries. The schedule hours should be decided by members. To lower delivery costs, farmers should try to focus on groups of customers living a short distance from each other, and identify the person responsible for the entire delivery to one location. The location may act as a small distribution center for the neighborhoods which participate in the CSA (Grimsbo Jewett et al., 2007). Transport can be optimized with the many logistic tools available (Brandimarte and Zotteri, 2007). Individual deliveries should be avoided, because they are too costly. For the same reason, the possibility of customizing each share in terms of quantity, type of products, or delivery times should not be offered. Customization over the web is fairly easy, but the real problem arises with the physical delivery of produce. Farmers should avoid individual deliveries, unless they intend to spread awareness of their CSA through marketing.

The necessary planning for growing a wide variety of crops (usually 30 or more different vegetables, herbs, fruits or other crops) throughout the growing season requires knowledge of different growing techniques (Jett and Hendrickson, 2006). Farmers should have several years of vegetable farming experience and planning skills to manage the variety of crops, the planting and harvesting schedules, and to produce many different FFVs throughout the season. Thorough and careful planning should facilitate scheduling planting, production, harvesting and postharvest treatment, as well as the delivery of the right product at the right time and to the right place. A management resource planning tool (Brandimarte and Zotteri, 2007) should help to make decisions about planting and seeding, and managing cultivation for steady, season-long production, so that customers receive the diverse, weekly box of produce they were promised on joining the CSA (Jett and Hendrickson, 2006; Grimsbo Jewett et al., 2007).

Food service personnel must often observe strict restrictions when it comes to food delivery schedules. To ensure that the delivered products are high-quality and fresh, a maximum delivery time of 1.5 hours is advised (Schofer et al., 2000). Consequently, prospective local farmers are often only able to win contracts with school food service providers if they are prepared to adjust their delivery schedules to meet the specific needs of their customer base. The fact that some cooperatives follow a strict delivery schedule has been a major sales incentive with the local school food service (Tropp and Olowolayemo, 2000). The delivery schedule should match school opening before the actual delivery date, and farmers must make a commitment to deliver their products to school kitchens at specific times that are safe for students, and allow enough time for meal preparation (Ringsberg, 2005). The delivery frequency to schools ranges from once to three times a week, because of high-volume usage and limited refrigerated storage capacity.

Restaurants also have strict delivery times, because they often have limited cold storage. Punctual and consistent deliveries, along with quality, are essential for business success (Nakamoto, 2003; Bachmann, 2004). Quality is measured by shelf life and freshness. Harvesting should be done as near to the delivery as possible. Restaurants should be notified promptly if there are any shortages in orders or if the delivery will be delayed.

Supermarkets are sometimes willing to buy directly from growers through direct store deliveries (DSDs) made by the farmer. DSDs are often possible with smaller grocery stores or chains, but are discouraged by many larger chains that require deliveries to a regional distribution center (Rowell et al., 1999). Supermarkets usually buy through distributors, brokers and foragers, therefore the logistic requirements vary according to their operating procedures. The time span for deliveries is usually longer than for food service. Distributors usually have their own trucks, and delivery may occur either with the distributor's truck or be organized by a farmer. In some cases, farmers deliver directly to a local supermarket, while the ordering and processing is done by a cooperative (Piccarolo, 2006). In this way, the shelf life of the produce is optimal, due to direct delivery, eliminating the central distribution phase. Delivery occurs between 5:30 am and 11:00 am for orders placed the previous day. Some supermarkets which are located very close to the production point could plan two deliveries per day for orders placed the previous day, one in the morning, and one in the afternoon. The second daily delivery allows the supermarket to adjust its stock levels and provide fresh, high-quality produce with a longer shelf life. This also allows uniform labor utilization at the farm level.

H. Pricing and costs

Market price levels and price stability are particularly important issues for small farmers (Tropp and Olowolayemo, 2000; Jett and Hendrickson, 2006). Often the prices are the same as those which wholesale dealers charge customers (Tronstad, 2003). When determining prices, farmers should know the product costs, the demand, the competitors' offer and the uniqueness of their produce (Tronstad, 1995). The volume per purchase, the date of purchase, the crop production curve and the cost of disposal all have to be considered in setting the margin for each type of produce (Busato et al., 2007). A detailed tracking of expenses and labor is crucial to understanding the profitability of each type of locally-grown produce and supply chain. A chart and table which compare different distribution channels under these aspects can be found in Rowell et al. (1999) and Grimsbo Jewett et al. (2007).

For farmers' markets, many growers forget that marketing involves time spent in the market as well as costs such as transportation, advertising, containers, signs and stall fees. Actual costs must include these expenses (Tronstad, 1995). In addition, the cost of insurance and liability should be considered (Cook, 1995; Uchtmann, 1995; Tronstad, 2003). Allowing customers payment options influences both the costs of the service and customer service. Some options have implementation costs, but operational costs should be considered (DHHS, 2007). If credit card purchases are allowed, transaction costs must be considered, because banks usually add up to 5% per transaction (Tronstad, 1995).

On-farm stores often provide additional activities to attract customers, such as farm festivals, child attractions, U-pick, etc. It is important to recognize the return for such activities. To determine these costs, the activities have to be evaluated after a trial. In addition, detailed levels of expense tracking helps to set prices for different events or products (Rowell, 1999; Tronstad, 2003; Hendrickson, 2004). The value of the produce, and the return on customer service associated with the product, provides information which is used to decide which types of activities are crucial (e.g. direct delivery, extended open hours, e-mail and SMS, dynamic website, etc. (Tronstad, 2003)). The costs and risks associated with liability should be considered (Cook, 1995; Uchtmann, 1995; Tronstad, 2003).

For CSAs, the price is often very similar to the wholesale price offered by retailers. Here, consumers and farmers benefit from the price level. Accurate tracking of production and delivery costs is important to determine pricing. Since customers pay in advance, the farmer risks running out of money if production costs rise, or if something goes wrong in the production process. The activities should be tracked to allow for improved future accuracy of pricing (Tronstad, 2003; Grimsbo Jewett et al., 2007). For this reason, it is very important to include all the expenses, because it is not possible to raise the price later. As a precaution, farmers should raise the share cost about 25% at the beginning of the season, to cope with unforeseen adverse events during the season.

Food services often face extremely tight budget allocations for food purchases, and frequently have limited flexibility in the quality, range and variety of products that they are able to purchase for use in school meals. Farmers can expect to be paid the wholesale price typically paid by the food service (Tropp and Olowolayemo, 2000). The activities should also consider distribution time, transportation costs, sales time and packing, because the farmer has to deliver directly to the customer, bypassing middle-men or wholesale distributors. Participation in a cooperative, with cost reductions and service improvements, is an opportunity to reduce costs and increase profits when dealing with the sale and delivery of produce to a food service (Tronstad, 1995; Tropp and Olowolayemo, 2000; Bellows et al., 2003). Insurance and liability costs should also be included (Cook, 1995; Uchtmann, 1995; Tronstad, 2003).

High-end niche markets, such as top restaurants and resort hotels, are attractive, potentially lucrative opportunities, because for these customers the price of the produce is not an issue, as long as the farmer provides excellent quality produce. Price is not necessarily the most important factor to buyers. Instead, the focus on value, the perceived benefit for the paid price, is more important (Nakamoto, 2003; Jett and Hendrickson, 2006). There may be additional costs associated with marketing to restaurants. Growers that spend extra time preparing a product specifically to a chef's specifications should set a price that accounts for the extra production time. Other "hidden costs" could be fuel and time expenses for delivering the produce to the restaurant (Ernst and Woods, 2005b). It is important for producers to be familiar with the wholesale prices that restaurants are accustomed to paying for produce.

I. Promotion

There is a great deal of material on the web for promotion policy regarding local food and locally-grown produce provided by universities, extension services, local organizations and organic production groups (Tronstad, 1995, 2003; Bachmann, 2002, 2004; La Trobe, 2002; Adam, 2006; Lamb and Taylor, 2007). However, customers still lack knowledge about locally produced FFVs, despite many publications and web advertisements. Therefore, it is also the farmer's responsibility to promote locally-grown produce to consumers (Lobo and Takele, 2003). Promotions increase sales per customer, the number of clients and enhance the image and visibility of the farm, company or produce. When farmers choose promotion strategies, they should define their target audience (DHHS, 2007). It is important for farmers to decide who their potential customers are, and how they got their information about FFVs purchases (e.g. newspapers, fliers, radio or word of mouth).

Providing good customer service and a good product which yields word-of-mouth advertising by satisfied customers is priceless, and cannot be purchased or engineered. An estimated 80% of business comes from return buyers, and the focus is on rewarding loyal customers by offering discounts, gift certificates or a free delivery service (Adam et al., 1999). Coverage by the local newspaper or radio/television station can bring in more sales than any paid advertisement. Advertising budgets generally range between 4% and 10% of sales. Direct e-mail is a form of advertising with a personal touch, and requires an up-to-date and extensive mailing list. Postcards with pictures of the farm, along with a logo and promotional message may be sent just before a farm festival or when produce is available. Mailing lists should be revised each year. Group SMSs with cell phones are now easy to manage through websites, at low cost.

The greater access to fresh produce items through farm-to-school marketing programs is especially attractive to the large number of food service directors currently seeking to expand the number of vegetarian entrees and low-fat products available in school menus (Tropp and Olowolayemo, 2000; Helliot, 2004). For the promotion of locally-grown produce, it is necessary to develop and refine marketing proposals such as health benefits, local economic development and community and environmental sustainability for people who participate in community food systems (Hendrickson, 2004). These proposals have to be based on credible academic and market research, and refined for the targeted consumer groups including mothers, people with limited resources who participate in food and nutrition programs, skilled consumers interested in the benefits of community food systems, chefs, wholesale buyers and food service managers interested in purchasing locally-produced FFVs.

Educational resources such as recipes, healthy eating brochures, food safety materials and storage tips, could be included with FFV purchases. This is useful information for consumers, and could also promote local produce (DHHS, 2007). The Internet also helps to shorten the distance between producers and consumers. The farm website will keep customers updated, by informing them about produce availability, events on the farm, or an upcoming farmers' market. E-mails and SMSs on cell-phones are also useful techniques (Nakamoto and Fleming, 2003; Tronstad, 2003).

For farmers' markets, an invitation to visit the farm could be very important to strengthen relationships with customers. The participation in farmers' markets involves sharing advertising costs. This also applies to radio or TV, especially when there are special events. For roadside stands, attractive road signs are an effective form of advertising. Signs that are legible to the quick-moving motorist are a way to induce people to stop and visit the roadside market or farm store. Signs should have a logo, and should reflect the kind of goods being sold. For on-farm stores, farm tours have proven to be a successful method for differentiating produce from that of competitors. Customers remember these occasions, and it is possible that they link the brand name of high-quality produce to the region, as if only this product existed in that region. The farm tour is not an end in itself, but is a way to build a customer base and strengthen consumer loyalty (Nakamoto and Fleming, 2003; Tronstad, 2003).

Farmers should also differentiate their services and produce. The U-pick could help customers to be aware of the farmer's activity, though some farmers have experienced it as an unprofitable activity (Tronstad, 2003). When planning events for marketing farm produce, it is necessary to identify which period is better for hosting an event that could attract more people. This is not the case in farm visits in which one paid service is provided to customers (e.g. schools) who pay for it.

For CSAs, a visit to the farm could be a part of the business, and could also promote the CSA to potential new customers. Researching the strategies of similar companies facilitates plans to strengthen the farm's business. Promotion for supermarkets and food services is done through personal meetings with managers. Having personal contact is not easy; the director of a food service for a school district or academic institution usually has the primary, if not the sole, responsibility for making procurement decisions and selecting prospective vendors (Tropp and Olowolayemo, 2000). Therefore, sales appointments tend to be far more effective when they are held with the primary decision-maker, rather than with other food service personnel. The same approach applies to promotion to supermarkets.

J. Policies and regulations

The combination of policies and regulations for each distribution channel are different and some of them are so costly that a single small farm cannot afford them (Lobo and Takele, 2003; Tronstad, 2003). Policymakers support and regulate, to different extents, locally-grown produce and local farmers through the regulation of farmers' markets (Gibson, 1995; Hamilton, 2005). The regulations are relative to farm location and facilities, market rules (who sells and what is sold), food safety and traceability, and market funding (Marr and Gast, 1995). The specific rules of operation for farmers' markets may vary. In order to prevent misunderstandings, both formal and informal market rules should avoid questions of favoritism, promote quality assurance, and maintain acceptable business practices (DHHS, 2007).

Usually the market has a clear set of rules, and a procedure for enforcement of these rules, to ensure that all vendors are treated equally and fairly. Topics covered by typical farmers' market rules are: membership fees; restrictions regarding the farm's distance from the market; production practices or farm size; types of products allowed; required information to be displayed and how space is allocated to the farmers (Grimsbo Jewett et al., 2007). The on-farm store and roadside stand marketing sales regulations vary depending on the location (on-farm or off-farm, city or countryside), so it is important to contact local and county authorities before establishing a roadside stand (Rowell et al., 1999). The legal rules and regulations are much more numerous for off-farm sales than for on-farm sales. Insurance is an important requirement for direct marketing. Liability insurance is also often required (Cook, 1995; Uchtmann, 1995; Tronstad, 2003). Some farm activities, such as farm tours and farm festivals, could lead to high insurance costs. Procurement policies for food service are complex. If farmers wish to sell to food services in the US, they should consider being certified by Department of Defense (DOD). This simplifies the procurement process for school districts (Tropp and Olowolayemo, 2000). The regulation usually requires liability insurance for the farmers (Cook, 1995; Uchtmann, 1995; Tronstad, 2003).

K. Producer abilities and willingness

Often locally-grown produce comes from small producers with no possibility of investment either in transportation, or in handling, processing and packaging technologies (Tropp and Olowolayemo, 2000). For farmers who lack transportation, a local supply chain is feasible only in the vicinity of large cities where enough consumers are nearby. Producers should think about their personal preferences and strengths for conducting business.

When a distribution channel is too limited for the volume produced, a farmer can sell the surplus to other types of customers, such as food service, farmers' markets or CSAs. Sales through alternative distribution channels force changes in the logistic customer service level, the quality of product offered and prices. Using several distribution channels is efficient, although it is common for farmers to use a combination of approaches, and gradually move to the one that works best for their goals and operations (Grimsbo Jewett et al., 2007).

Farmers' markets require a significant amount of time for marketing the produce and therefore this, may not be an efficient use of time for all growers (Rowell et al., 1999). Often farmers are not interested in spending too much time at farmers' markets, or in changing their crop rotations to produce the large variety of crops that consumers expect to see in farmers' markets or street markets (Concaro and Capurro, 2006). The farmer's flexibility in adapting to different channels is important for coping with difficult situations (e.g. low price of commodity crops) or with niche markets that absorb only small volumes of high-priced, high-quality FFVs (Nakamoto, 2003). Experience is also important when many different types of crops need to be grown (Grimsbo Jewett et al., 2007). Training in production, postharvest, logistics and information technology are also important for farmers to enhance their skills (Hendrickson, 2004). There are many self-assessment tools and tables for choosing distribution channels for locally grown FFVs that take into account all the aforementioned aspects (Rowell et al., 1999; Jett and Hendrickson, 2006; Grimsbo Jewett et al., 2007).

L. Logistic plan monitoring

Once goals for the production and distribution of locally-grown produce have been established (e.g. customer service, logistic performance and costs) it is necessary to choose indexes that describe their performance. Some of the indexes are related to customer service, others to economic aspects or to logistics. Logistic indexes describe logistic performance and customer service. Some of the indexes that can be monitored are: the number of new customers, customer loyalty, shortage of produce, frequency of deliveries to schools and restaurants, weekly production of a single item, percentage of correct deliveries in terms of produce quality and quantity, percentage of correct deliveries in terms of scheduled deliveries, and the occurrence of food safety problems (Nakamoto, 2003).

Economic indexes require the tracking of all activities (Tronstad, 2003; Buck, 2007). New traceability software available on the web has additional features that allow farmers to track economic activities such as the direct costs of production, postharvest and distribution of FFVs. Some software can also track fixed costs. It is important to evaluate the project's success rate in order to make improvements in the future. Surveys on customer and farmer satisfaction are very useful to keep track of how many people purchased items, and which FFVs were most popular (DHHS, 2007; Buck, 2007). The year-long monitoring of the chosen index will help to track business, the changes in consumer behavior/supply chain, and to identify problems or sectors which need improvement in order to improve customer service and maintain or increase the customer base. When the indexes refer to benefit for a school food service, there are also other aspects that are not directly related to the efficiency of the distribution channel, such as student and personnel education on locally-grown FFVs (Buck, 2007).

VII. Systems approach with simulation models to improve the logistics of locally-grown produce

Logistics operations that describe a part or all of the supply chain are organized in a system. The systems approach is the process that refers to the study of the system as a whole, rather than examining the individual operation of its components. The logistics of FFVs production is certainly a discipline where simulation can make important contributions to the organization of the processes as well as the ways in which targeted interventions may be implemented to improve efficiency throughout the whole supply chain (Busato, 2008).

Using the systems approach (Prussia and Mosqueta, 2006), a simulation model was built to evaluate traditional and short supply chains for locally-grown peaches, taking into account their shelf life and firmness (Berruto et al., 2003). The proposed model embeds both discrete events, mainly devoted to the description of logistics and external condition changes, and continuous time behavior. The model demonstrates that local produce can be transported short distances without the support of a distribution center, allowing a shelf life extension of 22 hours, resulting in more uniform firmness of the produce at the point-of-sale.

Computerized simulation models were developed from storage studies for predicting blueberry and peach quality during distribution (Aggarwal et al., 2003). The tools were then applied to each link in a typical refrigerated supply chain to evaluate practical postharvest situations such as the impact of different time delays before cooling. The models developed could be suitable for evaluating postharvest situations of locally-grown produce. Another simulation concerned the distribution of fresh produce by forecasting the quality loss from packer to consumer, and allowing the testing of diverse logistic and transport solutions. The event-oriented model tracks the shelf life of each single box of the fruit and vegetables along the supply chain in detail (Busato and Berruto, 2006). The percentage of filled orders, the transit time, and the remaining shelf life at consumer location are the main parameters provided by the model. The model shows that storing FFVs produces a higher percentage of filled orders and lower shelf life, compared to delivery of fresh produce without storage facilities. The stakeholders in the supply chain may use it to explore different scenarios and to establish the price of high-quality produce.

The potential of information exchange to increase supply chain profits while distributing highly perishable FFVs, has been shown using a simulation model (Busato et al., 2007). The model shows that information sharing effectively improves the performance of the supply chain for fresh fruits and vegetables with a rise in profits from 9% to 24%. This shows that the sharing of information along the supply chain can be very effective, especially when there are procedures in place to exploit valuable information. Profit optimization in this case also increases the sustainability of the supply chain. In fact, information sharing affects not only the produce sold and profits made, but also reduces waste from unsold products.

Some refinements of the previous model were performed using a combination of simulation and derivative-free optimization methods to study the logistic and information flow at the retail level (Busato et al., 2008). Some stock management policies for the retailer were compared, and the most relevant economic factors were identified in the context of high product perishability. The most influential factor affecting profits was the consumer purchase policy (FIFO or LIFO), followed by the demand variability, and then average cost.

The SCAR (Standing Committee for Agricultural Research) established in the DG Research European Commission of the EU hypothesizes some future scenarios of agriculture development (SCAR, 2006). One of the four scenarios related to food crisis claims that the main priorities are related to self-reliance in rural communities, low external input agriculture, and the relocalization of food production, markets and local economies. Long-distance trading of goods that are production surplus or not produced locally should no longer play an important role in society. The diversity of local food can be very wide. Small farm consolidation allows for the use of new technology. Production-enhancing technologies should be introduced into farming and food processing in a sustainable way (Shewfelt and Henderson, 2003). Simulation tools can be used jointly with a systems approach, to identify the variability of new scenarios to strengthen locally-grown produce and to increase its importance in local communities.

Key words

Logistics, locally grown produce, postharvest, handling, farmers' market, CSA, food service, restaurant, distribution system, systems approach.

References

ActionAid (2006). Hungry for solutions: progress towards securing the right to food ten years after the world food summit (20.10.06). Available online at http://www.actionaid.org/assets/pdf/HungryforSolutions_2112006_112539.pdf Accessed 7 March 2008.

Adam, K., Balasubrahmanyam, R., Born, H. (1999). Direct marketing. ATTRA Publication #IP113. Available online at http://www.attra.org/attra-pub/directmkt.html Accessed 25 March 2008.

Adam, K. (2006). Community supported agriculture. ATTRA Publication #IP289 Available online at http://www.attra.org/attra-pub/csa.html Accessed 25 March 2008.

Aggarwal, D., Prussia, A.J., Prussia, S., Nunez, A., NeSmith, D.S., Florkowski, W.J., Lynd, D.E. (2003). Predicting fresh produce quality in supply chains. Acta Hort., 604, 179–188. Accessed 25 March 2008.

Bachmann, J., Earles, R. (2000). Postharvest handling of fruits and vegetables. ATTRA Publication #IP116. Available online at http://attra.ncat.org/attra-pub/postharvest.html#harvest Accessed 14 March 2008.

Bachmann, J. (2002). Farmers' markets. ATTRA Publication #IP146 Available online at http://www.attra.org/attra-pub/farmmrkt.html Accessed 25 March 2008.

Bachmann, J. (2004). Selling to restaurants: business and marketing. ATTRA Publication #IP255. Available online at http://www.attra.org/attra-pub/sellingtorestaurants.html Accessed 25 March 2008.

Batt, P.J., Parining, N. (2000). Price–quality relationships in the fresh produce industry in Bali. International Food and Agribusiness Management Review, 3, 177–187.

Batt, P.J. (2006). Fulfilling customer needs in agribusiness supply chains. Acta Hort., 699, 83–90.

Bellows, B.C., Dufour, R., Bachmann, J. (2003). Bringing local food to local institutions. ATTRA Publication #IP242. Available online at http://www.attra.org/attra-pub/farmtoschool.html Accessed 25 March 2008.

Benocci, L. (2005). Smart eating: Tuscany informs. Frutticoltura, 10, 62–64.

Berruto, R., Gay, P., Peano, C. (2003). Hybrid modelling for fruit quality prediction in supply chain networks. Acta Hort., 604, 137–144.

Berruto, R. (2004). Logistics and strategies evaluation of grain receiving operation using the system simulation approach. PhD Thesis. Purdue University, West Lafayette, IA, USA.

Berruto, R., Busato, P. (2006). EnergyFarm: Web application to compare crop systems under technical, economic and energetic aspects. Computers in Agriculture, 24–26 July. Lake Buena Vista, FL, USA, pp. 481–487.

Bhaskaran, S., Polonsky, M., Cary, J., Fernandez, S. (2006). Environmentally sustainable food production and marketing: opportunity or hype? British Food Journal, 108(8), 677–690.

Bignebat, C., Codron, J.M., Rouvière, E. (2006). Industry voluntary approach to food safety: does heterogeneity matter? ISNIE Conference, 21–24 September. Boulder, CO, USA.

Bignebat, C., Codron, J.M. (2006). *Innovations organisationnelles et contrôle de la qualité sanitaire dans la filière fruits et légumes*. INRA UMR Moisa, Montpellier, Vol. 5. Available online at http://www.inra.fr/internet/Departements/ESR/publications/iss/pdf_eng/iss06-5_3Organizational_Eng.pdf Accessed 25 March 2008.

Birthal, P.S., Joshi, P.K. (2007). Smallholder farmers' access to markets for high-value agricultural commodities in India. In: Food policy for developing countries: the role of government in the global food system, Per. Pinstrup-Andersen, F. Cheng (eds). Cornell University, Ithaca, NY, USA. Available online at http://cip.cornell.edu/ Accessed 7 March 2008.

Bollen, A.F., Riden, C.P., Opara, L.U. (2006). Traceability in postharvest quality management. International Journal of Postharvest Technology and Innovation, 1(1), 93–105.

Borrie, R., Potter, B. (2005). The potential for marketing of produce from local orchards in Yorkshire and Humberside. Available online at http://www.orchardfruitresearch.co.uk/documents/produce_from_local_orchards.pdf Accessed 7 March 2008.

Borsari, B. (2003). Fruit and vegetable quality perspective from producers and consumers at a local university in Western Pennsylvania. Acta Hort., 604, 69–74.

Borsari, B., Liller, L. (2005). Students attitudes about fruit and vegetable quality at Slippery Rock University of Pennsylvania. Acta Hort., 682, 659–664.

Boyette, M.D., Sanders, D.C., Rutledge, G.A. (1996). Packaging requirements for fresh fruits and vegetables. Postharvest commodities series. University of North Carolina, Available online at http://www.bae.ncsu.edu/programs/extension/publicat/postharv/ Accessed 7 March 2008.

Boyhan, G.E., Hurst, W.C., Kelley, W.T., Krewer, G.W., Taylor, K.C. (2004). Postharvest handling and transportation of fruits and vegetables. Available online at http://pubs.caes.uga.edu/caespubs/pubcd/FS-100.htm Accessed 7 March 2008.

Brandimarte, P., Zotteri, E. (2007). Introduction to distribution logistics: a quantitative approach. Wiley, New York, NY, USA.

Brückner, B. (2006). Addressing consumer notions and individuality. Acta Hort., 712, 121–130.

Bryant, C.R., Johnston, T.R.R. (1992). Agriculture in the city's countryside. University of Toronto Press, Toronto, Canada.

Buck, M. (2007). A guide to developing a sustainable food purchasing policy. Food Alliance, Oregon. Available online at http://www.foodalliance.org/sustainablefood-policy/Sustainable%20Food%20Policy%20Guide.pdf Accessed 7 March 2008.

Busato, P., Berruto, R. (2006). FruitGame: simulation model to study the supply chain logistics for fresh produce. Computers in Agriculture, 24–26 July. Lake Buena Vista, FL, USA, pp. 488–493.

Busato, P., Berruto, R., Brandimarte, P. (2007). FruitGame: a simulation tool to evaluate supply chain logistics and the effects of information sharing for fresh produce. 5th Biennial Conference of the European Federation of IT in Agriculture (EFITA), Glasgow, 2–5 July. Electronic proceedings.

Busato, P. (2008). Postharvest logistics of agricultural products: system approach study with simulation models. PhD Thesis. University of Turin, Italy.

Busato P., Berruto, R., Brandimarte, P., Chino, M. (2008). Learning ordering rules for perishable fresh produce: an exercise in integrating optimization and simulation. 2nd International European Forum on System Dynamics and Innovation in Food Networks, 15–22 February (in press).

Buzby, J.C., Guthrie, J.F., Kantor, L.S. (2003). Evaluation of the USDA fruit and vegetable pilot program: Report to congress. Available online at http://www.ers.usda.gov/publications/efan03006/efan03006.pdf Accessed 10 March 2008.

Cairncross, F. (2004). Local food supply means fresher food in London hospitals. Available online at http://www.sustainweb.org/pdf/29_01_04.pdf Accessed 10 March 2008.

Cantwell, M. (2007). Postharvest handling of horticultural products: Keeping principles in perspective. Sustainable food center, Austin, TX. Available online at http://www.sustainablefoodcenter.org/documents/PostharvestPrinciples.pdf Accessed 10 March 2008.

Carvajal, L.M., Ospina, N., Zapata, J.E. (2005). Design of a protocol for handling perishable food products using papaya as the model system. Acta Hort., 682, 1851–1858.

Casey, D., Giguère, J., Sarnecki, M., Welsh, A. (2003). Room at the table – Santropol Roulant and food security. Available online at http://www.santropolroulant.org/images/Room%20At%20the%20Table%20MURB%20june%202003.pdf Accessed 28 November 2006.

Chowdhury, S., Negassa, A., Torero, M. (2005). Market institutions enhancing the value of rural-urban links. International Food Research and Policy Institute. Available online at http://www.ifpri.org/divs/fcnd/fcndp.asp Accessed 7 March 2008.

Codron, J.M., Fares, M., Rouvière, E. (2006). Le contrôle sanitaire des fruits et légumes: les conventions d'autocontrôle des importateurs français. Economie et Sociétés, Série Systèmes Agroalimentaires, 28, 599–612.

Codron, J.M., Fares, M., Rouvière, E. (2007). From public to private safety regulation in the fresh produce import industry. International Journal of Agricultural Resources, Governance and Ecology, 6(3), 415–427.

Cohen, L., Larijani, S., Aboelata, M., Mikkelsen, L. (2004). Cultivating common ground: linking health and sustainable agriculture. Prevention Institute, p. 34. Available online at http://www.noharm.org/details.cfm?ID=990&type=document Accessed 7 March 2008.

Collins, R. (2006). The function and consequences of alternative fresh produce supply chain models. Acta Hort., 712, 67–74.

Concaro, G., Capurro, R. (2006). Survey report on horticultural district in Alessandria province. CADIRLAB, internal report. Italy.

Connecticut Department of Agriculture (2007). Farmers' market reference guide. Available online at http://www.ct.gov/doag/lib/doag/pdf/farmers_market_manual_1_03_08.pdf Accessed 7 March 2008.

Cook, D. (1995). Examining insurance needs is essential to marketing. In: Direct farm marketing and tourism handbook, R.Tronstad (ed.). University of Arizona. Available online at http://ag.arizona.edu/AREC/pubs/dmkt/dmkt.html Accessed 25 March 2008.

Cottingham, M. (2007). Fresh, local and organic – a successful recipe for improving Europe's hospital food. Health care without harm. Available online at http://www.noharm.org/Europe Accessed 10 March 2008.

CSCMP (2008). Definition of logistic management. Council of Supply Chain Management Professionals. Available online at http://cscmp.org/aboutcscmp/definitions/definitions.asp Accessed 7 March 2008.

CTIFL (2006). Le commerce de proximité vue par le consommateur. Infos Ctifl, 208, 17–21.

CTIFL (2007a). Local procurement from growers: the consumers' opinion. Infos Ctifl, June, 232, 10–14.

CTIFL (2007b). Supply by local growers: importance and perception of professionals in short channel distribution. Infos Ctifl, October, 235, 13–16.

CTIFL (2007c). Distribution flow diagram for 2006: indicators for the sector. Infos Ctifl, December, 237, 11–15.

Dargan, L. (2006). CORASON WP6: Local food production and knowledge dynamics in the rural sustainable development. Available online at http://corason.hu/download/wp6/wp6_uk.pdf Accessed 20 March 2008.

DEFRA (2003). Local food – A snapshot of the sector report of the working group on local food. DEFRA. Available online at http://www.defra.gov.uk/foodrin/foodname/lfood/pdf/local-foods-report.pdf Accessed 7 March 2008.

DHHS (2007). Eat smart North Carolina brings fresh produce to your setting. N.C. Department of Health and Human Services. Available online at http://www.eatsmartmovemorenc.com/programs_tools/community/fresh_produce.html Accessed 25 March 2008.

Eckert, J.W., Eaks, I.L. (1989). Postharvest disorders and diseases of citrus fruits. In: The Citrus Industry, W. Reuther, E.C. Calavan, G.E. Carman (eds), Vol. 4. University of California Press, Berkeley, CA, USA, pp. 179–260.

Enachescu Dauthy, M. (1995). Fruit and vegetable processing. FAO Agricultural Services, bulletin n.119. Available online at http://www.fao.org/docrep/V5030E/V5030E00.htm#Contents Accessed 7 March 2008.

Ernst, M., Woods, T. (2005a). Marketing fresh produce at farmers markets. Department of Agricultural Economics, University of Kentucky, KY. Available online at http://www.uky.edu/Ag/NewCrops/marketing/farmmarket.pdf Accessed 7 March 2008.

Ernst, M., Woods, T. (2005b). Marketing fresh produce to restaurants. Department of Agricultural Economics, University of Kentucky, KY. Available online at http://www.uky.edu/Ag/NewCrops/marketing/restaurants.pdf Accessed 7 March 2008.

Gibson, R. (1995). Legal structure rules & regulations for direct marketing enterprises. In: Direct farm marketing and tourism handbook, R. Tronstad (ed.). University of Arizona. Available online at http://ag.arizona.edu/AREC/pubs/dmkt/dmkt.html Accessed 25 March 2008.

Gorny, J.R. Zagory, D. (2004). Food safety. In: The commercial storage of fruits, vegetables, and florist and nursery stocks. U.S. Dept. of Agriculture. Agriculture Handbook, 66, 130. Available online at http://www.ba.ars.usda.gov/hb66/024foodsafety.pdf Accessed 7 March 2008.

Granger, C., Cheung, J. (2007a). A guide to establishing a worksite farmers' market. DHCS publication. Available online at http://www.dhs.ca.gov/ps/cdic/cpns/worksite/download/FitBusinessKitTools/Farmers%20Market%20Tool_Final.pdf Accessed 25 March 2008.

Granger, C., Cheung, J. (2007b). Simple steps to ordering farm fresh produce for the worksite. Available online at http://www.dhs.ca.gov/ps/cdic/cpns/worksite/download/FitBusinessKitTools/Produce%20Delivery_Final.pdf Accessed 25 March 2008.

Gregoire, M.B., Strohbehn, C. (2002). Benefits and obstacles to purchasing from local growers/producers. Journal of Child Nutrition and Management. Available online at http://docs.schoolnutrition.org/newsroom/jcnm/02spring/gregoire/Accessed 7 March 2008.

Grimsbo Jewett, J., Nelson, B., Braaten, D. (2007). Marketing local food. MISA. Available online at http://www.misa.umn.edu/vd/publications/marketing_local_food.pdf Accessed 7 March 2008.

Gross, K.C., Wang, C.Y., Saltveit, M. (2004). The commercial storage of fruits, vegetables, and florist and nursery stocks. U.S. Dept. of Agriculture, Agricultural Handbook, 66. Available online at http://www.ba.ars.usda.gov/hb66/contents.html Accessed 7 March 2008.

Halweil, B. (2002). The case for local food in a global market. Worldwatch paper, 163, 84. Available online at http://www.worldwatch.org/system/files/EWP163.pdf Accessed 7 March 2008.

Hamilton, N.D. (2005). Farmers market policy: an inventory of federal, state, and local examples. Drake University Agricultural Law Center, Des Moines, IA. Available online at http://www.pps.org/pdf/FarmersMarketPolicyPaperFINAL.pdf Accessed 7 March 2008.

Harris, B., Burres, D., Eitcher, S. (2000). Demands for local and organic produce: a brief review of the literature. Institute for Public Policy and Business Research, internal report 254A. Available online at http://www.ipsr.ku.edu/resrep/pdf/m254A.pdf Accessed 7 March 2008.

Helliot, J. (2004). Food and drink in Yorkshire and the Humber: regional supply chains mapping study. Available online at http://www.yorkshire-forward.com/asset_store/document/food_supply_mapping_2005_92554.pdf Accessed 7 March 2008.

Hendrickson, M. (2004). Building community-based food systems to enhance food security in Missouri. Food Circles Networking Project. Available online at http://foodcircles.missouri.edu/proposal.htm Accessed 7 March 2008.

Hewett, E.W. (2006). An overview of preharvest factors influencing postharvest quality of horticultural products. International Journal Postharvest Technology and Innovation, 1(1), 4–15.

Heyes, J., Bycroft, B. (2002). Handling and processing of organic fruits and vegetables in developing countries. FAO. Available online at http://www.fao.org/DOCREP/004/AC300E/AC300e00.htm Accessed 7 March 2008.

Heyes, J.A. (2003). Post-harvest action: the global postharvest forum. Acta Hort., 628, 55–61.

Hinrichs, C.C. (2000). Embeddedness and local food systems: notes on two types of direct agricultural markets. Journal of Rural Studies, 16(3), 295–303.

Jett, L.W., Hendrickson, M. (2006). G06221, marketing vegetables in Missouri. Available online at http://extension.missouri.edu/explore/agguides/hort/g06221.htm Accessed 10 March 2008.

Johnson, D.B., Stevenson, G.W. (1998). Something to cheer about: national trends and prospects for sustainable agriculture products in food service operations of colleges and universities. University of Wisconsin-Madison, Center for Integrated Agricultural Systems. Available online at http://www.cias.wisc.edu/pdf/Johnson.pdf Accessed 10 March 2008.

Kader, A.A. (2005). Increasing food availability by reducing postharvest losses of fresh produce. Acta Hort., 682, 2169–2176.

Kidwell, J., Thompson, G. (1995). The organic market: results from a Tucson study. In: Direct farm marketing and tourism handbook, R. Tronstad (ed.). University of

Arizona. Available online at http://ag.arizona.edu/AREC/pubs/dmkt/dmkt.html Accessed 10 March 2008.
Kienholz, J., Edeogu, I. (2002). Fresh fruit and vegetable pre-cooling for market gardeners in Alberta. Alberta Agriculture, Food and Rural Development. Available online at http://www1.agric.gov.ab.ca Accessed 10 March 2008.
Kitinoja, L., Kader, A.A. (2002). Small-scale postharvest handling practices: a manual for horticultural crops, 4th edn. Post-harvest Horticulture Series, 8E, July. Available online at http://www.fao.org/inpho/content/documents/vlibrary/ae075e/ae075e02.htm Accessed 10 March 2008.
La Trobe, H. (2002). Local food, future directions. Friends of the Earth report. Available online at http://www.foe.co.uk/resource/reports/local_food_directions.pdf Accessed 25 March 2008.
Lamb, D., Taylor, C. (2007). Local food marketing guide. SAC Food Marketing. Available online at http://www.sac.ac.uk/mainrep/pdfs/localfoodguide.pdf Accessed 25 March 2008.
Leopold Center (2005). Using organic agriculture and sustainable crops and livestock in local food system. Iowa University Extension Service. Available online at http://www.extension.iastate.edu/Publications/PM1995.pdf Accessed 7 March 2008.
Liu, Wen, F. (1999). Postharvest handling in Asia: horticultural crops. Department of Horticulture. National Taiwan University. Available online at http://www.agnet.org/library/eb/465b/eb465b.pdf Accessed 7 March 2008.
Lloyd, R., Nelson, J., Tilley, D. (1995). Roadside stands. In: Direct farm marketing and tourism handbook, R. Tronstad (ed.). University of Arizona. Available online at http://ag.arizona.edu/AREC/pubs/dmkt/dmkt.html Accessed 25 March 2008.
Lobo, R. & Takele, E. (2003). Farming on the urban edge. In: Western profiles of innovative agricultural marketing: Examples from direct farm marketing and agri-tourism enterprises. Western Extension Marketing Committee. Available online at http://cals.arizona.edu/arec/wemc/westernprofiles.html Accessed 25 March 2008.
López Camelo, A.F. (2004). Manual for the preparation and sale of fruits and vegetables: from field to market. FAO Agricultural Services Bulletin, 151. Available online at http://www.fao.org/docrep/008/y4893e/y4893e00.htm Accessed 10 March 2008.
Macchi, E. (2006). Il mercato al dettaglio delle fragole in Italia. Frutticoltura, 6, 4–6.
MacLeod, M., Scott, J. (2007). Local food procurement policies: a literature review ecology action centre for the Nova Scotia department of energy. Available online at http://www.ecologyaction.ca/food_action/publications/LocalFoodProcurementPolicies.pdf Accessed 25 March 2008.
Macsuga, R. (2007). Farmer's market reference guide. Available online at http://www.ct.gov/doag/lib/doag/pdf/farmers_market_manual_1_03_08.pdf Accessed 10 March 2008.
Marr, C., Gast, K. (1995). A guide to starting, operating, and selling in farmers markets. In: Direct farm marketing and tourism handbook, R. Tronstad (ed.). University of Arizona. Available online at http://ag.arizona.edu/AREC/pubs/dmkt/dmkt.html Accessed 25 March 2008.
Mazereeuw, B. (2005). Urban agriculture report. Available online at http://chd.region.waterloo.on.ca/web/health.nsf/4f4813c75e78d71385256e5a0057f5e1/

F9E487C67FAC45E885256FE90060ADF6/$file/UA_Feasibility.pdf?openelement Accessed 18 November 2006.

McGarry, J. (2007). The value of local produce. Available online at http://www.midweek.com/content/columns/tabletalk_article/the_value_of_local_produce/ Accessed 10 March 2008.

McKelvey, B., Hendrickson, M., Parcell, J. (2007). Selling strategies for local food producers. DHCS publication. Available online at http://extension.missouri.edu/explore/agguides/hort/g06222.htm Accessed 25 March 2008.

Michael, S. (2006). Best practice in sustainable public-sector food procurement. DEFRA. Available online at http://www.localfood.org.uk/library/Defra-FLUK%20best%20practice%20final%20June%2006.pdf Accessed 10 March 2008.

Nakamoto, S. (2003). Servicing high-end restaurants. In: Western profiles of innovative agricultural marketing: examples from direct farm marketing and agri-tourism enterprises. Western Extension Marketing Committee. Available online at http://cals.arizona.edu/arec/wemc/westernprofiles.html Accessed 25 March 2008.

Nakamoto, S., Fleming, K. (2003). Marketing memorable experiences and high-quality products. In: Western profiles of innovative agricultural marketing: examples from direct farm marketing and agri-tourism enterprises. Western Extension Marketing Committee. Available online at http://cals.arizona.edu/arec/wemc/westernprofiles.html Accessed 25 March 2008.

Nasolini, T., Brighi, A., Mazzoni, F. (2007). Frutta snack, merende anti-obesità si affermano nelle scuole italiane. Frutticoltura, 5, 24–26.

Nguyen, C.N., Prussia, S., Holly, C., Dinkins, S., Yocum, R. (2004). Evaluation of the technical and economical feasibility of a suspended wagon for transporting fresh peaches from the field to the packinghouse. ASAE technical paper, 04 6106.

Opara, L.U. (2003). Traceability in agriculture and food supply chain: a review of basic concepts, technological implications and future prospects. Journal of Food, Agriculture and Environment, 1, 101–106.

Peeters, L.J.C.M. (2007). Implementation of food safety standards in fruits and vegetables cooperation. Acta Hort., 741, 25–29.

Phillips, E. (2007). The growing trend of farmers' markets in the United States. In: Food policy for developing countries: the role of government in global, national and local food systems. Cornell University Press. Available online at http://cip.cornell.edu/ Accessed 20 March 2008.

Piccarolo, P. (2006). Analysis of the flow and marketing of locally grown strawberries and potatoes marketed by large supermarket chain. DEIAFA, internal report. University of Turin, Italy.

Pineiro, M., Diaz, L.B. (2007). Improving the safety and quality of fresh fruit and vegetables (FFV): a practical approach. Acta Hort., 741, 19–24. Available online at http://www.fao.org/ag/agn/CDfruits_en/launch.html Accessed 10 March 2008.

Pirog, R., Van Pelt, T., Enshanyan, K., Cooke, E. (2001). Food, fuel and freeways: an Iowa perspective on how far food travels, final usage, and greenhouse gas emission. Leopold Center for Sustainable Agriculture, Iowa State University Press, Ames. Available online at http://www.ag.iastate.edu/centers/leopold Accessed 15 October 2007.

Pirog, R., Schuh, P. (2002). The load less traveled: examining the potential of using food miles in ecolabels. Proceedings from Ecolabels and the Greening of the Food Market Conference, November 7–9. Massachusetts, USA, p. 69.

Pirog, R. (2004). Checking the food odometer: comparing food miles for local versus conventional produce sales to Iowa institutions. Available online at http://www.leopold.iastate.edu/pubs/staff/files/food_travel072103.pdf Accessed 7 March 2008.

Pirog, R., Paskiet, Z. (2004). A geography of taste: Iowa potentials for developing place-based and traditional foods. Leopold Center for Sustainable Agriculture. Available online at http://www.leopold.iastate.edu/pubs/staff/files/taste.pdf Accessed 7 March 2008.

Prussia, S., Florkowski, W., Sharan, G., Naik, G., Deodhar, S. (2001). Management simulation game for improving food chains. Acta Hort., 566, 231–236.

Prussia, S. (2005). Systems thinking for improving modern quality management systems. Proceedings of the APEC Symposium on Quality in Postharvest Systems, 3–5 August. Bangkok, Thailand, pp. 39–46.

Prussia, S., Mosqueta, M.R.P. (2006). Systems thinking for food supply chains: fresh produce applications. Acta Horticolturae, 712, 91–104.

Rangarajan, A., Pritts, M., Reiners, S., Pedersen, L. (2000a). Reduce microbial contamination with good agricultural practices. Gaps Project. Available online at http://www.gaps.cornell.edu/Educationalmaterials/Samples/PamphletEng.pdf Accessed 25 March 2008.

Rangarajan, A., Bihn, E., Gravani, R., Scott, D., Pritts, M. (2000b). Food safety begins on the farm. Gaps Project. Available online at http://www.gaps.cornell.edu/FSBFEng.html Accessed 25 March 2008.

Ringsberg, K. (2005). Logistic opportunities for local suppliers to municipal units. Local and Regional Food. Report from the European Conference on Local and Regional Food, 27–28 September. Lerum, Sweden. Available online at http://www.ksla.se/sv/retrieve_file.asp?n=733 Accessed 14 March 2008.

Ritenour, M., Brecht, J., Sargent, S. (2008). New developments in vegetable packaging. Vegetarian Newsletter, Issue 529. University of Florida. Available online at http://www.hos.ufl.edu/vegetarian/ Accessed 14 March 2008.

Robbins, L.T. (May 2005). Pass the Peas Please. State Legislatures, May 2005, 30–31.

Roth, A.V., Tsay, A.A., Pullman, M.E., Gray, J.V. (2008). Unraveling the food supply chain: strategic insights from China and the 2007 recalls. The Journal of Supply Chain Management, 44(1), 22–39.

Rowell, B., Woods, T., Mansfield, J. (1999). Marketing options for commercial vegetable growers. Kentucky Department of Agriculture. Available online at http://www.ca.uky.edu/agc/pubs/id/id134/id134.pdf Accessed 25 March 2008.

Sanders, L.D., Ancev, T. (2003). Institutional food service survey: a summary and review. Oklahoma Food Policy Council. Available online at http://www.kerrcenter.com Accessed 14 March 2008.

SCAR (2006). FFRAF report: foresighting food, rural and agri-futures. DG Research European Commission. Available online at http://ec.europa.eu/research/agriculture/scar/pdf/foresighting_food_rural_and_agri_futures.pdf Accessed 25 March 2008.

Schofer, D., Holmes, G., Richardson, V., Connerly, C. (2000). Innovative marketing opportunities for small farmers: local schools as customers. USDA marketing series. Available online at http://www.ams.usda.gov/tmd/MSB/PDFpubList/InnovativeMarketing.pdf Accessed 28 February 2008.

Shaffer, J., Cox, B. (2006). USDA releases new farmers' market statistics. USDA. Available online at http://www.ams.usda.gov/tmd/MSB/PRFarmersMarketStatistics.pdf Accessed 14 March 2008.

Sharrock, K. (2008). Active and intelligent packaging: packaging that enhances and monitors quality. Hortresearch. Available online at http://postharvest.ucdavis.edu/ Accessed 14 March 2008.

Shewfelt, R.L., Henderson, J.D. (2003). The future of quality. Acta Hort., 604, 49–59.

Shewfelt, R.L. (2006). Defining and meeting consumer requirements. Acta Hort., 712, 31–38.

Sirieix, L., Grolleau, G., Schaer, B. (2007). Consumers and food miles. AIEA2 and Sober International Conference. Londrina Parana, Brazil, 22–27 July. Available online at http://www.montpellier.inra.fr/moisa/bartoli/download/moisa2007_pdf/WP_3-2007.pdf Accessed 14 March 2008.

Skende, D. (1999). The study of post-harvest losses in horticultural crops in Albania with the main focus on apple. In: Post-harvest losses of perishable horticultural products in the Mediterranean region, D. Gerasopoulos (ed.). Chania, CIHEAM-IAMC, pp. 167–177. Available online at http://ressources.ciheam.org/om/pdf/c42/CI020471.pdf Accessed 7 March 2008.

Smith, A., Watkiss, P., Tewddle, G., McKinnon, A., Browne, M., Hunt, A., Trevelen, C., Nash, C., Cross, S. (2005). The validity of food miles as an indicator of sustainable development. DEFRA, London.

Sonesson, U. (2005). Overview of the life cycle environmental impact from food products. Kungliga skogs-och lantbruksakademiens tidskrift, n. 9. Available online at http://www.ksla.se/sv/retrieve_file.asp?n=733 Accessed 7 March 2008.

Starr, A., Card, A., Benepe, C., Auld, G., Lamm, D., Smith, K., Wilken, K. (2003). Sustaining local agriculture: Barriers and opportunities to direct marketing between farms and restaurants in Colorado. Agriculture and Human Values, 20, 301–321.

Strohbehn, C. (2002). Local food connections from farm to school. Leopold Center. Available online at http://www.extension.iastate.edu/publications/PM1853a.pdf Accessed 25 March 2008.

Strohbehn, C., Gregoire, M.B. (2002a). Local food connections from farms to restaurants. Leopold Center. Available online at http://www.extension.iastate.edu/Publications/PM1853B.pdf Accessed 14 March 2008.

Strohbehn, C., Gregoire, M.B. (2002b). Local food connections: food service considerations. Leopold Center. Available online at http://www.extension.iastate.edu/publications/PM1853C.pdf Accessed 25 March 2008.

Strohbehn, C., Gregoire, M.B. (2003). Case studies of local food purchasing by central Iowa restaurants and institutions. Foodservice Research International, 14(1), 53–64.

Suslow, T. (1997a). Postharvest handling for organic crops. UC ANR Publication, University of California, UC Davis, CA, USA. Available online at http://anrcatalog.ucdavis.edu/pdf/7254.pdf Accessed 14 March 2008.

Suslow, T. (1997b). Postharvest chlorination: basic properties and key points for effective disinfection. ANR publication 8003. Available online at http://anrcatalog.ucdavis.edu/pdf/8003.pdf Accessed 14 March 2008.

Tellström, R., Gustafsson, I.B., Fjellström, C. (2003). Food culture as a political tool – meal construction during the Swedish EU-chairmanship 2001. Food Service Technology, 3(2), 89–96.

Thompson, J.F., Spinoglio, M. (1996). Small scale cold rooms for perishable commodities. ANR Publication 21449. Available online at http://postharvest.ucdavis.edu/datastorefiles/234-701.pdf Accessed 7 March 2008.

Thompson, J.F. (2004). Pre-cooling and storage facilities. In: Handbook in the commercial storage of fruits, vegetables, and florist and nursery stocks. U.S. Dept. of Agriculture. Agriculture Handbook, 66. Available online at http://www.ba.ars.usda.gov/hb66 Accessed 7 March 2008.

Tronstad, R. (1995). Pricing. In: Direct farm marketing and tourism handbook, R. Tronstad (ed.). University of Arizona. Available online at http://ag.arizona.edu/AREC/pubs/dmkt/dmkt.html Accessed 25 March 2008.

Tronstad, R. (2003). A project that quickly mushroomed into a large direct-marketing business. In: Western profiles of innovative agricultural marketing: examples from direct farm marketing and agri-tourism enterprises. Western Extension Marketing Committee. Available online at http://cals.arizona.edu/arec/wemc/westernprofiles.html Accessed 25 March 2008.

Tropp, D., Olowolayemo, S. (2000). How local farmers and school food service buyers are building alliances. USDA. Available online at http://www.ams.usda.gov/tmd/MSB/PDFpubList/localfarmsandschool.pdf Accessed 7 March 2008.

Uchtmann, D. (1995). How growers can reduce liability risks. In: Direct farm marketing and tourism handbook, R. Tronstad (ed.). University of Arizona. Available online at http://ag.arizona.edu/AREC/pubs/dmkt/dmkt.html Accessed 25 March 2008.

Udas, S., Rai, B.K., Gurung, M., Thapa, R., Khatiwada, P.P. (2005). Assessment of postharvest handling systems of vegetables in the eastern hills of Nepal. Acta Horticolturae (ISHS), 682, 2191–2198.

Valentini, D. (2007). Frutta fresca e spuntini regionali contro l'obesità. Ristorazione Collettiva, 5, 49–50.

Van Der Meulen, H., Ventura, F. (1993). The contribution of high-quality food production to endogenous rural development in Umbria, Central Italy. In: Strengthening endogenous development patterns in European agriculture, Chania, CIHEAM-IAMM, J.D. Van Der Ploeg. (ed.). Available online at http://ressources.ciheam.org/om/pdf/a23/CI000382.pdf Accessed 7 March 2008.

Van En, R., Manes, L., Roth, C. (2007). What is community supported agriculture and how does it work? Community supported agriculture of North America. CSANA. Available online at http://www.localharvest.org/csa.jsp Accessed 7 March 2008.

Wikipedia (2008). Wikipedia the free encyclopaedia. Available online at http://en.wikipedia.org/wiki/Main_Page Accessed 28 February 2008.

Wilkins, J., Eames-Sheavly, M. (2001). A primer on community food systems: linking food, nutrition and agriculture. Cornell University, Ithaca, NY. Available online at http://foodsys.cce.cornell.edu/pdfs/Primer.pdf Accessed 7 March 2008.

Wilson, L.G., Boyette, M.D., Estes, E.A. (1995). Postharvest handling and cooling of fresh fruits, vegetables and flowers for small farms. Leaflets 800–804. North Carolina Cooperative Extension Service. 17 p. Available online at http://www.ces.ncsu.edu/depts/hort/hil/post-index.html Accessed 7 March 2008.

12

Traceability in Postharvest Systems

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I. Introduction

Traceability is an expected attribute of the modern postharvest system. Traceability is a well-coordinated and well-documented movement of product and documented activities associated with the product, from the producer, through a chain of intermediaries, to the final consumer. The previous edition of this book emphasized how the components of the postharvest system interacted and what the impacts of component interactions on other parts of the system were. It is a sign of how well systems and supply chain thinking has embedded within this sector of the international economy that it is now important to include a discussion on an activity that helps to integrate and bind a supply system from end-to-end, the activity of traceability.

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This chapter introduces the concept of traceability in the context of an industrialized supply chain, and the reasons for its emergence as a critical component of the modern food supply system. The postharvest system's ability to provide accurate traceability is not without limitations. This chapter discusses the limitations, along with an introduction to identification technologies and information systems which support traceability.

While traceability is primarily driven by the need to provide information to buyers and consumers, there are opportunities to leverage this required activity to provide information feedback, to improve performance in other parts of the chain, and some of these are discussed later in the chapter. There is no single all-encompassing definition of traceability. The interpretation of traceability varies widely, and depends on the industry, its relative location within the supply chain, and the perspectives of both the suppliers and users of the information. The definition, therefore, varies slightly through the course of the following discussion.

A. Drivers of traceability

The drivers for traceability can be separated into two main categories. Bollen et al. (2006) defined these drivers as "hard" or "soft" traceability requirements. Hard traceability requirements are those with which international or domestic marketers of perishable products are required to comply to meet regulatory or international trade treaty obligations. Among those requirements are trace back for food safety, trace forward for market access or compliance with production standards and the meeting of security requirements (Zaske, 2003; Hobbs, 2004). Soft requirements do not control the ability to trade, but can have significant impact on the economics of particular supply chains. These can include improving performance of supply chains, meeting changing consumer needs or responding to the requirements of third parties, such as retailers or importers.

Food safety

The European Union (EU) and North America have two of the most industrialized food sectors in the world. In these economies consumers are generally well-removed from the producers of their food (Sarig, 2003). The separation necessitates consumers, or in many cases retailers acting on their customer's behalf, to have confidence in the supply chain to deliver safe food. Media reports of large and small food scares continually shake consumer and retailer confidence. Major international food safety issues have included Bovine Spongiform Encephalopathy (BSE) in the UK (Pettitt, 2001), Canada and the US (Ward et al., 2005), and dioxin in Belgium (Opara, 2003). Smaller scale or local concerns over other food hazards, including microbial, physical and chemical hazards in the food supply, further undermine retailer and consumer confidence. Finally, the presence of genetically modified organisms (GMO) in their food supply is of concern to a large proportion of the world's consumers (EU, 2001, Nilsson et al., 2004).

While many food scares relate to issues with meat supply, there has been a concern about other foods, such as fresh and minimally processed fruit and vegetables.

The major consumer concern (Opara, 2003) in this area is the use of agrichemicals, and the possible existence of high levels of pesticide on fruit and vegetables. All concerns about food wholesomeness need to be addressed through some form of traceability or audit system.

The EU has been particularly proactive in adopting a highly-regulated regime for ensuring food safety. A number of prescriptive traceability requirements were introduced, such as EU Regulation No. 178/02 (EU, 2002; Giacomini et al., 2001). This specific regulation requires (Article 18) that there is an obligation for whole supply chain traceability on all food stuffs and animal feed, extending to all farms. The EU has also implemented regulations to specify how GMOs are to be traced through the food supply system (EU, 2001).

The US has more generally taken the approach that individual businesses can derive competitive advantage through their own individual information and traceability systems. The emphasis is placed on the ability to trace back unsafe food rapidly and efficiently (Golan et al., 2004). There is also the incentive to reduce legal liability in the event of some trace back issues, which encourages the development of appropriate systems (Hobbs and Young, 1999). There has however, been recognition in the postharvest area of the need for standards throughout the supply chain, and this has seen the initiation of the joint Produce Traceability Initiative from the Canadian Produce Marketing Association, the United Fresh Produce Association and the Produce Marketing Association (Hanson, 2007; Robison, 2007).

Production standards

Besides the requirements for a safe food supply, there is a growing consumer awareness of the effects that agricultural production techniques are having on the environment. Several large supermarket chains are now adopting sustainable production standards to control and monitor production practices (Tesco, 2005; Wal-Mart, 2007). The standards are being used as an assurance service to customers, and also as competitive points of differentiation. The outcome of such activities is the development of minimum production standards and good agricultural practice (GAP) protocols which control certain activities of an orchard or farm. The programs generally require “activity” traceability in the form of information, such as proof of fertilizer, pesticide and water applications. With an increasing frequency, such programs include other issues, such as carbon footprint and energy use. While much of the above can be considered soft traceability requirements, many of these are likely to become embedded in regulations over time.

The supply of product to other countries, or out of state, often involves the need to provide evidence that the product conforms to the importing country or state’s quarantine regulations. Increasingly, quarantine regulations require evidence of product conforming to certain production practices or postharvest treatments, in conjunction with independent auditing and inspection regimes.

Common to all these issues is the need to capture information on production activities, and trace some of this information (e.g. agrichemical use) forward through the supply chain alongside the products. The technologies developed for precision agriculture offer the opportunity to improve dramatically the quality of the production-related data (McBratney et al., 2005a; Hoownicki, 2004). Precision agriculture involves the capture of spatial, temporal and quantitative information on production activities, such as spraying or fertilizer applications (Demmel et al., 2002), as well as crop quality and production measurements (McBratney et al., 2005b). All data are collected with a spatial location (usually global positioning system (GPS) measured), so that they can then be displayed on maps using a geographical information system (GIS). Information is electronically stored and readily available to the traceability system in different formats and levels of detail.

Security

The third area with hard traceability requirements which must be met to trade across international boundaries is the increasing need for secure track-and-trace systems for international trade (Bollen et al., 2004). The requirements for traceability in the shipping and air freight sectors, particularly into the US, require registration of goods several days prior to shipping. This can have detrimental impacts on highly perishable products, which require shipping in short time frames.

Consumers

Some consumer concerns over food safety and sustainable production are, as already discussed, addressed through the provision of regulatory frameworks. Many consumer concerns that were soft requirements for traceability earlier have now become hard requirements.

Outside of regulatory protocols, it is retailers who assume the bulk of the responsibility to assure their customers of product quality, safety and sustainability. At this level, individual supermarkets or branded marketers require traceability systems that deliver information and product that support particular businesses' market positioning.

Part of soft traceability requirements is the ability to segregate the market, and the products in the market, to meet consumer expectations. Product and market segregation involves the segregation of inherently variable biological products into a number of more consistent lines, which requires trace forward of information on products and their attributes (Bollen et al., 2006). In order to incentivize growers to produce product, or packers to segregate product to meet market specifications, it is also useful to trace back or feedback market performance to producers.

Supply chain performance

Supply chains can gain commercial advantage in their ability to use traceability information for a number of purposes, one of which is to meet internal operational and performance improvements (Pierce and Cavalieri, 2002). Typically, the traceability systems in the postharvest cool chain have been used to improve cool store stocking and management, speed product location and improve planning and picking operations for shipping. New opportunities exist to use non-destructive measurement technologies to assist in quality monitoring and prediction of quality changes, to further improve these operations by providing information on matching product quality to current pricing to optimize returns, and to identify lines for early or late shipping based on their storage potential.

The multiple sharing of information between businesses necessitated by some traceability requirements can also have spin-off benefits for whole chains as transparency increases. Transparency potentially leads to the improving vertical integration of supply chains which, in turn, leads to more efficient food supply systems (Hobbs and Young, 1999).

Feedback to producers

An often overlooked opportunity for traceability systems (Bollen, 2004) is to provide feedback to producers. Postharvest systems generally involve a sorting and grading process (see Chapters 14 and 15). During sorting and grading all produce is individually measured. By linking the quality information obtained from sorting and grading to the individual bin or trailer, and backtracking to a specific orchard location, it is possible to provide feedback to producers on the overall quality, variation in quality, and yield across their farm or orchard. An application of such information is discussed further at the end of this chapter.

B. Definitions of traceability

The complexities of the supply chain for perishable products mean that a succinct definition of traceability is difficult. ISO 9000:2005 (ISO, 2005) defines traceability within a business entity as the ability to retrace the history, use or location of an entity, using recorded data based on some unique identification. Giacomini et al. (2001) suggested a useful extension to this definition is to include the movement of product between businesses.

In the context of a food manufacturing system, Moe (1998) defined traceability as: "… the ability to track a product batch and its history through the whole, or part, of a production chain from harvest through transport, storage, processing, distribution and sales," which was defined as chain traceability. Moe further defined internal traceability as all product batches and activities within one step of the chain. Moe's work built on the work of Kim et al. (1995) who had stated that: "… the fundamental and necessary core in an ideal traceability system is the ability to face both products and activities."

Bodria (2002) observes the obligation of traceability is unique, in that the responsibility to provide traceability is shared by all businesses involved in a particular supply chain. Therefore, traceability requires the unique identification of products and processes, coupled with information systems which are able to deliver relevant information to meet trace forward or trace back requirements. The meeting of requirements has to occur across several business boundaries.

In its fullest sense, traceability is a subset of quality systems, which are in turn a subset of information systems. Traceability is essentially about information flows within a postharvest system. Opara (2003) identified three types of traceability that are relevant in a postharvest system.

Production and postharvest system traceability

The traceability of production and postharvest activities involves providing information on GAP activities linked to the production process. Of particular interest is information on use of fertilizers, pesticides, and water, as well as social considerations such as labor conditions. Information collection will likely expand to include evidence of sustainable production systems and energy efficiency. Similarly, there is a requirement to provide information on postharvest activities, such as drenching, washing, dips, additives or the use of agrichemicals. It is expected that traceability requirements will grow to consider energy use and energy type (renewable or non-renewable) for cool chain and transport activities. This type of traceability of information is associated with components of good manufacturing practice (GMP) protocols.

Pest, disease and genetically modified organism (GMO) traceability

Quarantine-required traceability involves the ability to trace and record activities in order to assure importers that no prohibited pests, diseases or GMOs are introduced to the market through implementation of programs that monitor disease incidence, pest incursion or accidental GMO release. Also, if an event compromising product safety does occur, traceability systems are required to enable the response and location of all possibly affected product and to assure markets that no product is sourced, or in some cases even transits, through areas and exclusion zones around any such incident.

Product traceability

Product traceability is the ability to identify product at any stage in the supply chain, as described by ISO 9000:2005 (2005). The identification of the product and its traceability is the primary form of traceability, but is only one integral component of traceability with other information and activity records as discussed in the previous sections. Product traceability is the core component of the system, because it is possible to access information on certain products only if the product itself is traced. Product traceability is the focus of the remainder of this chapter.

II. Theory of traceability in postharvest systems

A. Identifiable units

A critical component of the traceability information system is the identification system and the definition of the unit that can be uniquely identified. Moe (1998), using the terminology defined by Kim et al. (1995), defined the unit, or batch, that could be traced as the traceable resource unit (TRU). The TRU has to be a unique unit, and must have characteristics that are different from all other TRUs. The definition of the TRU arose from the domain of the quality system, and Kim et al. (1995) take traceability to be backward in time only.

A broader definition of traceability for the postharvest system mentioned earlier requires tracing of products and activities. Bollen et al. (2007) have, therefore, defined a broader term, the identifiable units (IUs). The IUs adhere to the uniqueness requirements defined by Moe (1998), but have additional attributes; they can be abstractions or aggregates, they apply to resources, products or activities, and there exist parent–child relationships within any IU structure. Figure 12.1 shows a set of typical IUs in the postharvest system for fruit. There are several points in the supply chain where much of the transformation of IUs occurs. The transformation takes place initially at packing, where fruit is placed into packs loaded onto pallets and into trucks etc., and eventually at retail where the reverse occurs.

B. Traceability is not absolute

The postharvest system can be split into three parts in terms of traceability. At the packing house product is placed into packaging and onto pallets. From this stage in the process, product is well-identified and can generally be traced through the logistics chain. Through the logistic sector of the system it is possible to achieve complete traceability, provided adequate recording of activities and product movement is carried out. Once the pallets and packs are broken down, traceability becomes less accurate because product is mixed and the local recording systems tend to be less robust. The traceability also poses a challenge from the orchard until the point of product packing. So, the system is characterized by a central component of high traceability sandwiched between two components of low traceability. While it is common in discussions of traceability to assume absolute traceability, in fact in the context of the entire postharvest system traceability will never be absolute.

A traceability system can be described by different sizes of IU, also termed the granularity of the traceability. At the coarsest level of granularity, a fruit or vegetable may be traceable to a state or country of origin, or perhaps an individual farm or orchard, whereas finer levels include individual shipments, pallets or packs. The ultimate level of traceability would be individual fruit, but currently there are no practical systems that enable traceability at this level.

The processing operations, such as cleaning, sorting and grading of fruit in a packing house, involve taking fruit from definable IUs, such as individual bins picked in

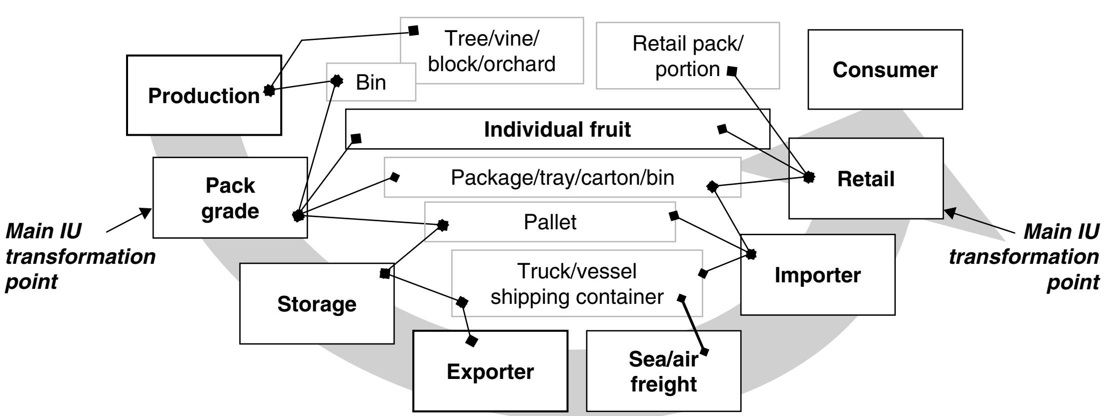

Figure 12.1 Typical identifiable units (IUs) in a postharvest system. Source: Bollen et al. (2007).

the orchard, and handling these as a continuous stream. The packing house generally, but not always, splits the fruit into batches of common product (from the same orchard, or orchard block). Batches are packed in sequence through the facility and tracked onto the final pallets. Often there may be fruit from a different grower on the same pallet, and the individual growers are generally identified on the packs, but in many cases the pack simply contains a generic grower ID that is not specifically linked to a batch. There are also likely to be packs at the changeover from one batch to another filled with fruit from both batches. Traceability in this case relies on both the pallet IU, which will generally be linked to a batch, as well as grower IDs associated with this IU. Trace back, however, would require manual identification of individual packs, because there is no potential to link individual packs into a traceability information system without a unique pack ID.

C. Precision of traceability

The degree of granularity of the IUs defines the precision of traceability possible from a postharvest system. Large IUs may only enable traceability to the level of country of origin. Small IUs, such as bins or individual packs, may enable traceability to an individual packing house, or perhaps orchard, or even an area (block) within an orchard. Granularity is, however, not the sole determinant of precision.

Bollen et al. (2007) conducted studies of traceability and fruit mixing through an apple packing facility. Various mixing and packing house operational set-ups were modeled (Riden and Bollen, 2007) to estimate the levels of precision possible from a typical medium-sized apple processing operation. In their study, Riden and Bollen (2007) formally defined precision of traceability as the ratio between IUs at two points in the postharvest system. The two defined points were the input to the packing house (bins with approximately 2400 fruit) and the output (packs containing 36, 80, 150 or 220 fruit).

The average precision measured in one experiment was 3.6 bins per pack (8400 fruit). By tripling the size of the input unit (essentially a bin trailer with three bins) the ratio improved to 2.0 "triples" per pack (14 400 fruit), but precision was reduced as tripling the size of the input unit did not result in tripling the ratio. At the level of the IU of a production run, Riden and Bollen (2007) estimated a traceability precision to only 136 800 fruit. It is useful, therefore, to trace with a fine level of granularity, because such granularity level improves the potential precision of system traceability.

D. Tracking

Tracking is the ability to trace product when it moves forward through the supply chain. At any individual process in the system it is possible to describe the magnitude of a tracking activity as a measure of the number of output units that derive from each input unit (Riden and Bollen, 2007). That is to say: "how many output units need to be tracked to know where the entire product from an input unit has gone?" At the level of a batch, it is possible simply to count all the pallets and part pallets linked to the particular batch. However, when the size of the IU gets smaller, tracking becomes more complex.

For example, in the case of the studied apple packing house, the incoming quantity of fruit from one bin would have filled approximately 20 packs. Because the fruit is sized and placed in different "count" packs, the fruit from each bin was calculated to be spread over 35–40 packs, assuming there was no mixing in the system. If realistic levels of mixing in the in-feed system were factored in, across the water dump, brushes and sorting tables, and mixing at the packing lanes, the fruit from each bin was estimated to be spread over 100 packs.

E. Tracing

Tracing is the ability to trace back through the supply chain. Riden and Bollen (2007) defined the magnitude of a tracing activity as the number of input units that might potentially belong to each output unit from any segment of the supply chain. They answered the question "how many input units need to be found that directly link with a particular output unit of interest?" At the level of a batch, all batches associated with a particular pallet must be found. For the studied apple packing house, Riden and Bollen (2007) measured tracing precision as the ratio of input bins per output pack. Packs with an uncommon fruit size (large or small fruit) were found to be supplied by fruit from six to 13 bins, and the amount of in-feed mixing had little effect on this ratio. Packs with a common fruit size had a much better ratio of one to three bins per pack, and the ratio was predominantly affected by in-feed mixing. Only 5% of packs with a common fruit size contained fruit sourced from only one bin, and the ability to trace product from one bin to one pack is not common. The ability to trace back up the supply chain is, therefore, significantly affected by both the proportion of product segregated into a particular grade, but also by the mixing within the system.

F. Tolerances and purity

While the concept of the existence of tolerances within a traceability system is unusual, there are times where the use of such limits is appropriate. The allowance of some error (tolerance) in the estimate of the source or destination of some product in an IU will be acceptable for traceability applications, where quality management or statistical feedback are the objectives, because errors due to the presence of other product will be small. By adopting a traceability system with fine granularity and built-in tolerances, it is possible to aggregate IUs to a level where absolute traceability is possible, if necessary. If it is not possible to reverse-engineer such a system if requirements change in the future, it is useful to consider designing traceability systems at fine granularity IUs with built-in tolerances.

Riden and Bollen (2007) have also introduced the concept of purity for postharvest system traceability. Purity is an alternate way to consider tolerance. Tolerance describes the certainty of the relationship between packs and bins, for example, and purity describes the degree of membership or dilution that is "allowed" to effectively have one-to-one membership. A 99% purity pack would, therefore, be a pack where 99% of the fruit is from a particular bin. Purity is a useful concept to apply in sampling processes, because for trace back it is more useful to sample a pack which has a known composition (e.g. 99% purity) than one that might be difficult to trace back (say only 40% purity).

III. Components of traceability systems

A. Identification technologies

The basic traceability of product through the postharvest system is achieved by being able to identify each IU with a unique code. There is a vast array of technology providers seeking to provide machine-readable solutions, which become incrementally more reliable than their predecessors (Bollen et al., 2006). There are three main ways of identifying IUs.

Alphanumeric identification

The alphanumeric identification (ID) is still a common system in particular sectors of the supply chain, including orchard, air and sea freight, and retail. Generally alphanumeric IDs are read by humans, and manually input into an information system. There is a reasonable chance for errors in this situation, and some major international ports use optical character recognition to automatically capture and record sea freight container IDs (Bollen et al., 2004).

Barcode

The barcode is the most successful machine-readable ID system. It has been applied worldwide over the last 30 years because it is a very reliable, low-cost system. The system involves printing a label, or directly printing onto a pack, with a series of bars and gaps of varying widths. The code is then read and interpreted using a laser to scan the bars. The codes conform to one of a number of standards (GS1, 2007). Code sizes range in lengths from 8 numerical or 13 numerical through to 48 alphanumeric digits (Figure 12.2). To meet the ever-increasing demand for information included with the product there is now also a reduced space symbology (RSS) standard for a 2-D barcode which enables 2335 alphanumeric digits to be recorded (GS1, 2007). Barcodes are generally printed with an associated alphanumeric ID for times when a human readable ID is needed.

0123 4565
EAN-8
8 Numeric

5 012345 678900
EAN-13
13 Numeric

(00) 0 0123456 123456789 6
EAN-128
48 Alphanumeric

(01)00012345678905
GS1 Datamatrix
3116 Numeric, 2335 Alphanumeric

Figure 12.2 Examples of barcodes with 8 numerical, 13 numerical and 48 numerical digits.

Radio frequency identification (RFID)

RFID is the most automated technology of IUs in the postharvest system. The improved automation is the ability to read the ID "tag" more readily, without the need to shine a laser directly at the barcode. The implementation of RFID has however, been slower than expected due to costs and limitation on reader performance (range and reliability), which have hampered expansion of the technology.

The RFID technology has two primary components (Figure 12.3). The tag consists of a small chip with onboard memory which holds a unique ID (read-only tag) or has the ability to have some information written to the tag (read-write tag). The tag also contains a small radio antenna. The second component is the reader, which consists of a pair of antennae with an operating and recording system. When the tag is close to the reader, the reader powers the tag through the tag antennae and the tag reports information it contains to the reader. There are a number of different tag technologies, some small enough to be embedded in labels on packaging.

B. Information systems

While it is important to be able to read and identify product throughout the postharvest system, it is the information system which provides the underlying platform for traceability. Unfortunately, the information system in most supply chains is essentially a set of disparate local information systems designed to serve the needs of each individual business. Data are exchanged between businesses as required, using a myriad of data exchange protocols and arrangements (Figure 12.4). Generally, information only flows in the same direction as the product. The only information that flows backwards through the chain is summary data (such as quality performance) or trace back when required. The problem with this structure of information system is that the system's performance is affected by any weakness at any link in the information exchange.

Figure 12.3 RFID system on orchard bins.

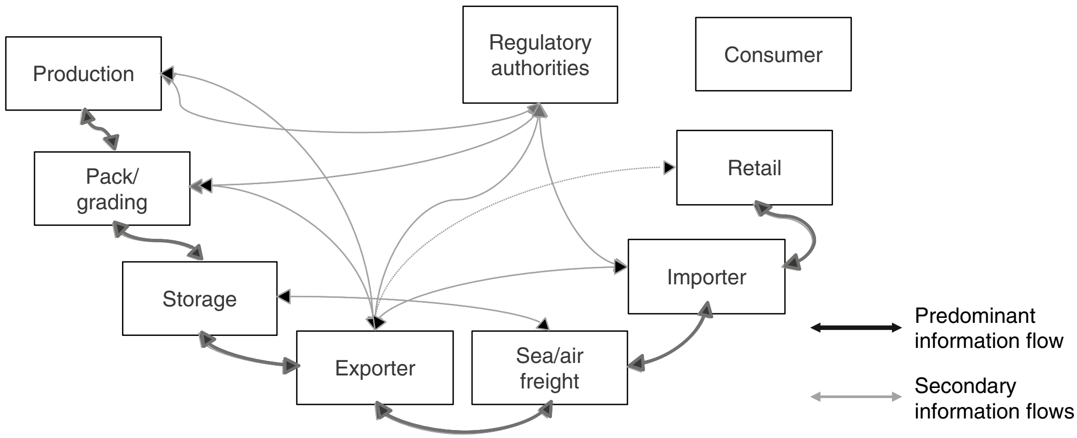

Figure 12.4 Formal exchange of information in a generalized postharvest system.

One solution to the lack of a common data system is to continue to place more data on the tag or label. From an information systems design point-of-view, the addition of information can lead to issues such as multiple copies of data, data being static once written to the tag without the ability to be updated, and the transport of a large amount of data which is never used. A preferable design is to use a distributed database approach (Lo Bello et al., 2004), where the unique ID on each IU is shared and data from each point of the supply chain is available to all other parties. Improved data sharing leads to better vertical integration of a postharvest system, which enables the businesses involved to share the benefits of improved performance (Hobbs and Young, 1999).

A study of track-and-trace systems within the Asia–Pacific Economic Community (APEC) (Bollen et al., 2004) identified that the economies with high "ease of trade" were those with sophisticated information systems. If systems are designed to deliver on supply chain performance, then it is relatively easy to provide traceability data. However, a system focused inward, on a particular business, makes it often difficult and costly to meet regulatory traceability requirements (Johnson, 2007).

IV. Extended uses of traceability systems

One of the opportunities of the current emphasis on traceability in modern agricultural systems is to use this emphasis to help improve the performance of the entire postharvest system. The preceding sections have discussed how traceability to small lots or low levels of detail is incomplete. While this may not be of sufficient accuracy for standard traceability requirements, it may well be of sufficient accuracy to allow new management and productivity activities to be undertaken. There are a number of opportunities to exchange information along the supply chain which can potentially benefit the entire system or, at least, benefit individual businesses within the system. Examples of two opportunities are discussed here.

A. Grower feedback tools

In the postharvest system the packing house grades fruit and places it in packs for shipping. Fruit is graded on one or a number of attributes such as size, color, firmness, number of defects and dry matter. Growers are paid according to the quality profile of the product packed. There are usually payment schedules that will reward the production of the desired attributes (e.g. high dry matter, preferred color, large size, etc.). Currently, the information provided to the grower is summarized at a level that relates to the level of granularity equivalent to some operational requirement, such as payments, for example, by day, week or batch. There is an extreme loss in the precision of the information as, while all the fruit have been individually measured by the grader, this data is only ever available in a summarized form.

An enhanced traceability system was profiled by Praat et al. (2003), where the location of picking every bin of kiwifruit was identified, and the fruit tracked through the packing house. Grader data on size and dry matter for all fruit were recorded. Approximately one-half of the information on fruit from each bin was discarded, because there was bin-to-bin overlap due to mixing. The remaining fruit data were used to calculate quality statistics for each bin, and the resulting information was traced back to the appropriate location in the orchard. The information was also mapped on a geographic information system (GIS) similar to that shown in Figure 12.5. Growers can use maps to identify orchard areas which are performing

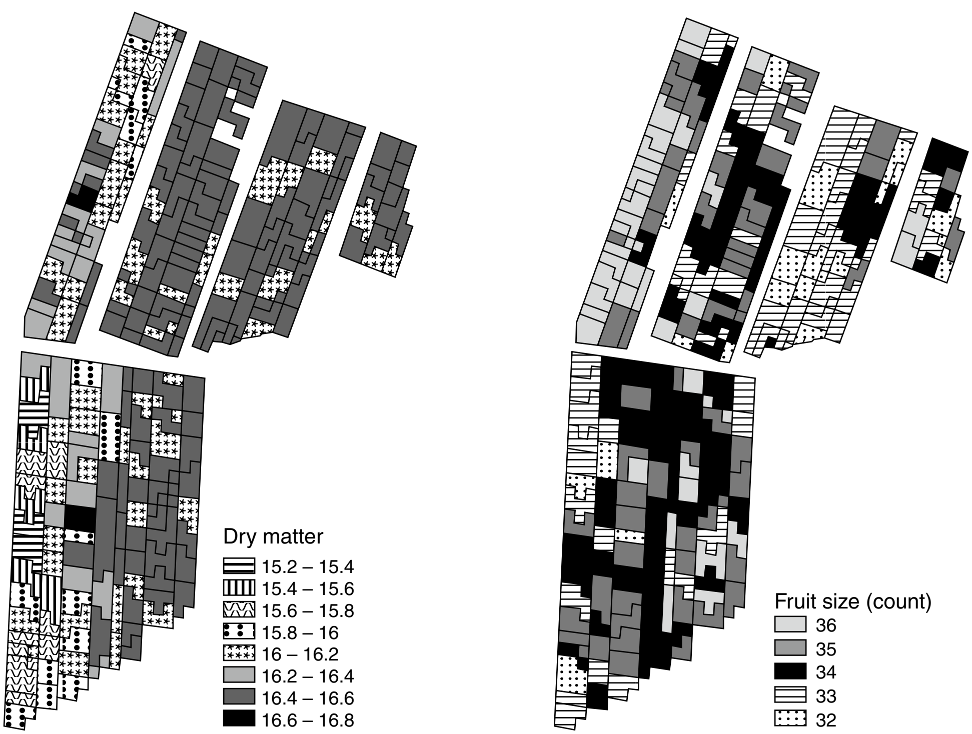

Figure 12.5 Typical quality maps for a kiwifruit orchard generated by tracking information at the level of each bin in an orchard.

well, or underperforming. In this example, the left hand map shows fruit average dry matter levels. The western blocks have generally lower levels of dry matter, measured as a percentage of wet weight, and the north eastern blocks are the most consistently high. The right hand map shows average fruit size measured as the count of fruit fitting into a standard weight pack, so a Count 32 is a larger fruit than a Count 36. This map shows the north east and south west blocks have generally large fruit, with the smallest fruit occurring in the north west of the property. The grower can further investigate the within-block patterns. This type of information, produced by the traceability system, is very useful to the grower and can be generated at marginal cost by the packer. The system also then provides a traceability dataset that can be aggregated to any higher level, as may be required by other users of this information (e.g. summarized to a block level or an orchard level).

B. Cool chain quality management

One of the most critical measurements that are useful in the management of quality in the postharvest system is the measurement of temperature. Tracing temperature and other environmental conditions represent traceability of activities, as opposed to traceability of product. This distinction was discussed earlier. Le Blanc and Vigneault (2006) conducted an extensive review of technologies available for tracking temperature, and included inventory management recording systems such as cool store temperature monitoring and dataloggers. The temperature recording systems collectively can provide a number of measures in a traceability system. The use of dataloggers is a simple way to link directly the net effects of a cool chain to the quality of a particular product. The use of product traceability for all other product that has moved through the same cool chain (spatial and temporal) allows operators to associate a cool chain history with a particular "lot" of product. In general, the association is assumed to be with other packs in a pallet, or pallets within a shipping container, truck or vessel. There is, however, a considerable variation in temperature within these systems, which requires a large number of monitoring points to adequately characterize the cool chain performance.

An alternate approach suggested by Bollen et al. (2003) uses the product tracking system to locate product accurately throughout the postharvest system, and then use local environmental measurements to predict product temperatures. Bollen et al. (2007) discussed an example of apples, which were harvested over several days but packed as a single lot at the packing house. The fruit bins were identified in the orchard and recorded a time of harvest. Next, the bins were traced to the packing house and all bin movements were recorded, along with the local environmental conditions (mainly temperature). When fruit was packed, the temperature–time history of each bin was calculated, and this information was connected with the fruit observed in the final packs. The temperature–time histories were aggregated for each pallet. In some pallets all fruit was exposed to less than 45 degree–days, whereas other pallets had most fruit in the 45 to 75 degree–day range. Still other pallets were identified as having fruit with a very large range of temperature exposure, from 15 to 75 degree–days. The different temperature exposures can have marked affects on apple firmness so the traceability system can, therefore, also serve as a method for identifying pallets which have different potential quality outcomes. With this knowledge, the response of the postharvest systems can be improved.

V. Conclusions

The demand for traceability in the postharvest system is expected to continue to grow. This will be driven partially by market demand for better visibility and assurance of food safety, as well as technology push from product identification and information system providers. As the sophistication of the systems increases, the ability to trace product in ever smaller units will become important. Continually reducing the size of the identifiable units (IUs) means that it is eventually impossible to describe the exact membership of each output unit based on some known input unit. Unit membership and the ability to link two or more small sized identifiable units eventually becomes a statistical issue. The ability to trace product at this lower level of detail, with small IUs, opens up opportunities to add new tools to the information system.

The traceability system is a subset of a postharvest information system. Traceability is one of the main activities shared across the entire supply chain. Increasing traceability requirements require improved integration of individual information systems within the supply chain. Improvements in information integration, in turn, will also lead to increased vertical integration of supply chains.

Bibliography

Bodria, L. (2002). System integration and certification. The market demand for clarity and transparency – Part 2. Presented at the Club of Bologna Meeting, 16 November 2002, Bologna, Italy. Agricultural Engineering International: the CIGR Ejournal, 4, 1–6.

Bollen, A.F., Riden, C.P., Cox, N.R. (2007). Agricultural supply system traceability, Part I: role of packing procedures and effects of fruit mixing. Biosystems Engineering, 98, 391–400.

Bollen, A.F., Riden, C.P., Opara, L.U. (2006). Traceability in postharvest quality management. Int. J. Postharvest Technology and Innovation, 1(1), 93–105.

Bollen, A.F. (2004). Traceability in Fresh Produce Supply Chains. Proceedings of the International Conference – Postharvest Unlimited Downunder 2004. Acta Hort., 687, 279–288.

Bollen, A.F., Kissling, C., Emond, J-P, Brecht, J., McAneney, J., Leake, J., Crompton, R., Nunes, C., Metz, A., Duval, K., Laniel, M., Ye, J. (2004). Sea and air container track and trace technologies: Analysis and case studies – final report. Transportation Working Group of APEC. Project No. TPT01/2002T.

Bollen A.F., Praat, J-P., Garden, G.M. (2003). Information Management for Apple Quality in the Supply Chain. Acta Hort., 2, 753–759.

Demmel, M.R., Ehri, M., Rothmund, M., Spangler, A., Auernhammer, H. (2002). Automated process data acquisition with GPS and standardized communication –

The basis for agricultural production traceability. 2002 ASAE annual meeting, paper number 023013.
EU (European Union) (2002). Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety. http://eur-lex.europa.eu/LexUriServ/site/en/oj/2002/l_031/l_03120020201en00010024.pdf Accessed 24 September 2007.
EU (European Union) (2001). Directive 2001/18/EC of the European Parliament and of the Council of 12 March 2001 on the deliberate release into the environment of genetically modified organisms. http://www.biosafety.be/PDF/2001_18.pdf Accessed 24 September 2007.
Giacomini, C., Mancini, M.C., Mora, C. (2001). Case study on the traceability systems in the fruit and vegetable sector. University of Florida, FL, USA. http://conference.ifas.ufl.edu/ifsa/papers/e/a17.doc Accessed 18 June 2007.
Golan, E., Krissoff, B., Kuchler, F., Calvin, L., Nelson, K., Price, G. (2004). Traceability in the U.S. food supply: Economic theory and industry studies. US Department of Agriculture, Econ. Res. Serv., Report No. 830.
GS1 (2007). Barcode types. http://www.gs1.org/productssolutions/barcodes/technical/bar_code_types.html Accessed 24 September 2007.
Hanson, A. (2007). Associations to launch joint traceability initiative. The Packer, CXIV, Nov 5, B10.
Hobbs, J.E. (2004). Information asymmetry and the role of traceability systems. Agribusiness, 20(4), 341–397.
Hobbs, J.E., Young, L. M. (1999). Increasing vertical linkages in agrifood supply chains: a conceptual model and some preliminary evidence. Research Discussion paper No. 35. Joint meeting of Canadian Agricultural Economics Society and Western Agricultural Economics Society, Fargo, ND, USA, July 10–14.
Hoownicki, R. (2004). Prospects of precision agriculture in plant protection. Progress in Plant Protection, 44(1), 104–113.
ISO (International Standards Organization) (2005). ISO 9000:2005 – Quality management systems – Fundamentals and vocabulary.
Johnson, B. (2007). Computer software – revolutionizing the way foodservice manages its produce aquisitions. Produce Business, September 2007, 96–98.
Kim, H.M., Fox, M.S., Gruninger, M. (1995). Ontology of quality for enterprise modeling. Proceedings of IEEE International Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises. WET-ICE, 105–116.
Le Blanc, D.I., Vigneault, C. (2006). Traceability of environmental conditions for maintaining horticulture produce quality. Stewart Postharvest Review, 2(3), 4.1–4.10.
Lo Bello, L., Mirabella, O., Torrisi, N. (2004). Modeling and evaluating traceability systems in food manufacturing chains. Proceedings of the 13th IEEE International Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises. WET-ICE '04, 173–179.
McBratney, A., Whelan, B., Ancev, T. (2005a). Evaluating the benefits from precision agriculture: the economics of meeting traceability requirements and environmental

targets. Precision Agriculture '05. Paper presented at the 5th European Conference on Precision Agriculture. Uppsala, Sweden.

McBratney, A., Whelan, B., Ancev, T., Bouma, J. (2005b). Future directions of precision agriculture. Precision Agriculture, 6, 7–23.

Moe, T. (1998). Perspectives on traceability in food manufacture. Trends in Food Science & Technology, 9, 211–214.

Nilsson, H., Tuncer, B., Thidell, A. (2004). The use of eco-labeling like initiatives on food products to promote quality assurance – is there enough credibility? Journal of Cleaner Productions, 12, 517–526.

Opara, L.U. (2003). Traceability in agriculture and food supply chain: a review of basic concepts, technological implications, and future prospects. Journal of Food, Agriculture and Environment, 1, 101–106.

Pettitt, R.G. (2001). Traceability in the food animal industry and supermarket chains. Rev. Sci. Tech., 20(2), 584–597.

Pierce, F.J., Cavalieri, R.P. (2002). Globalization and traceability of agricultural production: the role of mechanization. Presented at the Club of Bologna Meeting, 16 November 2002, Bologna, Italy. Agricultural Engineering International, The CIGR Ejournal, 4, 1–16.

Praat, J-P, Bollen, F., Gillgren, D., Taylor, J., Mowat, A., Amos, N. (2003). Using supply chain information: mapping pipfruit and kiwfruit quality. Acta Hort., 604(1), 377–385.

Riden, C.P., Bollen, A.F. (2007). Agricultural supply system traceability, Part II: implications of packhouse processing transformations. Biosystems Engineering, 98, 401–410.

Robison, B. (2007). Keeping track. Produce Business, October, 54–56.

Sarig, Y. (2003). Traceability of food products. Presented at the Club of Bologna Meeting, 16 November 2002, Bologna, Italy. Agricultural Engineering International, The CIGR Ejournal, 4, 1–17.

Tesco (2005). Nature's choice environmental standards, Tesco Corporate Responsibility Review. Available online at http://www.tesco.com/csr/g/g4.html Accessed 24 September 2007.

Wal-Mart (2007). Wal-Mart CEO Lee Scott Unveils "Sustainability 360". Available online at http://www.walmartfacts.com/articles/4784.aspx Accessed 24 September 2007.

Ward, R., Bailey, D.V., Jensen, R. (2005). An American BSE crisis: has it affected the value of traceability and country-of-origin certifications for US and Canadian beef? Int. Food and Agribusiness Mgmnt. Review, 8(2), 92–114.

Zaske, J. (2003). Mechanization and traceability of agricultural production: a challenge for the future. System integration and certification. The market demand for clarity and transparency – Part 1. Presented at the Club of Bologna meeting, 16 November 2002, Bologna, Italy. Agricultural Engineering International, The CIGR Ejournal, 5, 1–15.

13

Microbial Quality and Safety of Fresh Produce

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I. Introduction

Fresh fruits and vegetables are perceived by consumers to be healthy and nutritious food (see Chapters 3 and 5), because of the plethora of scientifically substantiated and documented health benefits derived from consuming fresh fruits and vegetables (Huxley et al., 2004). Demand for fresh fruits and vegetables has increased, along with consumption of whole crop or minimally processed foods. This increase in volume and sales of these fresh products has necessitated changes in how fresh commodities are produced, transported, processed, stored and marketed (Gorny, 2006). An important result of these changes is an increase in microbial-related postharvest problems, due to spoilage microorganisms and human pathogens (Brackett and Splittstoesser, 2001).

Factors leading to the increase in microbial contamination are numerous (Beuchat and Ryu, 1997; Waller, 2002; Narciso and Plotto, 2006). In the field, contamination factors include soil, irrigation water, animals, insects and handling by workers. During harvest, sources of contamination include workers, tools, bins and crates, and transport vehicles. Processing, transportation, distribution, retail display or preparation also contributes to the contamination problem (Gorny, 2006).

Most freshly harvested fruits and vegetables are cleaned, washed or disinfected by the grower, packer or processor to remove soil, plant debris, pesticide residue and microorganisms from the commodity surface. The removal is accomplished by dry or wet brushes, rinsing or immersion in tap water, hot water or solutions containing one of a number of cleaning or sanitizing agents, using equipment designed for the commodity (Fallik, 2004; Sapers, 2006). Furthermore, the globalization of fresh fruits and vegetables, including extended food storage, has resulted in a potentially increased risk of outbreaks of illness associated with the consumption of these raw commodities (Sivapalasingam et al., 2004).

Crops are classified into four categories according to the risk they pose. The greatest care is required for crops classified in category 1 (Monaghan, 2006). The risks depend upon the way the crop is prepared and eaten (with or without skin, cooked or raw), and upon the history of its pathogen contamination (e.g. lettuce, green onion, fresh herbs – category 1; asparagus, eggplant – category 4). The goal of this chapter is to summarize the latest information on pre-storage treatments to reduce or eliminate spoilage microorganisms and food-borne pathogens on fresh and fresh-cut products.

II. Factors affecting microbial quality

Microbial quality of fresh produce refers to the overall effects of microbial activity, including growth, enzymatic activity and metabolic by-products upon the visual and organoleptic quality of fruits and vegetable. Microbial quality is microorganism-dependent, and is highly affected by chemical, physical and biological factors pertaining to the cultivar and the environment. It is highly dependent on the conditions of cultivation, harvesting, handling, transport and postharvest storage, as well as marketing conditions. Physical factors affecting growth and metabolic activity of microorganisms include temperature, pH, atmosphere and moisture content (e.g. water activity). Chemical factors include the availability of nutrients and trace elements necessary for microbial growth, while biological factors include the presence of competing flora, and interactions with the plant.

A. Microbial growth

Microbial growth is usually referred to as increase in the number of microbes, rather than a change in microbial mass. Recent studies have indicated that microbial flora associated with fresh produce exist as aggregates or biofilms (Fett, 2000; Rayner et al., 2004; Aruscavage et al., 2006; Brandl, 2006). Biofilm describes microbial cells adherent to a surface or interface, and covered with layers of microbially produced exopolymeric substance (EPS) (Costerton et al., 1994). Biofilm development includes an attachment step, microcolony formation, and EPS expression and maturation. Direct microscopic observation of tomatoes, carrots, lettuce and mushrooms has indicated the high prevalence of biofilm on these common salad vegetables (Rayner et al., 2004). Biofilm communities have been shown to be highly resistant to chemical sanitizers and antibacterial agents compared to planktonic bacteria. Consequently, higher concentrations of antibacterial agents are required to kill biofilm flora (Fux et al., 2005; Szomolay et al., 2005). It is suggested that a better understanding of factors that contribute to produce spoilage and contamination by food-borne pathogens greatly depends on our knowledge of the various factors that control biofilm formation. A comprehensive discussion on microbial biofilms is beyond the scope of this chapter, and the reader is referred to recent review articles for further information (Stoodley et al., 2002; Ryu and Beuchat, 2005; Kolter and Greenberg, 2006). Following is a short discussion on various physical, chemical and biological parameters that may affect microbial growth.

B. Temperature

Temperature is a major factor influencing microbial growth. Microorganisms could be divided based upon their capacity to grow under a limited range of temperatures. Psychrophiles, or cold-loving microbes, grow slowly at refrigerated temperatures (below 7°C), (Olson and Nottingham, 1980; Kraft, 1992). Mesophiles are moderate temperature-loving microbes, that could survive at refrigeration temperature and grow well between 20–45°C, with optimum growth between 30–40°C (Jay, 1992). Some microbes can grow at low temperatures as psychrophiles, while their optimum growth rate is at the temperature of mesophiles. These microorganisms are termed psychrotrophs. It is important to note that, for each group, the growth rate increases as the temperature increases only up to an optimum, after which it rapidly declines.

Psychrophilic and mesophilic organisms are considered to be the chief microbiological concerns affecting the shelf life and safety of fresh produce. Fresh fruits and vegetables are naturally colonized with bacteria, molds and yeasts belonging to both mesophiles and psychrophiles. In the field and during storage at ambient temperatures, the mesophiles flourish and constitute the dominant flora on produce. During cold storage, a shift in the population occurs, and the predominant flora becomes psychrophiles. A list of the major genera of psychrophiles is presented in Table 13.1. Of special concern is the psychrophilic human pathogen, *Listeria monocytogenes*. This pathogen can grow at refrigeration temperatures, can persist as an environmental contaminant in the produce processing environment, and has the potential to cause mortalities associated with outbreaks (Fain, 1996).

It should be noted that mesophilic microorganisms could survive under refrigeration and may grow in numbers during any temperature abuse of the stored produce.

C. Hydrogen ion concentration (pH)

Another parameter which greatly influences microbial growth and metabolic activity is pH. The optimum pH for most bacteria is near the neutral point (pH 6.5 to 7.5). Certain bacteria are acid-tolerant and will survive at reduced levels (pH 4.5). Notable acid-tolerant bacteria include *Lactobacillus* and *Streptococcus*, which can withstand a pH from 3.8 to 7.2. In the food industry pH is commonly used to control bacterial growth. In many fresh fruits the pH is usually acidic, thus limiting the growth of multiple bacterial species. On the other hand, molds and yeasts can survive and grow under a wider range of pH. For example, *Fusarium oxysporum* can grow in a pH range of 1.8 to 11.1, and *Candida pseudotropicalis* can grow between 2.3 to 8.8 (Brackett, 1992b). Their adaptation to a wide range of pH makes molds and yeasts frequent causative agents responsible for fruit spoilage (Deak and Beuchat, 1993).

D. Moisture content

All microorganisms require water for viability, but the amount necessary for growth varies between species. The amount of water that is available in food products is

Table 13.1 Psychrotrophic spoilage microorganisms

Bacteria
Acinetobacter, Aeromonas, Alcaligenes, Arthrobacter, Bacillus, Chromobacterium, Citrobacter, Clostridium, Corynebacterium, Enterobacter, Erwinia, Escherichia, Flavobacterium, Klebsiella, Lactobacillus, Leuconostoc, Listeria, Microbacterium, Micrococcus, Moraxella, Proteus, Pseudomonas, Serratia, Streptococcus, Streptomyces, Vibrio, Yersinia
Molds
Aspergillus, Penicillum
Yeasts
Candida, Cryptococcus, Torulopsis

Source: Brackett (1992b).

commonly expressed in terms of water activity (Aw), where the Aw of pure water is 1.0 and that of dry surface (no water available) is 0. Water activity is a measure of the water available to microorganisms, and is affected by the presence of solutes, such as salts and sugars. Aw is calculated by dividing the partial vapor pressure of the product (or solution) by that of pure water. Each microorganism has a maximum, optimum and minimum Aw for growth and survival. Generally bacteria dominate in foods with high Aw (above 0.90), while yeasts and molds, which require less moisture (above 0.70), dominate in low Aw foods.

Fresh fruit and vegetables have a high Aw and therefore, moisture is not considered a limiting factor for microbial growth. Moreover, accumulation of water on fresh or minimally processed produce, due to condensation or inadequate drying steps (following water wash), further supports the growth of organisms. Free water enables solubilization of carbohydrates from produce's exudates, therefore facilitating microbial growth due to the availability of nutrients.

E. Atmosphere

Microorganisms vary greatly in their requirement for oxygen for metabolic activities. Consequently, they can be classified according to the oxygen requirements necessary for their growth and survival, as follows:

- obligate aerobes: require oxygen;
- facultative anaerobes: grow in the presence or absence of oxygen;
- obligate anaerobes: grow only in complete absence of oxygen (in some cases the presence of oxygen can be lethal);
- microaerophilic: grow best at very low levels of oxygen;
- aerotolerant anaerobes: oxygen is not required for growth, but is not harmful if present.

Under standard storage conditions, oxygen availability is not a limiting factor for spoilage bacteria. However, in packed produce, respiration of the produce decreases O_2 concentration and increases CO_2 production. These physiological changes will affect the microbial flora, and a shift toward microbes that can grow in a low oxygen environment will occur (e.g. lactic acid bacteria, yeasts). In a microenvironment where O_2 is completely lacking, anaerobic populations will prevail. Some harmful microbes, such as *Clostridium botulinum* might grow under these conditions.

Carbon dioxide (CO_2) also affects microbial growth and activity. Gaseous CO_2 inhibits growth of psychotrophic microorganisms and prevents spoilage of fruits and vegetables. Carbon dioxide is used as a direct additive in the storage of fruits and vegetables under controlled or modified environments. The optimum levels of O_2 and CO_2 (5–10%) to extend a product's shelf life are determined by factors such as the nature of the product, variety, climate and length of storage. Carbon dioxide combined with oxygen affects produce shelf life, mainly by delaying respiration and ripening, as well as by retarding the growth of most aerobic spoilage microorganisms. However, under certain conditions, the growth of some anaerobic psychotrophic pathogens may occur or even be stimulated (Soliva-Fortuny and Martín-Belloso, 2003).

The specific effect of modified or controlled atmosphere on the growth of certain spoilage microorganisms and food-borne pathogens should be experimentally tested for each product.

F. Time

Microbial growth is measured over time. Although the effect of time on microbial growth seems to be taken for granted, it should be reiterated that time is a critical factor allowing microbial growth. While advances are being made in extending the shelf life of fresh produce, microbes have more time to colonize and grow (even slowly) within or on the surface of fruits and vegetables. Thus, unless produce is treated with agents that specifically inhibit microbial growth, it is likely that populations of microorganisms associated with fresh vegetables and fruits will increase with increasing storage or shelf life time.

G. Nutrients

All microorganisms require a source of nutrients for metabolism. Fermentative bacteria require carbohydrates, either simple sugars, such as glucose and fructose, or complex carbohydrates, such as starch or cellulose. The energy requirements of microorganisms are very high, so limiting the amount of available nutrient can inhibit their growth.

The nutritional requirements are quite organism-specific, and differ widely between organisms. Nutritional requirements include carbon source, energy source, various elements (e.g. nitrogen, sulfur, phosphorus, potassium, magnesium, calcium) and trace elements (e.g. copper, iron, zinc, cobalt, and other). Not all microorganisms require or are even able to assimilate all the required nutrients from the environment. For example, nitrogen is required for amino acid and protein synthesis. Some microbes may use inorganic nitrogen as the sole source for all their nitrogen requirements. Nitrogen-fixing bacteria convert atmospheric nitrogen (gas) into organic molecules available for cellular metabolism, while other bacteria require inorganic nitrogen in the form of ammonium or nitrate. Fastidious microbes may require organic nitrogen, such as preformed amino acids or peptides. Some microbes cannot grow without organic growth factors e.g. organic compounds that are products of the metabolism of other organisms and are necessary for growth. Fresh produce contains sufficient carbohydrate to support the growth of numerous microorganisms. Upon growth of the initial population, it may produce and secret multiple degradative enzymes, such as pectinases, cellulases, amylases and proteases, that release more nutrients from the injured plant's tissue, giving rise to the development of other populations that feed on these nutrients. The situation is more problematical in fresh-cut fruit and vegetables, where exudates from the injured plant's tissue are freely availably for immediate consumption by the resident microbial flora.

H. Competing flora

Fresh fruits and vegetables are colonized by many microorganisms, including bacteria, yeasts and molds. There is wide biodiversity in the nature of these microorganisms, and populations may vary in size under different environmental conditions. Microbial colonization of produce surfaces requires attachment and growth of microorganisms, usually in the form of biofilm (Rayner et al., 2004; Aruscavage et al., 2006). While some microbes can obtain all their nutritional requirements from the plant's tissue, others need to acquire particular growth promoting factors made by other microbial populations, as discussed above. Thus, colonization of microsites on the surface of fruits and vegetables depends on the growth rate of a particular organism, under complex environmental conditions, and will depend to a great extent upon the presence of neighbor microorganisms that compete for the same physical space and nutrient sources (Aruscavage et al., 2006). A competitive advantage can be gained by an organism that grows quickly, establishing dominance when nutrient levels are high, or by being able to grow when there are few nutrients remaining. Therefore, organisms that have highly efficient modes of nutrient uptake have a competitive advantage (Beattie and Lindow, 1994). Microorganisms also employ other strategies to outgrow their competitors. These include secretion of metabolic by-products or secondary metabolites that may be harmful to other microorganisms, such as fermentation products that lower the pH and make the environment less favorable for certain populations. This strategy is commonly used by many fermentative microbes, such as lactic acid bacteria. Certain bacteria, yeasts and molds are capable of producing antibiotics, which kill or inhibit the growth of susceptible species and thus, facilitate their own occupancy of the specific ecological niche. Many microorganisms also produce and secrete proteinaceous toxins, called bacteriocins, which inhibit the growth of similar or closely related species. Bacteriocins may affect a wide or narrow range of susceptible microbes (Baba and Schneewind, 1998). Although limiting microbial growth is crucial for extending the shelf life of fresh produce, care must be taken to maintain the diversity and intrinsic balance between members of the natural flora. Interfering with this balance, for example, in the case of product disinfection, might have important consequences on the composition of the population. For example, it has been suggested that reducing the native microbial populations by washing and sanitizing or by controlled atmosphere storage can allow human pathogens to flourish on produce surfaces (Brackett, 1992a).

On the other hand, future strategies to reduce food-borne pathogens on fresh produce might take advantage of the "competitive exclusion" approach, similar to that employed in other foods. For example, it was recently shown that *Lactobacillus salivarius* and *Streptococcus cristatus* reduce *Salmonellae* colonization in poultry (Zhang et al., 2007).

I. Plant defense mechanisms

Besides the production of a wide array of antimicrobial factors by the intrinsic microbial flora of fruits and vegetables, plants have evolved barriers to limit microbial growth as part of their intrinsic defense. It is not the aim of this chapter to review the literature regarding pathogen–plant interactions however, a few antimicrobial factors that might affect microbial growth on fresh or fresh-cut produce will be discussed. An important general defense mechanism is the production of phytoalexins by many plants. Phytoalexins are defined as low molecular weight antimicrobial compounds biosynthesized *de novo* in response to diverse forms of stress, including microbial attack (Harborne, 1999). Phytoalexins play a significant role in microbial–plant interactions. In fact, some fungi have acquired mechanism to inactivate these molecules, as part of their pathogenesis (Pedras and Ahiahonu, 2005). Phytoalexin expression is also induced during some processes, such as hot water washing of produce (Fallik et al., 1995) and following UV light irradiation in fresh (Rodov et al., 1992) and fresh-cut melons (Lamikanra, 2002).

Recently, dietary phytochemicals extracted from fruits and herbs were reported to have anti-quorum sensing (QS) activity (Vattem et al., 2007). QS is a cell density dependent regulation of gene expression in bacteria, mediated by hormone-like compounds called autoinducers (AI), that affect numerous activities in bacteria, including bacterial colonization and biofilm formation (Koutsoudis et al., 2006). Taken together, plants have evolved multitargeted means of inhibiting microbial growth.

III. Microorganisms involved in spoilage

A. Background

Microorganisms that cause spoilage of vegetables and fruits belong mainly to the taxonomic domains Bacteria and Eukarya. Bacteria are prokaryotic single-celled organisms, around 1 μm in diameter, without internal differentiated organelles. They appear in nature as rods, cocci, spiral form or filaments, and sometimes form a chain or aggregate of single cells. Most bacteria possess a rigid cell wall composed of peptidoglycan (PG) polymer cross-linked by peptides. Based on their cell wall structure, bacteria are divided into those that are stained negative or positive by Gram stain. In Gram-positive bacteria, the cell wall is a thick layer of PG, while in Gram-negative bacteria the cell wall is relatively thin and is composed of a thin layer of PG surrounded by a membranous structure called the outer membrane. The PD is a substance unique in nature to bacterial cell walls. Bacteria possess ribosomes different from those of Eukaria. Their ribosomal RNA is composed of 16S, 23S and 5S RNA molecules that are highly conserved. These molecules, especially the 16S, are currently used for phylogenetic analysis of bacteria. Bacteria reproduce asexually by dividing their cell into two daughter cells, in a process known as binary fission.

A unique class of bacteria, the *Mollicutes*, includes phytoplasmas and spiroplasmas which are microorganisms, considered to be the smallest prokaryotes due to their size, typically only 0.2–0.3 μm. They differ from other bacteria in that they lack a rigid cell wall, and their cell membrane contains sterols, similar to Eukarya membranes. Although *Mollicutes* include several plant pathogens, they are not considered to be spoilage bacteria.

Perhaps the major group of microorganisms that are typically involved in spoilage and losses of fresh produce are the yeasts and fungi. Taxonomically, yeasts and fungi belong to the kingdom Fungi in the Eukarya domain. The fungi are saprophytes characterized by a cell wall made largely of chitin and other polysaccharides.

A majority of the species is filamentous and appear as multicellular hyphae forming a branched filamentous colony called mycelium. Some fungal species (yeasts) also grow as single cells. Under different conditions, some yeast may have filamentous growth. Fungi reproduce both sexually and asexually via production of spores, often on specialized structures or in fruiting bodies. While some fungal species are considered to be major spoilage microorganisms, other species are necessary for plant root function, such as the mycorrhizae.

B. Microbial colonization

There are various ways in which fruits and vegetables might become colonized by microbial flora which could cause postharvest spoilage. Perhaps the most common route is the field's colonization by soil saprophytes and plant parasites. However, microbial colonization could result from contaminated seeds, as well as via contact with other fruits and vegetables at any stage during harvest and postharvest, including handling, transportation, processing and packaging (Beuchat and Ryu, 1997). Microbial biota could spread not only by direct contact, but also through air and water. For example, washing produce in a water tank might share microorganisms within the entire lot.

C. Common microbial quality parameters

The numbers and kinds of microorganisms found on fresh produce, and on fresh-cut (minimally processed) produce, are highly variable and depend on the microbiological method used for identification and enumeration. The microbial quality of fresh produce, similar to other food products, is frequently evaluated in terms of "total plate count" (TPC), "standard plate count" (SPC) or more accurately "aerobic mesophilic count" (AMC). AMC reflects the total number of cultivable bacteria at a temperature of 30–37°C present in association with food, and does not necessarily imply the presence of specific spoilage or pathogenic organisms (Harrigan, 1998). In fact, many published studies report no link between spoilage and the size of bacterial populations (Zagory, 1999). AMC numbers vary widely in fresh vegetables and fruits, and their initial number at harvest is determined by many factors, such as geographical region, cultivar and environmental factors. In some food products AMC is used as a parameter to evaluate the general microbiological quality of the product as it increases during shelf life, especially if the product is exposed to temperature abuse. Thus, AMC is frequently correlated to the duration of shelf life under specific storage conditions. AMC determination provides information regarding the number of bacteria capable of growing at storage temperature abuse (above refrigeration temperature). In some cases, knowledge of the number of bacteria that can grow during storage at low temperature is beneficial for evaluating microbial quality, and can predict shelf life duration. In such circumstances, the total number of psychrotrophic bacteria (total psychrotrophs count) is determined. Although variation exists regarding the temperature and time required for incubation, it is currently recommended that plates should be incubated at 7°C for 10 days for many food products (Cousin et al., 2001).

The range of mesophilic bacteria on fresh produce can vary widely, and is typically between 10^3 to 10^9 CFU g^{-1}. Total counts on products after processing range from 10^3 to 10^6 CFU g^{-1} (Nguyen-the and Carlin, 1994; Ragaert et al., 2007). Total counts of yeasts and fungi on fresh and minimally processed vegetables also vary to a great extent. For example, in a recent survey conducted in the Washington, DC, area yeast and mold counts were determined in 39 ready-to-eat salads, 29 whole fresh vegetables and 116 sprout samples (Tournas, 2005a). Yeasts were the most prevalent organisms found in these samples, at levels ranging from less than 100 to $\sim 10^8$ CFU g^{-1}. Mold counts generally ranged from less than 100 to 10^4 CFU g^{-1} (Tournas, 2005a). Mold and yeast counts in some fresh and minimally processed vegetables are listed in Table 13.2.

Table 13.2 Mold and yeast counts in fresh and minimally processed vegetables

Product	Number of samples	Mold and yeast, CFU g^{-1}	
		Mean	Range
Salads			
Lettuce	18	1.1×10^5	$1.3 \times 10^3 - 9.4 \times 10^5$
Coleslaw	4	8.1×10^5	$1.4 \times 10^5 - 1.8 \times 10^6$
Carrots	4	5.3×10^4	$<100 - 2.1 \times 10^5$
Celery chunks	1	3.8×10^4	–
Salad bar items			
Broccoli chunks	2	9.2×10^4	$1.4 \times 10^4 - 1.7 \times 10^5$
Cauliflower	1	5.8×10^5	–
Cucumbers (sliced)	2	1.7×10^4	$1.1 \times 10^4 - 2.2 \times 10^4$
Iceberg lettuce	1	1.6×10^3	–
Iceberg and red cabbage mix	1	2.6×10^3	–
Green peppers (sliced)	1	9.1×10^4	–
Romaine lettuce	2	1.9×10^4	$1.2 \times 10^4 - 2.6 \times 10^4$
Spinach	1	9.5×10^4	–
Tomatoes (sliced)	1	9.2×10^6	–
Miscellaneous whole vegetables			
Chives	1	2.2×10^4	–
Cucumbers	3	2.5×10^3	$1.0 \times 10^2 - 6.0 \times 10^3$
Green peppers	3	6.6×10^3	$1.3 \times 10^3 - 1.2 \times 10^4$
Green onions	3	1.9×10^3	$2.0 \times 10^2 - 4.0 \times 10^3$
Lettuce (iceberg)	2	1.2×10^4	$1.0 \times 10^4 - 1.3 \times 10^4$
Lettuce (Romaine)	3	3.7×10^4	$1.9 \times 10^3 - 9.5 \times 10^4$
Parsley	1	9.5×10^4	–
Radishes	3	1.0×10^4	$6.8 \times 10^3 - 1.2 \times 10^4$
Spinach	2	2.0×10^4	$2.4 \times 10^3 - 3.8 \times 10^4$
Tomatoes			
Cherry	4	2.5×10^4	$1.3 \times 10^4 - 3.4 \times 10^4$
Grape	1	2.4×10^5	–
Roma	3	5.0×10^5	$<100 - 1.5 \times 10^6$

Source: Tournas (2005a).

D. Type of spoilage microorganisms

Tournas (2005b) has recently published a review of the microorganisms that cause spoilage of vegetables by bacteria and fungi. Bacterial spoilage of vegetables is most commonly caused by members of the genera *Erwinia* and *Pseudomonas* (Nguyen-the and Carlin, 1994). Many of these bacteria can ferment a variety of vegetable sugars and alcohols that are not utilized by other bacterial species and cause soft rot (reviewed by Tournas, 2005b). In general, bacterial spoilage is characterized by a watery and slimy appearance, though some fungal rots are also soft and watery. Most bacteria that cause spoilage of fresh and minimally processed vegetables and sprouts are psychrotrophic, e.g. capable of growth at low temperatures, including at refrigeration temperatures. Vegetables rich with sugar may undergo microbial fermentation by lactic acid bacteria or yeasts, whereas others might develop soft rot symptoms due to the growth of Gram-negative (pectinolytic) bacteria. Frequently, spoilage cannot be attributed to a single type of microorganism (Nguyen-the and Carlin, 1994; Varoquaux et al., 1996; Pingulkar et al., 2001). A list of the major bacterial species that are involved in vegetable spoilage, the type of spoilage and the vegetable affected is shown in Table 13.3.

Fungal spoilage is usually distinguished from bacterial decay by the presence of mycelium and characteristic spore-forming structures. Frequently, fungi cause spoilage by penetrating areas of broken skin. Injury could be inflicted through mechanical damage, chilling injury or bacterial enzymatic activity (Tournas, 2005a). A list of common fungi that cause spoilage on a variety of vegetables is presented in Table 13.4. Major spoilage fungi include *Botrytis cinerea*, various species of the genera *Alternaria*, *Aspergillus*, *Cladosporium*, *Colletotrichum*, *Phomopsis*, *Fusarium*, *Penicillium*, *Phoma*, *Phytophthora*, and *Pythium*. Some fungi show a preference for a particular substrate, whereas others such as *Botrytis cinerea*, *Colletotrichum*,

Table 13.3 Frequent spoilage bacteria found on fresh vegetables

Bacterial species	Type of spoilage	Vegetables
Corynebacterium michiganense	Canker and fruit spot	Tomatoes, other
C. sepedonicum	Tuber rot	White potatoes
Erwinia carotovora	Bacterial soft rot	Leafy crucifers, lettuce, endives, parsley, celery, carrots, onions, garlic, tomatoes, beets, peppers, cucumbers
Pseudomonas chicorii	Bacterial zonate spot	Cabbage and lettuce
P. marginalis group	Soft rot of vegetables	Lettuce, other
P. morsprunorum group	Halo blight	Beans
P. tomato group	Bacterial specks	Tomatoes
P. syringae group	Diseases in soybeans	Soybeans
Xanthomonas campestris	Black rot	Cabbage, cauliflower

Source: Based on Tournas (2005b).

Table 13.4 Common fungi causing spoilage of fresh produce

Fungal species	Type of spoilage	Vegetables
Alternaria alternata	Alternaria rot	Tomatoes, peppers, cucurbits
Alternaria brassicola and *A. oleracea*	Alternaria rot	Leafy crucifers
Aspergillus alliaceus	Black rot	Onions, garlic
Botrytis allii	Neck rot	Onions
B. cinerea	Gray mould rot	Leafy crucifers, lettuce, onions, garlic, asparagus, pumpkin, squash, carrots, celery, sweet potatoes and most other vegetables
Bremia lactucae	Downy mildew	Lettuce
Ceratocystis fimbriata	Black rot	Sweet potatoes
Cladosporium cucumerinum	Scab	Cucumber, pumpkin
Colletotrichum coccodes *Colletotrichum spp.*	Anthracnose	Cucumbers, squash, pumpkin, peppers, tomatoes
Diaporthe batatis		Sweet potato
D. vexans		Eggplant fruit
Fusarium spp.	Dry rot	Potatoes
Geotrichum candidum	Sour rot	Asparagus, crucifers, onions, garlic, beans, carrots, parsley, parsnips, lettuce, endives tomatoes, globe artichokes, various vegetables

Source: Based on Tournas (2005b).

Alternaria, *Cladosporium*, and *Phytophthora*, may be found in a wide variety of produce.

The range of yeasts counts and details of major fungi found on vegetables salads and on several whole vegetables are listed in Table 13.5.

Spoilage of fruits is also inflicted by a variety of fungi. For example, harvested grapes were found to harbor a diverse range of fungal pathogens, such as *Alternaria*, *Aspergillus*, *Botrytis*, *Cladosporium*, *Epicoccum*, *Eurotium*, *Fusarium* and *Rhizopus* (Abrunhosa et al., 2001; Bellí et al., 2003). It should be noted in this context that, besides causing devastating economic losses to the agri-food sector, some fungi may synthesize toxic and carcinogenic secondary metabolites known collectively as mycotoxins, which are capable of causing disease and death in humans and other animals (Bennett and Klich, 2003). For example, aflatoxins are carcinogenic difuranocoumarin derivatives produced by many strains of *Aspergillus flavus* and *Aspergillus parasiticus*; citrinin is a potent nephrotoxin in animal species, which was identified in species of *Penicillium* and *Aspergillus* (*Aspergillus terreus* and *Aspergillus niveus*). Fumonisins, another mycotoxin, affect animals by interfering with sphingolipid

Table 13.5 Fungi found in fresh and minimally processed vegetables

Organism	Range (CFU g^{-1})	Frequency (% contaminated samples)
Salads (39 samples)		
Alternaria	$<100 - 5.0 \times 10^3$	10.3
Cladosporium	$<100 - 5.9 \times 10^3$	23.3
Penicillium	$<100 - 2.0 \times 10^3$	5.1
Yeasts	$<100 - 9.2 \times 10^6$	94.9
	Miscellaneous whole vegetables	
Tomatoes (8 samples)		
Alternaria	$<100 - 2.0 \times 10^3$	12.5
Cladosporium	$<100 - 1.4 \times 10^4$	50.0
Geotrichum	$<100 - 2.4 \times 10^5$	12.5
Penicillium	$<100 - 3.2 \times 10^4$	25.0
Yeasts	$<100 - 1.5 \times 10^6$	62.5
Cucumbers (3 samples)		
Alternaria	$<100 - 2.1 \times 10^3$	33.3
Cladosporium	$<100 - 2.0 \times 10^2$	66.7
Yeasts	$<100 - 1.5 \times 10^3$	66.7
Green onions (3 samples)		
Cladosporium	$<100 - 1.9 \times 10^3$	66.7
Yeasts	$<100 - 2.1 \times 10^3$	66.7
Lettuce (5 samples)		
Alternaria	$<100 - 6.0 \times 10^2$	20.0
Cladosporium	$<100 - 8.2 \times 10^3$	40.0
Penicillium	$<100 - 1.0 \times 10^2$	20.0
Yeasts	$1.9 \times 10^3 - 9.5 \times 10^4$	100.0
Green peppers (3 samples)		
Alternaria	$<100 - 1.0 \times 10^4$	66.7
Cladosporium	$<100 - 6.4 \times 10^3$	33.3
Yeasts	$<100 - 2.0 \times 10^3$	33.3
Spinach (2 samples)		
Cladosporium	$<100 - 1.0 \times 10^3$	50.0
Yeasts	$2.0 \times 10^3 - 3.7 \times 10^4$	100.0
Radishes (3 samples)		
Alternaria	$<100 - 2.0 \times 10^3$	33.3
Cladosporium	$<100 - 1.3 \times 10^3$	66.7
Yeasts	$6.8 \times 10^3 - 1.1 \times 10^4$	100.0

Source: Tournas (2005a).

metabolism and are probably linked with esophageal cancer in humans. They are produced by a number of *Fusarium* species, notably *Fusarium verticillioides*. Other potent mycotoxins include ochratoxin, a potent nephrotoxin produced by different species of *Aspergillus*, including *Aspergillus alliaceus*, *Aspergillus auricomus*, and patulin, synthesized by *Penicillium griseofulvum* (Bennett and Klich, 2003).

IV. Microbial hazards associated with fresh produce

A. Background

Increased public concern about healthy diet, together with advances in agronomics, processing, preservation, distribution and marketing technologies, and expansion of global trade has enabled the produce industry to supply nearly all types of high-quality fresh fruits and vegetables year-round. In addition, new, minimally processed, ready-to-eat fruits and vegetables are being introduced into the marketplace, making consumption of fresh produce easier and more convenient. While major food-borne diseases in the past were attributed to consumption of foods from animal sources, such as meat, eggs and dairy products, during the last two decades outbreaks related to the consumption of fresh vegetables, herbs and fruits have been increasingly reported (reviewed by Brandl, 2006; Beuchat and Ryu, 1997; Sivapalasingam et al., 2004; Bowen et al., 2006).

Fresh produce does not receive any "lethal" treatment that kills all pathogens prior to consumption (Beuchat, 2002). Hence, pathogens that might have been introduced at any point of the production chain may still be present when the produce is consumed. The microflora of fresh fruits and vegetables is diverse, but is predominately Gram-negative bacteria. The produce can become contaminated with pathogens from human or animal sources during growth, harvest, packaging, transportation and further processing and handling (Beuchat and Ryu, 1997; Brackett, 1999; Brandl, 2006). Handling in retail outlets could also introduce pathogenic microorganisms to the surface of the fresh produce, as well as non-hygienic storage and handling in the consumer's kitchen. Therefore, the basic assumption regarding the produce chain from farm-to-fork is that there is no guarantee of pathogen-free produce. Accordingly, it is important to understand the risks of contamination, to identify the sources of contamination, and to use technologies and treatments to minimize contamination (Beuchat, 1996; Monaghan, 2006).

Factors that may contribute to produce contamination include both pre- and postharvest factors. Potential sources of preharvest contamination were recently reviewed, and include the use of manure as a fertilizer, the presence of wild or domestic animals in or near fields and the use of poor quality water, such as partially treated effluents, as well as flood water, for irrigation (Beuchat and Ryu, 1997; Brackett, 1999; Beuchat, 2002; Steele and Odumeru, 2004; Brandl, 2006). Human pathogens may be transmitted to the plants via air (aerosols, dust), through water, as well as by vectors such as insects and protozoa (reviewed by Brandl, 2006).

Postharvest contamination might also occur in the packaging house, due to cross-contamination with raw produce, either on processing and packaging surfaces, or during washing steps, if the quality of the water is low. Poor sanitation in the packaging house may also cause contamination. Still, an important cause of contamination is human. Individuals suffering from intestinal diseases or health carriers of human pathogens might contaminate the fresh produce at any stage from farm-to-fork.

B. Human pathogens involved in outbreaks related to fresh produce

Outbreaks associated with fresh produce involved several microbial pathogens, including bacteria, parasites and viruses. Common human pathogens reported to be associated with produce-borne illness outbreaks include, *Escherichia coli* O157:H7, *Salmonella* spp., *Shigella* spp., *Listeria monocytogenes*, *Crytosporidium* spp., *Cyclospora* spp., *Clostridium botulinum*, hepatitis A virus (Beuchat, 1996; Harris et al., 2003; Bowen et al., 2006).

Escherichia coli O157:H7

E. coli strains are considered to be part of the natural intestinal flora of humans and other mammals. However, this species contains numerous virulent strains, categorized into several pathogenic groups, which may cause diseases in humans. The Enterohemorrhagic *E. coli* (EHEC) group, also known as Shiga toxin-producing *E. coli* (STEC), is of special importance and contains several pathogenic serogroups (Kaper et al., 2004). *E. coli* O157:H7 is the most commonly reported serogroup in human infections. The bacterium was first recognized as a cause of serious acute diarrheal illness in humans in 1982 (Riley et al., 1983). These infections are frequently complicated by hemorrhagic colitis and hemolytic uremic syndrome (HUS); the latter is particularly common in children (Decludt et al., 2000). The natural reservoirs of STEC are domestic and wild animals, particularly ruminants such as cattle, sheep and goats (Beutin et al., 1993). The bacterium reaches humans through direct or indirect contact with infected animals or through contaminated food or drinking water. Following infection, the bacteria can also spread from one person to another.

Although *E. coli* O157:H7 has traditionally been associated with disease outbreaks related to beef products, this strain has also recently emerged as a pathogen associated with fresh produce. Outbreaks linked to the consumption of unpasteurized apple juice were reported as early as 1991, in a situation where fallen apples were used for making juice and cattle were raised near the orchard (Besser et al., 1993). In 1996, a large, multi-state outbreak in the US and Canada affected 70 people. Again, the source was traced to the consumption of fallen apples. These apples came from orchards frequented by deer that were subsequently shown to carry *E. coli* O157:H7 (Cody et al., 1999). Several other outbreaks related to the consumption of apple cider followed, in both Canada and the US (Tamblyn et al., 1999; Hilborn et al., 2000).

Contaminated lettuce has also been implicated in outbreaks related to this pathogen (Ackers et al., 1998; Hilborn et al., 1999). In one case the contamination was traced to cattle raised near the lettuce field. During September and October of 2006, a major multi-state disease outbreak linked to the presence of *E. coli* O157:H7 in fresh, bagged spinach was reported in the US. As of October 6, 199 ill people had been reported to the US Center for Disease Control (CDC); 102 (51%) of these cases required hospitalization. Thirty-one of these people (16%) developed HUS, and three deaths were recorded (CDC, 2006a). Another *E. coli* outbreak later in the same year was associated with the consumption of contaminated lettuce by customers at multiple restaurants of a single restaurant chain in the northeastern US. By December 13, 2006, 71 people had become ill with *E. coli* O157:H7 in association with this outbreak. Among these, 53 (75%) were hospitalized and 8 (11%) developed HUS. Shredded lettuce consumed at the restaurants was the most likely source of the outbreak. It has been hypothesized that this lettuce was probably contaminated before it reached the restaurants (CDC, 2006b).

Salmonella enterica

Another major human pathogen involved in outbreaks related to fresh produce is *Salmonella enterica*. This pathogen is a Gram-negative, rod-shaped bacillus of the genus *Salmonella* that is part of the family *Enterobacteriaceae*, just like *E. coli*. There are more than 2500 known serotypes of *S. enterica*. However, only a small number of these are frequently isolated in a given geographic region. It is estimated that 1.4 million cases of salmonellosis occur annually in the US (Voetsch et al., 2004). This pathogen is transmitted through contaminated food and water, as well as contact with infected animals. The majority of *Salmonella* infections have been linked to consumption of raw meats, poultry, eggs, milk and dairy products. In recent years, there has been an increase in both the frequency and magnitude of tomato-associated *Salmonella* outbreaks reported to the CDC. This pathogen caused 1616 reported illnesses in nine outbreaks between 1990 and 2004, representing approximately 60 000 illnesses when taking into account the estimated proportion (97.5%) of illnesses which go unreported (Voetsch et al., 2004). Two *Salmonella* outbreaks, one in 1990 (176 cases of *S*. Javiana) and one in 1993 (100 cases of *S*. Montevideo), were both traced to a South Carolina packing house. It was hypothesized that cross-contamination might have occurred at the packing house, where substantial numbers of tomatoes passed through a common wash tank (Hedberg et al., 1999). This allowed for the inoculation of large numbers of tomatoes with the pathogen. More recently, *S*. Baildon was implicated in a third outbreak related to consumption of raw tomatoes (Cummings et al., 2001).

Salmonella has also been implicated in disease outbreaks associated with other types of produce. For example, *Salmonella* caused a multi-state disease outbreak due to consumption of contaminated citrus juice (Parish, 1998). In 2002, *S*. Poona-contaminated cantaloupe from Mexico caused a multi-state outbreak in the US and Canada, resulting in 58 infections. Sewage-contaminated irrigation water was considered to be one of the possible sources of this contamination (CDC, 2002). Outbreaks due to consumption of watermelons contaminated with *S*. Javanica, *S*. Oranienburg and *S*. Saphra have also been reported (Blostein, 1993; Deeks et al., 1998; Mohle-Boetani et al., 1999). In each of these cases, the pathogen may have first come into contact with the melon rind. Both *E. coli* O157 and *Salmonella* infections have also been associated with the consumption of various sprout types (Mohle-Boetani et al., 2001). Recently, *Salmonella* was also linked to outbreaks related to contaminated tahini in Australia and New Zealand. The source of contamination was traced to sesame seeds (Unicomb et al., 2005).

Other bacterial pathogens

Several other bacterial pathogens have been implicated in diseases associated with eating contaminated produce (Harris et al., 2003). *Shigella sonnei*, a species closely related to invasive *E. coli*, was implicated in outbreaks related to the consumption of contaminated parsley (CDC, 1999), melon (Fredlund et al., 1987) and lettuce (Martin et al., 1986). *Clostridium botulinum*, a Gram-positive, spore-forming, rod-shaped bacillus has also been implicated in produce-related outbreaks. Its toxin and spores were found in a coleslaw dressing that contained cabbage and carrot pieces (Solomon et al., 1990).

Protozoan pathogens

Cyclospora cayetanensis is a unicellular parasite that causes a disease called cyclosporiasis. *C. cayetanensis* caused disease outbreaks in the US and Canada from 1995 to 1999, which were linked to the consumption of raspberries imported from Guatemala. In one instance, the crop may have become contaminated when it was sprayed with insecticides and fungicides mixed with contaminated water (Herwaldt and Ackers, 1997; Fleming et al., 1998). In the other cases, the source of contamination could not be identified (CDC, 1997b,c; Koumans et al., 1998; Herwaldt and Beach, 1999; Herwaldt, 2000).

Another protozoan pathogen implicated in produce-related outbreaks is *Crytosporidium parvum.* This unicellular parasite can survive in extreme environments as an oocyte (Dawson, 2005). The pathogen has particular clinical significance for immunocompromised persons, including AIDS patients and cancer patients receiving toxic chemotherapeutic drug regimens. *C. parvum* was detected on lettuce and several other vegetables (reviewed by Moore et al., 2007), and it has been linked to outbreaks related to the consumption of unpasteurized fresh apple juice, most likely contaminated with cattle feces (CDC, 1997a).

Giardia lamblia, another protozoan pathogen, is the causative agent of giardiasis. A common route of infection is through fecal-oral transmission. Food-borne giardiasis has been linked to eating fruit salad and raw sliced vegetables (reviewed by Dawson, 2005).

Viral pathogens

The involvement of viruses in outbreaks related to fresh produce was thoroughly reviewed by Seymour and Appleton (2001). The two major virus groups that have been associated with the consumption of fresh produce are Norwalk-like viruses (NLV), the most commonly identified etiological agent of viral gastroenteritis, and hepatitis A (HAV). NLV has been identified in salad items and fresh-cut fruits. HAV infections were reported following consumption of contaminated iceberg lettuce, diced tomato, strawberries, coleslaw, potato salad and frozen raspberries (Seymour and Appleton, 2001).

C. Interactions of enteric pathogens with fresh produce

Pathogenic microorganisms associated with food-borne diseases have been detected in numerous fruits and vegetables, including lettuce, melons, seed sprouts, berries, tomatoes, green onions, carrots, apples, pears, pineapples, basil, celery, cucumbers, as well as in apple, orange, lemon and elderberry juices (Sivapalasingam et al., 2004). Recent years have witnessed a marked increase in the fresh-cut or ready-to-eat fruit and vegetables market that reflects increasing consumer demand for a quick and convenient but healthy diet. Consequently, extensive efforts have gone into research concerning microbiological quality, safety, processing and packaging of these types of products. While the majority of fresh vegetables and fruits remain almost intact after harvest, fresh-cuts undergo several processing steps that affect their microbiological quality and safety, such as trimming, washing, disinfection and additional cutting or slicing steps. During all these steps, fresh-cut produce have the potential for contamination with pathogenic bacteria, as well as the possibility of enhancing growth of these contaminants (Brackett, 1999). Contamination may come from unhygienic personnel, through contact with contaminated surfaces in the food plant, or from contact of the processed, decontaminated product with raw, untreated produce (cross-contamination). The process of slicing and shredding destroys surface cells, bruises underlying layers and allows exudates to leak from inner tissues, providing essential growth nutrients to the microbial flora residing on these products.

Bacteria present on produce or on abiotic contact surfaces may potentially infiltrate into inner tissue which enables further growth, and provides a protected niche against further washing and disinfection steps. Furthermore, exudates may directly contaminate equipment (knives, processing surfaces, conveyer belts, etc.) with organic material which contributes to colonization and growth of microorganisms (Francis et al., 1999).

Recently, a study was conducted to characterize the routes of microbial contamination in produce, and to identify areas of potential contamination from production through postharvest handling (Johnston et al., 2005). A total of 398 produce samples (leafy greens, herbs and cantaloupe) were collected through production and the packing shed, and assayed by enumerative tests for total aerobic bacteria, total coliforms, total *Enterococcus* and *Escherichia coli*. These samples were also analyzed for *Salmonella*, *Listeria monocytogenes* and *E. coli* O157:H7. For all leafy greens and herbs, the aerobic plate count ranged from 4.5 to 6.2 log CFU g^{-1}; less than 1 to 4.3 log CFU g^{-1} (coliforms and *Enterococcus*); and less than 1 to 1.5 log CFU g^{-1} (*E. coli*). In many cases, total counts remained constant throughout the packing shed. However, in the case of cilantro and parsley, total coliform levels increased during the packing process. For cantaloupe, microbial levels significantly increased from field through packing, with ranges of 6.4 to 7.0 log CFU g^{-1} (aerobic plate count); 2.1 to 4.3 log CFU g^{-1} (coliforms); 3.5 to 5.2 log CFU g^{-1} (*Enterococcus*); and less than 1 to 2.5 log CFU g^{-1} (*E. coli*). The prevalence of pathogens for all samples was

0, 0 and 0.7% (3 of 398) for *L. monocytogenes*, *E. coli* O157:H7 and *Salmonella*, respectively.

In another study, Golden Delicious apples taken from different points throughout the production chain and shelf life were analyzed for *Enterobacteriaceae*, thermotolerant coliforms, *E. coli*, *E. coli* O157:H7 and *Salmonella* spp. A total of 36 samples picked up in the orchard, 36 after storage and handling in the packing house, and 144 from different retail stores were analyzed using standardized techniques. *Enterobacteriaceae* counts varied greatly. *Pantoea* spp. was the main genera isolated. The percentage of samples with thermotolerant coliforms was 16.6%, 22.2% and 10.4% after harvest, after handling in the packing house and in the stores, respectively. Strains belonging to *Citrobacter*, *Enterobacter*, *Klebsiella* and *Escherichia* were isolated. Three samples coming from orchards, five from the packing house and two from retailers harbored *E. coli*. However, none of the *E. coli* strains isolated had the virulence genes that are pathogenic for humans. None of the samples was *Salmonella* positive (Abadias et al., 2006).

The phyllosphere, or plant leaf surface, is a habitat for many epiphytic microorganisms. The population size of these colonies can vary dramatically from one leaf to another, and undergoes constant change in both size and composition (Kinkel et al. 2000). Microorganisms may arrive on or depart from a leaf surface through the action of rain, wind or insects. Although plants were not considered to be a natural habitat for human enteric pathogens, recent studies have reported on the attachment, growth and survival of human pathogens on leafy vegetables (reviewed by Brandl, 2006). This is perhaps not surprising, given the findings that nutrients released from the plant are adequate to support large microbial populations. Molecules leaching from plant leaves include a variety of organic and inorganic compounds, such as sugars, organic acids, amino acids, methanol and various salts (Mercier and Lindow, 2000). Indeed, even on an intact plant, populations of bacteria may be observed which can reach 10^5 to 10^7 CFU g^{-1} per leaf under favorable environmental conditions, such as when high relative humidity or free water is present (Hirano and Upper, 1990).

The capacity of enteric pathogens to colonize leaf surfaces was investigated by many researchers and was recently reviewed by Brandl (2006) and Aruscavage et al. (2006). Several intrinsic and extrinsic factors determine the ability of enteric pathogens to attach and proliferate in the phyllosphere of plants. These include motility of the pathogen, availability of nutrients on the plant surface, water availability and interaction with epiphytic organisms. It has been shown that under constant wet conditions, population sizes of *E. coli* and *S. enterica* resemble that of *Pseudomonas syringae* in bean and corn phyllospheres, but the populations were much lower following incubation under dry conditions (O'Brien and Lindow, 1989).

The colonization of the cilantro phyllosphere by *S.* Thompson under various environmental conditions was investigated by Brandl and Mandrell (2002), and compared to that of *Pantoea agglomerans* and *Pseudomonas chlororaphis*, two common colonizers of plant surfaces. *Salmonella* population size was ten-fold lower than that of the two other species when incubated at 22°C. However, at a warmer temperature *Salmonella* achieved significantly higher population levels, suggesting that warm temperatures may increase the competitiveness of this organism in the phyllosphere (Brandl and Lindow, 2002). Interestingly, the tolerance of the *Salmonella* strain to dry conditions on plants at 60% relative humidity was at least equal to that of *P. agglomerans* and *P. chlororaphis*. Confocal laser scanning microscopy (CLSM) studies demonstrated that *Salmonella* cells were detected at high densities on the veins and in natural lesions on the surface of the leaves (Brandl and Lindow, 2002).

The interactions of human pathogens with postharvest leaves were also investigated. In a series of studies cut lettuce leaves were incubated with a suspension of *E. coli* O157:H7, and the fate of the pathogen was studied. *E. coli* was found attached to the surface, trichomes, stomata and cut edges of the leaves. Interestingly, treatment with 20 mg liter^{-1} chlorine solution for 5 minutes did not eradicate many of the cells, which were located in the stomata and on cut tissues, suggesting that these niches provided some degree of protection (Seo and Frank, 1999). The pathogen showed preferential attachment to damaged tissues as compared to intact tissues. Penetration of *E. coli* O157:H7 into lettuce tissue was observed by CLSM at an average of 101 micron below the surface of the cut tissues. Penetration was greatest when lettuce was held at 4°C, compared to 10°, 22° or 37°C (Takeuchi et al., 2001).

The fate of *Salmonella* applied to tomato plants was also investigated (Guo et al., 2001). A mixture of five *Salmonella* serotypes were used to inoculate tomato plants before and after fruit set, either by injecting stems with inoculum or brushing flowers with it. Ripe tomato fruits were subjected to microbiological analysis. Results suggest that *Salmonella* cells survive in or on tomato fruits from the time of inoculation at flowering through fruit ripening. Tomato stems and flowers were considered to be possible sites at which *Salmonella* may attach and remain viable during fruit development, thus serving as routes or reservoirs for contaminating ripened fruit (Guo et al., 2001). The acidic environment of the tomato fruit (around pH 4.0) did not affect bacterial survival. In fact, it had already been demonstrated earlier that *Salmonella* can grow or survive on cut tomatoes (Asplund and Nurmi, 1991; Wei et al., 1995; Zhuang et al., 1995; Weissinger et al., 2000).

D. Human pathogens in organically-grown crops

Animal waste in the form of raw manure or composted manure containing human pathogens is routinely applied to the land as a crop fertilizer and/or for soil amendment. The pathogens may survive for extended periods of time in manure and manure-amended soils and, consequently, can be transmitted to growing vegetables (Natvig et al., 2002; Islam et al., 2004a; Islam et al., 2004b).

It has been speculated that since organic farming relies primarily on animal manure for fertilization of the soil, organically-grown produce might have a greater risk of pathogenic contamination than conventionally-grown produce. In an extensive longitudinal study performed during two consecutive harvest seasons (2003–2004), the microbiological quality of fruits and vegetables collected at the preharvest stage on farms in Minnesota and Wisconsin was undertaken to determine the effect of type of farm, produce variety and harvest season on coliform counts, *E. coli* prevalence, and the presence of *Salmonella* and *E. coli* O157:H7 (Mukherjee et al., 2006).

The farms studied included 14 organic farms, 30 semi-organic farms (used organic practices but not certified) and 19 conventional farms, and a total of 2029 preharvest produce samples (473 organic, 911 semi-organic and 645 conventional) were analyzed. Produce varieties included mainly lettuces, leafy greens, cabbages, broccoli, peppers, tomatoes, zucchini, summer squash, cucumber and berries. Produce samples from the three farm types had average coliform counts of 1.5 to 2.4 log most probable number per g. None of the produce samples were contaminated with *Salmonella* or *E. coli* O157:H7. However, *E. coli* contamination was detected in 8% of the samples, with leafy greens, lettuces and cabbages having significantly higher *E. coli* prevalence compared to the other produce types, for the three farm types. It was concluded that the preharvest microbiological quality of produce from the three types of farms was very similar during these two seasons, and that produce type appears to be more likely to influence *E. coli* contamination than farm type (Mukherzee et al., 2006). In another study, the microflora composition of spring mix or mesclun, a mixture of multiple salad ingredients, grown either by organic or conventional means was determined. It was found that the mean populations of mesophilic and psychrotrophic bacteria, yeasts, molds, lactic acid bacteria and coliforms on conventionally-grown spring mix were not statistically different from respective mean populations on organically-grown spring mix. *Salmonella* and *L. monocytogenes* were not detected in any of the samples analyzed (Phillips and Harrison, 2005).

E. Potential entry of human pathogens into plants

It has been reported that human pathogens, namely *E. coli* O157:H7 and *Salmonella* spp., are capable of penetrating from contaminated soil through the roots into the aerial parts of some vegetables. To date, internalization of human pathogens has been reported in lettuce seedlings (Solomon et al., 2002; Watchel et al., 2002a; Jablasone et al., 2005; Bernstein et al., 2007a; Franz et al., 2007), tomato plants (Guo et al., 2002), alfalfa (Gandhi et al., 2001; Dong et al., 2003), bean sprouts (Warriner et al., 2003), radish (Itoh et al., 1998) and corn seedlings (Bernstein et al., 2007b). The presence of Gram-negative bacteria within vegetable tissues have already been reported more than 40 years ago (Samish et al., 1962), however, the mechanism underlying this phenomenon is still not clear. The recent reports regarding possible internalization of *E. coli* O157:H7 and *Salmonella* by plants have raised public concern regarding potential health hazards related to the apparent inability of washing and disinfection treatments to eradicate internally protected cells (Powell and Chapman, 2007). Nevertheless, most studies which have established internalization of enteric pathogens have focused on short-term interaction between high inocula of pathogens and young seedlings or sprouts. There is a great knowledge gap regarding long-term survival of pathogens within mature plants. To address this question, Jablasone et al. (2005) have artificially contaminated seeds of carrot, cress, lettuce, radish, spinach and tomato by *E. coli* O157:H7, *S.* Typhimurium and *L. monocytogenes*. All the pathogens became rapidly established shortly after germination, attaining cell densities of the order of 5.5–6.5 log CFU g^{-1} (Jablasone et al., 2005). However, *E. coli* O157:H7 became internalized in cress, lettuce, radish and spinach seedlings, but was not recovered within the tissues of mature plants. Internalization of *Salmonella* was also observed in lettuce and radish, but not cress or spinach seedlings. In contrast, *L. monocytogenes* did not internalize within seedlings, but did persist on the surface of plants throughout the cultivation period. The researchers concluded that the results suggest that the risk associated with internalized human pathogens in salad vegetables at harvest is low (Jablasone et al., 2005). In other studies, no evidence for *E. coli* O157:H7 internalization into the aerial parts was observed in mature (50-day-old) lettuce (Johannessen et al., 2005), nor in spinach leaves, even when roots were biologically or mechanically damaged (Hora et al., 2005). In agreement with these findings, *S. enterica* serovar Newport was shown to enter 33-day-old lettuce seedlings via the root system. However, internalized bacteria were observed in leaves of lettuce plants with intact and damaged roots at two days post-inoculation, but not five days later (Bernstein et al., 2007a). When a field of young cabbage was accidentally irrigated with tertiary-treated effluents, cabbage samples taken at harvest showed non-pathogenic *E. coli* isolates in roots, but not in the edible portion of the cabbage (Watchel et al., 2002b). Although, internalization and in-plant survival might be restricted to pathogens, such as *E. coli* O157:H7 and *S. enterica* serotypes, these findings support the hypothesis that enteric pathogen may not be adapted for long-term survival within internal plant tissues.

In contrast, when tomato plants were artificially inoculated before and after fruit set with five *S. enterica* serotypes, either by injecting stems with inoculum or brushing flowers with it, ripe tomato fruits were found to harbor the pathogens. These results suggest that *Salmonella* cells survived in or on tomato fruits from the time of inoculation at flowering through fruit ripening. Hence, tomato stems and flowers were considered to be possible sites at which *Salmonella* may attach and remain viable during fruit development, thus serving as routes or reservoirs for contaminating ripened fruit (Guo et al., 2001).

Taken together, the potential risk related to a pathogen's internalization in preharvest produce is currently questionable and requires more study. Nevertheless, the mere capacity of human pathogens to colonize the surface of leaves, fruits and roots at pre- and postharvest stages, together with their demonstrated survival capabilities at these sites, make contaminated crops an important vehicle for outbreaks of enteric infectious diseases. The current lack of an efficient, acceptable "pasteurization" technique that would completely eliminate human pathogens from produce without compromising quality, suggests that prevention of contamination coupled with rapid and sensitive pathogen detection systems are critical for ensuring the safety of fresh and minimally-processed fruits and vegetables.

F. Limitation of common disinfectants in removing human pathogens from fresh produce

The effectiveness of any sanitizer or disinfectant depends on its chemical and physical state, treatment conditions, such as water temperature, pH, and contact time, the resistance of pathogens, and the nature of the fruit or vegetable surface. The most widely used sanitizer for decontaminating fresh produce is probably hypochlorite. Although chlorine is more effective in solution at acidic pH levels, chlorine-based sanitizers are usually used at pH values between 6.0 and 7.5, in order to minimize the corrosion of processing equipment. A produce sanitation step typically involves a solution of 50 ppm to 200 ppm chlorine with contact times of 1–2 minutes (FDA, 1998). Numerous reports have questioned the ability of chlorine to completely eradicate enteric pathogens from fresh produce. The efficacy of chlorine in reducing microbial load on fresh produce varies from no effect to 3 $\log_{10}$ reduction (reviewed by Beuchat and Ryu, 1997; Burnett and Beuchat, 2001; Aruscavage et al., 2006). For example, the efficacy of chlorine in killing *Salmonella* Baildon inoculated onto shredded lettuce and diced tomatoes showed that populations of the pathogen in lettuce and tomatoes inoculated with 3.60 log and 3.86 log CFU g^{-1}, respectively, were reduced by less than 1 log when the produce was immersed for 40 seconds in a 120 or 200 ppm free chlorine solution. Produce inoculated with 0.60–0.86 log CFU g^{-1} was positive for the pathogen after treatment with 200 ppm chlorine (Weissinger et al., 2000).

In another set of experiments, the effect of calcium hypochlorite on inactivation of *Escherichia coli* inoculated on fresh produce was investigated. Dipping inoculated lettuce leaves into hypochlorite solutions containing 50 ppm or greater free chlorine for 30 seconds or longer reduced *E. coli* cells by approximately 1.9–2.8 log CFU g^{-1} from an initial population of approximately 6.8 log CFU g^{-1}. Dipping inoculated broccoli florets into hypochlorite solution reduced *E. coli* cells by approximately 1.7–2.5 log CFU g^{-1}, depending on the time and concentration of the free chlorine. Dipping lettuce or broccoli in water alone reduced cell numbers by 1.5–1.8 log CFU g^{-1}. Dipping broccoli florets for 2 minutes in a 100 mg liter^{-1} free chlorine solution at temperatures between 4 and 25°C reduced *E. coli* cells by approximately 2.4 log CFU g^{-1} (Behrsing et al., 2000). To determine the effectiveness of different sanitizing treatments for reducing bacterial pathogens on fresh cantaloupes and bell peppers, *Salmonella* Typhimurium and *E. coli* O157:H7 inoculated fruits were treated with water wash alone or were washed and then waxed or rinsed with 200 mg/liter hypochlorite, 10% $Ca(OH)_2$, or 2% lactic acid solutions applied by dipping for 15 seconds or spraying for 15 seconds. Preliminary experiments with chlorine treatments indicated that spraying with a 200, 600, or 1000 mg liter^{-1} hypochlorite solution reduced populations of both pathogens by 2.1 to 2.6 and 1.5 to 2.1 log CFU g^{-1}, respectively. In general, no differences were observed between chlorine solutions without pH adjustment (pH 9.2) and those with pH adjusted to 6.0 (Alvarado-Casillas et al., 2007). The limited disinfection efficacy of chlorine compounds was found to be, in some cases, as successful at removing bacteria as non-chlorinated water, but its presence was required to keep the wash water free of contaminants (reviewed by Zagory, 1999). The failure of the disinfectant to remove adhered flora is believed to be related to localization of the microbes in protected microsites on the surfaces of fruits and vegetables, as well as to their growth in aggregates or biofilms (Brandl, 2006). In addition, low efficacy of disinfectants may also be attributed to chemical inactivation of the chlorine by organic residues found on the fruits and vegetables. Increasing chlorine concentration is not viable because of esthetic and sensory problems. Recent studies, however, suggest that chlorine dioxide (ClO_2), in relatively low concentration, might be more effective in reducing bacterial pathogens without affecting the quality of produce (Sy et al., 2005; Lee et al., 2004). Due to the environmental and health risks that are posed by the use of chlorine (Wei et al., 1985), its use in some European countries has been banned for disinfection of fresh-cut products. A continued trend towards a "greener" environment might result in the extension of this ban to other countries in the future. Consequently, there is a need for alternative treatments to be used for the decontamination of fruits and vegetables, and especially fresh-cut produce. A number of such chemicals and technologies are detailed in Section V, below.

V. Postharvest treatments to maintain microbial quality

The industry of fresh-cut fruits and vegetables is constantly growing due to consumer demand. New techniques for maintaining quality and inhibiting undesirable microbial growth are required in all the steps of the production and distribution chain. In this review, we summarize some of the new processing and preservation techniques that are available in the fresh and fresh-cut industry. Modified and controlled atmosphere, washing and sanitizing, photochemical treatments (UV-C), irradiation, physical treatments and ozone treatments, alone or in different combinations, have proved useful in controlling microbial growth and maintaining quality during storage of fresh and fresh-cut produce. In addition, combinations of physical and chemical treatments have been reviewed lately (Artes and Allende, 2005; Allende et al., 2006; Shah and Nath, 2006).

A. Modified atmosphere packaging (MAP), controlled atmosphere (CA) and active packaging

To control physiological and pathological deterioration, environmental gas concentration and storage temperature are usually controlled (Fonseca et al., 2002). The two systems that are used to maintain freshness of fruits and vegetables by controlling the environmental gas concentration include controlled atmosphere (CA) storage and modified atmosphere packaging (MAP) (Mattheis and Fellman, 2000). CA storage involves preservation of fruits and vegetables in an airtight storehouse where the levels of gases are consistently monitored, controlled and maintained at optimal conditions. However, the facility and the running cost involved are substantial. On the other hand, MAP is a method to maintain the freshness of fruits and vegetables in an environment similar to CA storage, but it is created by using plastic film packaging, and depends upon the fresh produce and the film's physical properties (Yasunaga, 2006). The quality of grated carrot (variety Nantes) was evaluated throughout 10 days of storage in two different atmospheres: air and vacuum at 2°C. The use of a vacuum was promising with respect to the capacity to extend the shelf life of grated carrot by reducing microbial load and by minimizing physico-chemical changes. The shelf life of grated carrot under vacuum was extended to 8 days at 2°C (Rocha et al., 2007).

Modified atmosphere packaging (MAP) has been used to increase the shelf life of green asparagus (*Asparagus officinalis*, L.), meeting the market demand for fresh high-quality products available year-round and without the use of additives. Green asparagus spears were stored under three different conditions until they were not fit for consumption: refrigeration at 2°C, MAP at 2°C and MAP at 10°C after 5 days at 2°C. MAP, combined with refrigeration at 2°C, showed the best results among the treatments in terms of retaining sensory, nutritional and microbial quality, increasing the safety and extending the shelf life of green asparagus (Villanueva et al., 2005). Five different packaging treatments, including two passive modified atmosphere packaging (MAP), two active MAP and a moderate vacuum packaging (MVP), were used for minimally-processed bunched onions. Various sealed-packaging treatments did not significantly influence microbiological populations, including mesophiles, psychrotrophs and lactic acid bacteria. However, MVP with a gas-permeable plastic film retained better quality bunched onions, with reduced microbial decay and visual sensory aspects, compared with the other packages (Hong and Kim, 2004).

A study was conducted to evaluate the effect of an edible coating combined with modified atmosphere (MA, 60% O_2, 30% CO_2, and 10% N_2) packaging and gamma irradiation on the microbiological stability and physico-chemical quality of minimally-processed carrots (Lafortune et al., 2005). Microbiological analysis revealed that for uncoated carrots irradiation at 0.5 and 1 kGy under air and MA reduced the aerobic plate counts (APCs) by 3.5 and 4 log CFU g^{-1}, and by 4 and 4.5 log CFU g^{-1}, respectively. For coated carrots, irradiation at 0.5 and 1 kGy under air and MA reduced the APCs by 4 and 4.5 log CFU g^{-1}, and by 3 and 4.25 log CFU g^{-1}, respectively.

Preliminary study showed that among 40 to 100 kPa O_2 atmospheres, 60 kPa O_2 reduced the respiration of fresh-cut Carabao mango cubes the most when held at 5°C or 13°C for 42 hours. Therefore, the effects of 60 kPa O_2 on the physiology and microbial quality of fresh-cut Caraba and Nam Dokmai mango cubes were determined and compared with those held in air (Poubol and Izumi, 2005b). The growth of mesophilic aerobic bacteria was stimulated at 60 kPa O_2 on Carabao cubes and yeasts on Nam Dokmai cubes at 13°C. Within Nam Dokmai mango cubes, the predominant genera in mesophilic aerobic bacteria were *Enterobacter*, *Klebsiella* and *Pantoea* and the yeasts were *Candida*, *Cryptococcus* and *Rhodotorula*. These results indicate that 60 kPa O_2 is not desirable for mango cubes when held at 13°C. However, 10% CO_2 only reduced the bacterial count on Carabao and Nam Dokmai cubes stored at 13°C. Bacterial flora in Nam Dokmai mango cubes consisted mostly of Gram-negative rods assigned primarily to phytopathogenic bacteria such as *Pantoea agglomerans* and *Burkholderia cepacia*. The genera of bacteria isolated from cubes stored in 10% CO_2 were similar to those from cubes on the initial day (Poubol and Izumi, 2005a).

The effects of high O_2 and high CO_2 throughout storage on the microbial and sensory quality of fresh-cut bell peppers from two commercial California cultivars grown under different climatic conditions were studied (Conesa et al., 2007). The results showed that 80 or 50 kPa O_2 combined with 15 kPa CO_2 inhibited growth of the spoilage microorganisms and *Enterobacteriaceae* in minimally processed bell peppers after 9–10 days at 5°C.

The use of antimicrobial agents, compounds that inhibit the growth of molds and bacteria without presenting a risk to consumer health, is one of the possible methods of microbial control. However, their direct application on the surface of the product by spraying or dipping may not be very effective. An alternative is antimicrobial active packaging technology, which involves incorporating the active agent into the package for subsequent release, in order to maintain a minimum inhibitory concentration on the surface of the product for a given time (Almenar et al., 2006).

Active packaging was developed by adding eugenol or thymol to table grapes stored for 56 days under modified atmosphere (MAP). Control fruit showed losses of quality in terms of sensory, nutritional and functional properties. These losses were significantly reduced in packages with added eugenol or thymol. In addition, lower microbial spoilage counts were achieved with the active packaging (Valero et al., 2006). Sweet cherries show serious problems for commercialization, mainly due to the incidence of decay and a fast loss of sensory quality, both for fruit and stem. A package has been developed based on the addition of eugenol, thymol, menthol or eucalyptol oils to trays sealed with polypropylene bags to generate a modified atmosphere (MAP) of 2–3% of CO_2 and 11–12% of O_2 at 1°C for 16 days. The microbial analysis showed that all essential oils reduced molds, yeasts and total aerobic mesophilic colonies by 4 and 2 log CFU compared with the controls, respectively (Serrano et al., 2005).

B. Washing, sanitizing treatments

Guidelines for packing fresh or minimally-processed fruits and vegetables generally specify a washing or sanitizing step to remove dirt, pesticide residues and microorganisms responsible for quality loss and decay (Sapers, 2006). However, washing procedures with water or chemical sanitizers typically result in only a 1 to 2 $\log_{10}$ decrease in microbial counts (Sapers, 2001). In addition to washing with plain water, various factors are used to enhance the washing effect of water, and to reduce the microbial load of whole or freshly cut produce more efficiently, e.g. washing with chlorine, hot water dips or rinsing and brushing, ozone, acidic electrolyzed water or H_2O_2 (Baur et al., 2004; Koseki et al., 2002; Palou et al., 2007).

For both organic and conventional operations, liquid sodium hypochlorite is the most common form used. For optimum antimicrobial activity with a minimal concentration of applied hypochlorite, the pH of the water must be adjusted to between 6.5 and 7.5. At this pH range, most of the chlorine is in the form of hypochlorous acid (HOCl), which delivers the highest rate of microbial kill and minimizes the release of irritating and potentially hazardous chlorine gas (Cl_2). Chlorine gas will exceed safe levels if the water is too acidic. Products used for pH adjustment must also be from a natural source, such as citric acid, sodium bicarbonate or vinegar. Calcium hypochlorite, properly dissolved, may reduce sodium injury to sensitive crops (e.g. some apples varieties), and limited evidence points toward extended shelf life for tomatoes and bell peppers due to calcium uptake. Amounts of sodium hypochlorite to add to clear, clean water for disinfection are given in Sapers, 2006. Food-grade hydrogen peroxide (0.5 to 1%) and peroxyacetic acid are additional options. In general, peroxyacetic acid (PAA) has good efficacy in water dump tanks and water flume sanitation applications. PAA has very good performance, as compared to chlorine and ozone, in removing and controlling microbial biofilms (tightly adhering slime) in dump tanks and flumes. At this time, one disadvantage is a higher cost per unit, and availability is restricted to large bulk units.

In a common scenario of water reuse in the fresh-cut produce industry, chlorine, a widely used sanitizer in the fresh produce industry, is readily inactivated upon contact with organic matter in the process water. Sanitizers that can maintain the efficacy of pathogen removal under fresh-cut processing conditions are urgently needed. A study was aimed to provide a side-by-side comparison of the efficacy of chlorine and three new sanitizers on pathogen reduction of shredded carrots under simulated commercial processing conditions (Gonzalez et al., 2004). Fresh carrot shreds were artificially inoculated with *E. coli* O157:H7 and washed in various sanitizer solutions, including 200 ppm chlorine, 1% Pro-San®, 80 ppm Tsunami® – 100, and 1000 ppm SANOVA®, under fresh tap water or simulated processing water conditions. SANOVA® (acidified sodium chlorite) provided a strong pathogen killing effect in both tap water and process water conditions, with more than 99% reduction when compared to a tap water wash. The role of sanitizers in maintaining the microbial safety of wash water was also evaluated, with no recovery of pathogenic *E. coli* O157:H7 or total bacteria from the sanitizer solutions used, eliminating the possibility of cross-contamination of other produce and potential quality deterioration. Leafy salad species are increasingly consumed in the human diet and there is increased concern about the levels of microbial organisms in these raw foods, and especially bacteria such as *Salmonella* that cause food poisoning. Various chemical sanitizers therefore, are used to control microorganisms and fungi, but there is very little information on the effects of these chemicals on food composition. Wild rocket (Diplotaxis tenuifolia L. DC) leaves were washed using tap water, chlorine (100 mg L^{-1}), ozonated water (10 mg L^{-1}), lactic acid (Purac$^{(R)}$ 20 ml L^{-1}), acidified sodium chlorite (Sanova$^{(R)}$ 250 mg L^{-1}) and peroxyacetic acid (Tsunami$^{(R)}$ 300 mg L^{-1}) (Martinez-Sanchez et al., 2006). The effects of sanitizers on the quality of rocket leaves were studied under air and low O_2 (1–3 kPa) plus high CO_2 (11–13 kPa) for 15 days at 4°C. All the sanitizers effectively reduced microbial growth on the day of processing, but only Purac, Tsunami and Sanova inhibited microbial growth throughout the shelf life.

New delivery, control and recycling technologies have been developed and incorporated into a new iodine delivery system called Isan™. Control of pH, so essential with chlorine, is not required for iodine dips with a pH below 8.5. Continual removal of sanitizer breakdown products during operation dramatically reduces any accumulation of undesirable breakdown products, and improves dip effectiveness and accuracy of control. When used as a general produce sanitizer at levels up to 30 ppm, iodine applied in the Isan™ unit is very effective, with even levels below 15 ppm giving a log reduction in surface microflora of 1.5 (i.e. apples, nectarines, peaches, tomatoes) (Klein and Morris, 2005).

Four different postharvest treatments for removal of *Salmonella* from bell pepper and cucumber were examined, including washes with chlorinated water (HOCl, 200 ppm), acidified sodium chlorite (ASC, 1200 ppm), peroxyacetic acid (PAA, 75 ppm) and treatment with gaseous chlorine dioxide (ClO_2, total 100 mg). For tests involving smooth surface inoculation, ASC and PAA treatments decreased contamination to undetectable levels on bell pepper and cucumber, while the chlorine treatment of bell pepper reduced contamination by approximately 2 logs. For stem scar contamination on bell pepper, ASC and PAA treatments both showed >2 log unit reductions, and chlorine treatment showed a <1 log unit reduction. For puncture wounds on bell pepper, HOCl, ASC and PAA treatments reduced bacterial levels approximately 2, 3, and 1 log units, respectively, indicating that HOCl and ASC were more effective than PAA. These aqueous treatments of cucumber with puncture wounds reduced bacterial levels approximately 1, 2, and 2 log units, respectively. ClO_2 treatment decreased counts to undetectable levels on all inoculation sites on cucumber and strawberry smooth surfaces, but failed to completely eliminate *Salmonella* from bell pepper and from the stem scar and the puncture wounds of strawberry. ASC treatment of bell pepper and ClO_2 gas treatments of cucumber showed the best efficiency for inactivation of *Salmonella.* ClO_2 treatments effectively reduced *Salmonella* cells inoculated on the smooth surface and stem scar of strawberries compared with unsanitized control (Hyun-Gyun et al., 2006).

C. Warm and hot water treatments

Washing with warm or hot water has also been used as a means to reduce the microbial load more efficiently than is observed with cold water (Lin et al., 2002). Physical treatments have been very effective in controlling pathogenic microorganisms. Various heat treatments, alone or combined with other means, have been extensively studied to control many postharvest fungi and bacteria (Fallik, 2004, 2007; Fallik and Lurie, 2006). Strawberries cv. Selva were heat-treated in an air oven (45°C for 3 hours) and then stored at 0°C for 0, 7 or 14 days. The treatment decreased the initial bacterial population, but did not reduce the amount of fungi initially present. This difference was still significant after 48 hours at 20°C. Heat-treated fruit that were stored for 7 or 14 days at 0°C, and then transferred to 20°C for 48 hours showed lower CFU value than controls in the case of fungi (Vicente et al., 2002). Keeping strawberries (*Fragaria* x *ananassa* cv Seascape) at 45°C for 3 hours reduced decay caused by *B. cinerea* and *R. stolonifer* (Pan et al., 2004).

A range of vapor heat temperatures (50–55°C) and treatment time intervals (12–32 minutes) were initially evaluated for their effects on *B. cinerea* in artificially inoculated table grapes. The most promising treatments were 52.5°C for 21 or 24 minutes and 55°C for 18 or 21 minutes, which reduced infection levels by 72–95% on the ninth day compared with controls (Lydakis and Aked, 2003). Curing is considered a moderate heat treatment. The effectiveness of curing oranges and lemons at 33°C for 65 hours, followed by storage under ambient and cold-storage conditions, was investigated. This treatment effectively reduced the incidence of *P. digitatum* (Pers) Sacc. and *P. italicum* Wehmer decay on inoculated and naturally infected oranges and lemons stored at 20°C for 7 days (Plaza et al., 2004). Golden Delicious apples were wound-inoculated with conidial suspensions of either *C. acutatum* or *P. expansum*, and then treated with heat (38°C) for 4 days, antagonists, or a combination of both. Heat or heat in combination with either antagonist eliminated decay caused by *P. expansum*. Either heat or the antagonists alone reduced decay caused by *C. acutatum*, but a combination of the two was required to completely eliminate the decay caused by this pathogen (Conway et al., 2004). Pre-storage 1-MCP, heat (38°C for 4 days), 1-MCP plus heat treatments, and CA storage decreased decay severity caused by wound-inoculated *P. expansum* Link, *B. cinerea* Pers.:Fr., and *C. acutatum* (Saftner et al., 2003). Dry hot air treatment (48.5°C or 50°C for 4 hours), especially in combination with the fungicide thiabendazole, decreased the growth of inoculated *C. gloeosporioides* (Perez-Carrillo and Yahia, 2004). Postharvest hot water dips of organically grown strawberries at 55 and 60°C for 30 seconds significantly reduced the incidence of decay to 3.4 and 2.7%, respectively, while that in the control was 28.5%. However, in another experiment, the efficacy of hot water treatment at 60°C was significantly better than that of hot water treatment at 55°C (Karabulut et al., 2004a). Applying a biocontrol agent following hot water treatment (45°C for 2 minutes) was as effective as the fungicide treatment, which gave 100% control of both green and blue molds on artificially inoculated Valencia and Shamouti orange cultivars (Obagwu and Korsten, 2003). Strawberries treated with the combination of hot water dips at 63°C for 12 seconds, biocontrol and CA, had significantly less decay caused by gray mold than those from all other treatments (Wszelaki and Mitcham, 2003). The use of a combination of hot water dips (42.5°C for 30 minutes) and MAP reduced decay on tomatoes during 2 weeks at 10°C and then for 3 days at 20°C (Suparlan-Itoh, 2003).

The most effective treatment to control decay development on sweet cherry inoculated by *P. expansum* and *B. cinerea* was immersion in 10% ethanol at 60°C for 3 minutes (Karabulut et al., 2004b). Heat treatment (50°C for 60 minutes) reduced the total microbial count during the first storage day on fresh-cut melon, and prevented growth of lactic acid bacteria that occurred in untreated fruit after 8 days in storage (Lamikanra et al., 2005). The optimal conditions of washing iceberg lettuce with acidified warm water to improve the hygienic product quality was achieved at 50°C, washing for 5 minutes at pH 4.9. The total bacteria and Enterobacteriaceae were reduced by 2.9 and 3.7 log CFU g^{-1}, respectively, after 13 days at 4°C (Wei et al., 2005). The combination of 200 ppm of sodium hypochlorite and mild heat treatment at 50°C for 1 minute reduced the native bacteria and the food-borne pathogens *Staphylococcus aureus*, *Escherichia coli* O157:H7 and *Salmonella typhimurium* populations by 94 to 98% (1.2 to 1.7 log reduction), without increasing browning in fresh-cut lettuce (Kondo et al., 2006). Hot water rinsing and brushing technology, which was reviewed recently by Fallik (2004), is the shortest physical treatment that can reduce decay development in fresh produce after harvest. This treatment is no longer than 30 seconds at temperatures between 48°C and 63°C, depending on the cultivar.

Most cases of microbial food contamination may be caused by cross-contamination at the food processing stage. Application of acidic electrolyzed water (AcEW) for pre-cut vegetables in combination with mild heat and sanitizers was examined for bacterial control at their processing stage (Koseki et al., 2004). Mildly heated AcEW and chlorinated water (200 ppm free available chlorine) with a treatment period of 1 or 5 minutes produced equal reductions of pathogenic bacteria of 3 log and 4 log CFU g^{-1}, respectively. The procedure of treating with mildly heated AcEW for 5 minutes, and subsequent washing with chilled (4°C) AcEW for a period of 1 or 5 minutes resulted in 3–4 log (10) CFU/g reductions of both the pathogenic bacterial counts on lettuce. Extending the mild heat pretreatment time increased the bactericidal effect more than that observed from the subsequent washing time with chilled AcEW.

Using a different technology, the effects of high intensity pulsed electric fields (HIPEF) processing on the microbial shelf life of orange juice was investigated during storage at 4°C and 22°C, and compared to traditional heat pasteurization (90°C for 1 minute) and an unprocessed juice (Elez-Martinez et al., 2006). HIPEF treatment ensured the microbiological stability of orange juice stored for 56 days under refrigeration without affecting juice quality, but spoilage by naturally occurring microorganisms was detected within 30 days of storage at 22°C.

D. Ozone

Ozone, the triatomic form of oxygen (O_3), is a highly reactive compound with potent antimicrobial activity and numerous potential applications in the agriculture and food industries. Ozone, in gas or aqueous applications, is an approved antimicrobial agent that can be used in direct contact with foods, including raw and minimally-processed fruits and vegetables (Palou et al., 2007). The first step in the use of ozone is to know the ozone concentration to apply. In general, fungi are more resistant to ozone than bacteria (Aguayo et al., 2006). However, ozone doses that kill spores of postharvest fungal pathogens vary widely, and depend on the fungal species, spore morphology, substrate, moisture status of the spores, length of exposure and ozone dosage (Palou et al., 2007). Tomatoes, strawberries, table grapes and plums were inoculated with *Botrytis cinerea*, transferred to chilled storage (13°C) and exposed to “clean air” or low-level ozone-enrichment (0.1 μl L^{-1}). Ozone-enrichment resulted in a substantial decline in spore production, as well as reduced visible lesion development in all treated fruit. However, data presented illustrate that optimal ozone treatment regimes are likely to be commodity-specific, and require detailed investigation before such practices can be contemplated commercially (Tzortzakis et al., 2007). Similar results were reported for artificially inoculated orange and lemon fruits exposed for 4 weeks to continuous concentrations of ozone (0.3 to 1.0 μl L^{-1}) at 5°C and 90% RH (Palou et al., 2001). The effectiveness of microbial sanitation with ozonated water (1.0 to 5.0 μg ml^{-1}) sprayed on fruits and vegetables in processing lines is typically modest, only slightly better than sterile water washing alone, and usually less effective than that obtained with chlorinated water (200 μg/ml) (Smilanick et al., 2002a,b).

Achen and Yousef (2001) reported that the population of *E. coli* O157:H7 on apple surfaces was reduced by 2.6 to 3.7 $\log_{10}$ units by 3 minutes of treatment in bubbling ozonated water. Six different washing treatments consisting of water, sodium sulfite, sodium hypochlorite, Tsunami, ozone and the combination of ozone–Tsunami were evaluated on the microbial quality of fresh-cut potatoes stored under passive MAP and vacuum packaging. Growth of aerobic mesophilic bacteria, psychrotrophic bacteria, coliforms, lactic acid bacteria (LAB), anaerobic bacteria, molds and yeasts were studied. The use of ozonated water alone was not effective in reducing total microbial populations. Ozone–Tsunami resulted in the most effective treatment to control microbial growth, achieving 3.3, 3.0 and 1.2 log reductions for LAB, coliforms and anaerobic bacteria, respectively. Therefore, although microbial growth was not slowed down by ozone alone, the combination of Ozone–Tsunami results in an efficient and promising treatment for controlling microbial growth and maintaining the sensory quality of potato strips under vacuum (Beltran et al., 2005b). The combined treatment of hot water (50°C, 2.5 minutes) followed by ozonated water (5 ppm, 2.5 minutes) had the same bactericidal effect as treatment with ozonated water (5 ppm, 5 minutes) or sodium hypochlorite (NaOCl, 200 ppm, 5 minutes), giving a reduction in bacteria numbers of 1.2 to 1.4 log CFU g^{-1} (Koseki and Isobe, 2006). However, bacterial populations on the lettuce treated with sanitizers were initially reduced, but then showed rapid growth compared with that of the water wash treatment, which did not reduce bacterial counts initially.

E. Photochemical treatment

Recently, many studies have demonstrated the effectiveness of surface decontamination techniques to reduce the microbial risk involved in the consumption of fresh fruits and vegetables (Erkan et al., 2001; Yaun et al., 2004). Non-ionizing, artificial ultraviolet-C (UV-C) radiation is extensively used in a broad range of antimicrobial applications, including disinfection of water, air, food preparation surfaces, food containers (Wang et al., 2005) and surface disinfection of vegetable products (Marquenie et al., 2002). Most of these studies showed the effectiveness of microbial reduction in fresh-cut fruits and vegetables by using chemical disinfection, low UV-C light doses (from 0.2 to 20 kJ m^{-2}) and storage under conventional MAP, without any detrimental effect on the organoleptic quality of the product (Allende and Artes, 2003; Lopez-Rubira et al., 2005; Allende et al., 2006). Postharvest UV-C treatments consist of exposing the commodities for a certain period of time under a bank of UV lamps with maximum emission at 254 nm.

In commercial trials, exposing packaged watermelon cubes to UV-C light at 4.1 kJ m^{-2} produced >1 log reduction in microbial population by the end of the product's shelf life, without affecting overall visual quality. In further experimentation, lower UV-C dose (1.4 kJ m^{-2}) reduced microbial populations to a lower degree, and only when complete surface exposure was ensured (Fonseca and Rushing, 2006).

Fresh-cut iceberg lettuce (*Lactuca sativa* L.) was washed at 4°C using three different ozonated water dips activated by ultraviolet C (UV-C) light, and the dips were compared with water and chlorine rinses. Treated lettuce was packaged in air or active modified atmosphere packaging (MAP) (4 kPa of O_2 + 12 kPa of CO_2) and stored for 13 days at 4°C. Initially, ozonated water and chlorine reduced the total mesophilic population by 1.6 and 2.1 log respectively, when compared with water. Active MAP was effective in controlling total microbial growth, achieving 2.0 log reduction in relation to samples stored in air at the end of storage. On the other hand, active MAP caused a 2.0–3.5 reduction in coliforms on sanitized samples, compared with water-washed samples. The most efficient treatments were ozone 20 and ozone 10 activated by UV-C, which were as effective as chlorine (Beltran et al., 2005a). Many researchers have already tested the synergistic effects of combining UV-C light with chemical disinfection and/or MAP on vegetable produce. Marquenie et al. (2002) tested the efficacy of heat treatments and UV-C light for controlling postharvest decay of strawberries and sweet cherries. In most of the cases, fungal inactivation was achieved for the treatments with the highest UV-C dose (10 kJ m^{-2}) combined with a long thermal treatment (15 minutes at 45°C).

F. Irradiation

Irradiation is a well-known technology for elimination of microbial contamination. Food irradiation has been approved by 50 countries around the world. Low-dose gamma irradiation is very effective in reducing bacterial, parasitic and protozoan pathogens in raw foods. Irradiation was approved by the FDA for use on fruits and vegetables at a maximum level of 1.0 kGy (IFT, 1983).

A low-dose irradiation (0.51 kGy) with subsequent refrigerated storage (4°C) can effectively reduce or eliminate *Listeria monocyrogenes* on chopped romaine lettuce, improving the safety of ready-to-eat salads (Mintier and Foley, 2006). A reduction of 4.7 and 3.8 logs for total plate and Enterobacteriaceae counts was observed for celery and cabbage, respectively, which were irradiated at 1 kGy. In both irradiated and non-irradiated vegetables, neither *E. coli* nor *Salmonella* spp. were detected. An increase of 1.6–1.7 logs in both microbiological parameters in non-irradiated samples was observed during storage. In irradiated products, only celery showed an increase of 1.2 log in total plate count (Lopez et al., 2005).

The combination of 7% calcium ascorbate and irradiation (0.5 or 1.0 kGy) enhanced microbial food safety while maintaining the quality of fresh-cut apple slices after 3 weeks at 10°C (Fan et al., 2005). A dose of 2.0 kGy completely controlled the fungal and bacterial counts on carrot slices stored at 5°C for 2 weeks. The irradiated samples (2.0 kGy) were also acceptable sensorially (Chaudry et al., 2004). The effect of a combination of a 1% calcium chloride dip with low-dose irradiation (1.5 kGy) on microbial populations was evaluated on fresh diced tomatoes during a two-week storage period (Prakash et al., 2007). The calcium dip was found to limit irradiation-induced loss of firmness. Irradiation, by itself and in combination with calcium treatment, resulted in a >3 log CFU g^{-1} decrease in total aerobic counts and psychrotrophs. Additionally, irradiation at 1.5 kGy eliminated >3 log CFU g^{-1} of *Salmonella* organisms from tomatoes contaminated with *Salmonella*. Counts continued to decrease to an undetectable level over the 11 day storage period. Fan et al. (2006) reported that the combination of hot water surface pasteurization (76°C for 3 minutes) of whole cantaloupe and low-dose irradiation (0.5 kGy) of packaged fresh-cut melon reduced the population of native microflora while maintaining the quality of this product.

VI. Future perspectives

Increasing consumption of fresh vegetables and fruits as part of a healthy diet, and a transition toward convenience foods, such as ready-to-eat fresh-cut, requires continuing efforts to conserve the nutritious value and extend shelf life without compromising on food safety. The few recent outbreaks of produce-associated illness reinforces that the agro-food industry generally produces high-quality and safe foods all year round. The food chain from farm-to-fork offers multiple opportunities for produce to become contaminated, and yet the vast majority of produce sold in markets in developed countries is considered safe. Although no one can guarantee that food safety will not be breached at some point during the production chain, producers and food industry should make every effort to minimize such events.

Consequently, future endeavors will have to focus on three main areas:

1. prevention of crop contamination;
2. development of more efficacious treatments to inactivate spoilage and food-borne pathogens; and
3. development of rapid and sensitive techniques for detecting the presence of human pathogens on minimally-processed fruits and vegetables.

In order to prevent contamination, future efforts should concentrate on a better understanding of the source of pathogens, their behavior in the field environment (soil, water), their potential reservoirs, distribution and survival on crops. Studies of the fate of human pathogens introduced during harvest and postharvest processing, and the effect of current and future treatments on their persistence are of special interest. Application of a microbial ecology approach, in conjugation with genomics and proteomics to analyze global gene expression, might reveal the molecular mechanisms that enable human pathogens to survive in the non-host environment, and may ultimately lead to the development of new intervention procedures to prevent contamination. Producers and the food industry must follow formal guidelines for the microbial safety of fresh produce that define good agricultural practices (GAP) and good manufacturing practices (GMP), such as those published by the US Food and Drug Administration (FDA, 1998, 2007). Hazard analysis of critical control points (HACCP) and prerequisite program (PRP) should be implemented by producers and food handlers (Walker et al., 2003).

Development of more efficacious decontamination treatments should focus on current and newly-introduced chemicals and techniques that will preserve nutritional values, as well as organoleptic and esthetic attributes. There are several new or revisited techniques for microbial inactivation that are being explored. Among them are biological treatments, such as the use of microbial antagonists against food-borne pathogens (Schuenzel and Harrison, 2002), bacteriophages (Greer, 2005;

Leverentz et al., 2003, 2006), as well as antimicrobial peptides (bacteriocins) produced by lactic acid bacteria (Gálvez et al., 2007). New physical treatments might include irradiation, ultra-sonication and pulsed light. As with other foods, it seems that no single method or treatment would be sufficient to inhibit microbial spoilage or eradicate microbial pathogens. The combined use of several disinfectant agents has been widely reported in the last few years (Beltrán et al., 2005b; Ukuku et al., 2005; Uyttendaele et al., 2004). Combinations of lactic acid, chlorinated water, thyme essential oil solution, sodium lactate, citric acid, hydrogen peroxide, ozone and peroxyacetic acid have already been tested. A recent tendency has been reported by Bari et al. (2005), who combined the efficacy of chemical disinfectant with the antimicrobial effect of bacteriocins.

In general, a combination of chemical disinfectants was found to have a synergistic effect and results in a better sensory and microbial quality of the product. In the past, a combination of preservation technologies was used empirically without much knowledge of the governing principles. However, the last two decades have witnessed intelligent application of hurdle technology, as the principles of major preservative factors for foods (e.g. temperature, pH, water activity, competitive flora) and their interactions became better understood (Leistner, 2000). Similarly, it is expected that knowledge regarding factors that govern survival of spoilage and human pathogens in the diverse and complex ecosystems along the food chain will facilitate the development and application of a science-based hurdle technology in the fresh-cut industry. It was argued previously that results of studies to determine the efficacy of sanitizers in killing human pathogens are often difficult to asses, because of the lack of sufficient reporting of methods or variations in procedures for preparing and applying inocula to produce, conditions for treatment and storage, and procedures for enumerating pathogens (Beuchat et al., 2001). Indeed, the development of new or improved treatments should follow the establishment of a widely-accepted standardization of the methodology used to test a treatment's efficacy.

Finally, the last important issue to be investigated for enhancing food safety is the development and application of rapid pathogen monitoring systems. Detection of pathogens in the end product, before it is shipped to market, is critical for preventing recall and the associated economic losses. Since the shelf life of fresh produce, and especially that of minimally-processed products, is very short (usually around 10 days) microbial analysis should be available in hours rather than days. Similarly, online monitoring of microbial contamination might enable rapid intervention procedures if contamination is found. Several recent methodologies and kit-based techniques, such as PCR, reverse-transcriptase real-time PCR, quantitative PCR, as well as a number of immunologic-based techniques might offer a suitable solution.

Bibliography

Abadias, M., Canamas, T.P., Asensio, A., Anguera, M., Vinas, I. (2006). Microbial quality of commercial "Golden Delicious" apples throughout production and shelf-life in Lleida (Catalonia, Spain). International Journal of Food Microbiology, 108, 404–409.

Abrunhosa, L., Paterson, R.R.M., Kozakiewicz, Z., Lima, N., Venâncio, A. (2001). Mycoflora production from fungi isolated from grapes. Letters of Applied Microbiology, 32, 240–242.

Achen, M., Yousef, A.E. (2001). Efficacy of ozone against *Escherichia coli* O157:H7 on apples. Journal of Food Science, 66, 1380–1384.

Ackers, M.L., Mahon, B.E., Leahy, E., Goode, B., Damrow, T., Hayes, P.S., Bibb, W.F., Rice, D.H., Barrett, T.J., Hutwagner, L., Griffin, P.M., Slutsker, L. (1998). An outbreak of *Escherichia coli* O157:H7 infections associated with leaf lettuce consumption. Journal of Infectious Diseases, 177, 1588–1593.

Aguayo, E., Escalona, V.H., Artes, F. (2006). Effect of cyclic exposure to ozone gas on physicochemical, sensorial and microbial quality of whole and sliced tomatoes. Postharvest Biology and Technology, 39, 169–177.

Allende, A., Artés, F. (2003). UV-C radiation as a novel technique for keeping quality of fresh processed Lollo Rosso lettuce. Food Research International, 36, 739–746.

Allende, A., Tomas-Barberan, F.A., Gil, M.I. (2006). Minimal processing for healthy traditional foods. Trends in Food Science and Technology, 17, 513–519.

Almenar, E., Hernandez-Munoz, P., Lagaron, J.M., Catala, R., Gavara, R. (2006). Advances in packaging technologies for fresh fruits and vegetables. In: Advances in Postharvest Technologies for Horticultural Crops, B. Noureddine, S. Norio (eds). Research Signpost, India, pp. 87–113.

Alvarado-Casillas, S., Ibarra-Sánchez, S., Rodríguez-García, O., Martínez-Gonzáles, N., Castillo, A. (2007). Comparison of rinsing and sanitizing procedures for reducing bacterial pathogens on fresh cantaloupes and bell peppers. Journal of Food Protection, 70, 655–660.

Artés, F., Allende, A. (2005). Processing lines and alternative preservation techniques to prolong the shelf-life of minimally fresh processed leafy vegetables. European Journal of Horticultural Science, 70, 231–245.

Aruscavage, D., Lee, K., Miller, S., LeJeune, J.T. (2006). Interactions affecting the proliferation and control of human pathogens on edible plants. Journal of Food Science, 71, R89–R99.

Asplund, K., Nurmi, E. (1991). The growth of salmonellae in tomatoes. International Journal of Food Microbiology, 13, 177–182.

Baba, T., Schneewind, O. (1998). Instruments of microbial warfare: bacteriocin synthesis, toxicity and immunity. Trends in Microbiology, 6, 66–71.

Bari, M.L., Ukuku, D.O., Kawasaki, T., Inatsu, Y., Isshiki, K., Kawamoto, S. (2005). Combined efficacy of nisin and pediocin with sodium lactate, citric acid, phytic acid, and potassium sorbate and EDTA in reducing the *Listeria monocytogenes* population of inoculated fresh-cut produce. Journal of Food Protection, 68, 1381–1387.

Baur, S., Klaiber, R.G., Hammes, W.P., Carle, R. (2004). Sensory and microbiological quality of shredded, packaged iceberg lettuce as affected by pre-washing procedures with chlorinated and ozonated water. Innovative Food Sciences and Emerging Technology, 5, 45–55.

Beattie, G.A., Lindow, S.E. (1994). Epiphytic fitness of phytopathogenic bacteria: physiological adaptations for growth and survival. Current Topics in Microbiology and Immunology, 192, 1–27.

Behrsing, J., Winkler, S., Franz, P., Premier, R. (2000). Efficacy of chlorine for inactivation of *Escherichia coli* on vegetables. Postharvest Biology and Technology, 19, 187–192.

Bellí, N., Pardo, E., Marín, S., Farré, G., Ramos, A.J., Sanchis, V. (2003). Occurrence of ochratoxin A and toxigenic potential of fungal isolates from Spanish grapes. Journal of the Science of Food and Agriculture, 84, 541–546.

Beltran, D., Selma, M.V., Marin, A., Gil, M.I. (2005a). Ozonated water extends the shelf life of fresh-cut lettuce. Journal of Agricultural and Food Chemistry, 53, 5654–5663.

Beltran, D., Selma, M.V., Tudela, J.A., Gil, M.I. (2005b). Effect of different sanitizers on microbial and sensory quality of fresh-cut potato strips stored under modified atmosphere or vacuum packaging. Postharvest Biology and Technology, 37, 37–46.

Bennett, J.W., Klich, M.A. (2003). Mycotoxins. Clinical Microbiology Reviews, 16, 497–516.

Bernstein, N., Sela, S., Neder-Lavon, S. (2007a). Assessment of contamination potential of lettuce by *Salmonella enterica* serovar Newport added to the plant growing medium. Journal of Food Protection, 70, 1717–1722.

Bernstein, N., Sela, S., Pinto, R., Ioffe, M. (2007b). Evidence for internalization of *Escherichia coli* into the aerial parts of maize via the root system. Journal of Food Protection, 70, 471–475.

Besser, R.E., Lett, S.M., Weber, J.T., Doyle, M.P., Barrett, T.J., Wells, J.G., Griffin, P.M. (1993). An outbreak of diarrhea and hemolytic uremic syndrome from *Escherichia coli* O157:H7 in fresh-pressed apple cider. Journal of the American Medical Association, 269, 2217–2220.

Beuchat, L.R. (1996). Pathogenic microorganisms associated with fresh produce. Journal of Food Protection, 59, 204–216.

Beuchat, L.R. (2002). Ecological factors influencing survival and growth of human pathogens on raw fruits and vegetables. Microbes and Infection, 4, 413–423.

Beuchat, L.R., Farber, J.M., Garrett, E.H., Harris, L.J., Parish, M.E., Suslow, T.V., Busta, F.F. (2001). Standardization of a method to determine the efficacy of sanitizers in inactivating human pathogenic microorganisms on raw fruits and vegetables. Journal of Food Protection, 64, 1079–1084.

Beuchat, L.R., Ryu, J.H. (1997). Produce handling and processing practices. Emerging Infectious Diseases, 3, 459–465.

Beutin, L., Geier, D., Steinruck, H., Zimmermann, S., Scheutz, F. (1993). Prevalence and some properties of verotoxin (Shiga-like toxin) – producing *Escherichia coli* in seven different species of healthy domestic animals. Journal of Clinical Microbiology, 31, 2483–2488.

Blostein, J. (1993). An outbreak of *Salmonella* javiana associated with consumption of watermelon. Journal of Environmental Health, 56, 29–31.

Bowen, A., Fry, A., Richards, G., Beuchat, L.R. (2006). Infections associated with cantaloupe consumption: a public health concern. Epidemiology and Infection, 134, 675–685.

Brackett, R.E., Splittstoesser, D.F. (2001). Fruits and vegetables. In: Compendium of Methods for the Microbial Examination of Foods, F.P. Downes, K. Ito (eds). American Publication Health Assistance, Washington, DC, USA, pp. 515–520.

Brackett, R.E. (1992a). Shelf stability and safety of fresh produce as influenced by sanitation and disinfection. Journal of Food Protection, 55, 804–814.

Brackett, R.E. (1992b). Microbial Quality. In: Post harvest handling: A system approach, R.L. Shewfelt, S.E. Prussia, S. Taylor (eds). Academic Press Inc., pp. 125–149.

Brackett, R.E. (1999). Incidence, contributing factors, and control of bacterial pathogens in produce. Postharvest Biology and Technology, 15, 305–311.

Brandl, M.T., Mandrell, R.E. (2002). Fitness of *Salmonella enterica* serovar Thompson in the cilantro phyllosphere. Applied and Environmental Microbiology, 68, 3614–3621.

Brandl, M.T. (2006). Fitness of human enteric pathogens on plants and implications for food safety. Annual Review of Phytopathology, 44, 367–392.

Burnett, S.L., Beuchat, L.R. (2001). Human pathogens associated with raw produce and unpasteurized juices, and difficulties in decontamination. Journal of Industrial Microbiology and Biotechnology, 27, 104–110.

Centers for Disease Control and Prevention (CDC) (1997a). Outbreaks of *Escherichia coli* infection and cryptosporidiosis associated with drinking unpasteurized apple cider – Connecticut and New York, October 1996. Morbidity and Mortality Weekly Report, 46, 4–8.

Centers for Disease Control and Prevention (CDC) (1997b). Update: Outbreaks of cyclosporiasis – United States and Canada, 1997. Morbidity and Mortality Weekly Report, 46, 521–552.

Centers for Disease Control and Prevention (CDC) (1999). Outbreaks of *Shigella sonnei* infection associated with eating fresh parsley – United States and Canada, July–August 1998. Morbidity and Mortality Weekly Report, 48, 285–289.

Centers for Disease Control and Prevention (CDC) (2002). Multistate outbreaks of *Salmonella* serotype Poona infections associated with eating cantaloupe from Mexico – United States and Canada, 2000–2002. Morbidity and Mortality Weekly Report, 51, 1044–1047.

Centers for Disease Control (CDC) (2006a). Update on multi-state outbreak of *E. coli* O157:H7 infections from fresh spinach, October 6, 2006. Available at: http://www.cdc.gov/ecoli/2006/september/updates/100606.htm Accessed 22 May 2007.

Centers for Disease Control and Prevention (CDC) (2006b). Multi-state outbreak of *E. coli* O157 infections, November–December 2006. Available at: http://www.2a.cdc.gov/HAN/ArchiveSys/ViewMsgV.asp?AlertNum = 00255 Accessed 22 May 2007.

Chaudry, M.A., Bibi, N., Khan, M., Khan, M., Badshah, A., Qureshi, M.J. (2004). Irradiation treatment of minimally processed carrots for ensuring microbiological safety. Radiation Physics and Chemistry, 71, 171–175.

Cody, S.H., Glynn, K., Farrar, J.A., Cairns, K.L., Griffin, P.M., Kobayashi, J., Fyfe, M., Hoffman, R., King, A.S., Lewis, J.H., Swaminathan, B., Bryant, R.G., Vugia, D.J. (1999). An outbreak of *Escherichia coli* O157, H7 infection from unpasteurized commercial apple juice. Annals of Internal Medicine, 130, 202–209.

Conesa, A., Artes-Hernandez, F., Geysen, S., Nicolai, B., Artes, F. (2007). High oxygen combined with high carbon dioxide improves microbial and sensory quality of fresh-cut peppers. Postharvest Biology and Technology, 43, 230–237.

Conway, W.S., Leverentz, B., Janisiewicz, W.J., Blodgett, A.B., Saftner, R.A., Camp, M.J. (2004). Integrating heat treatment, biocontrol and sodium bicarbonate to reduce postharvest decay of apple caused by *Colletotrichum acutatum* and *Penicillium expansum*. Postharvest Biology and Technology, 34, 11–20.

Costerton, J.W., Lewandowski, Z., deBeer, D., Korber, D., James, G. (1994). Biofilms: the customized microniche. Journal of Bacteriology, 176, 2137–2142.

Cousin, M.A., Jay, J.M., Vasavada, P.C. (2001). Psychrotrophic microorganisms. In: Compendium of methods for the microbiological examination of foods, F.P. Downes, K. Ito (eds), 4th edn. American Public Health Association, Washington, DC, USA, pp. 159–166.

Cummings, K., Barrett, E., Mohle-Boetani, J.C., Brooks, J.T., Farrar, J., Hunt, T., Fiore, A., Komatsu, K., Werner, S.B., Slutsker, L. (2001). A multistate outbreak of *Salmonella enterica* serotype Baildon associated with domestic raw tomatoes. Emerging Infectious Diseases, 7, 1046–1048.

Dawson, D. (2005). Foodborne protozoan parasites. International Journal of Food Microbiology, 103, 207–227.

Deak, T., Beuchat, L. (1993). Yeasts associated with fruit juices concentrates. Journal of Food Protection, 56, 777–782.

Decludt, B., Bouvet, P., Mariani-Kurkdjian, P., Grimont, F., Grimont, P.A., Hubert, B., Loirat, C. (2000). Haemolytic uraemic syndrome and Shiga toxin-producing *Escherichia coli* infection in children in France. Epidemiology and Infection, 124, 215–220.

Deeks, S., Ellis, A., Ciebin, B., Khakhria, R., Naus, M., Hockin, J. (1998). Salmonella Oranienburg, Ontario. Canadian Community Diseases Report, 24, 177–178.

Dong, Y., Iniguez, A.L., Ahmer, B.M., Triplett, E.W. (2003). Kinetics and strain specificity of rhizosphere and endophytic colonization by enteric bacteria on seedlings of *Medicago sativa* and *Medicago truncatula*. Applied and Environmental Microbiology, 69, 1783–1790.

Elez-Martinez, P., Soliva-Fortuny, R.C., Martin-Belloso, O. (2006). Comparative study on shelf life of orange juice processed by high intensity pulsed electric fields or heat treatment. European Food Research and Technology, 222, 321–329.

Erkan, M., Wang, C.Y., Krizek, D.T. (2001). UV-C radiation reduces microbial populations and deterioration in *Cucurbita pepo* fruit tissue. Environmental and Experimental Botany, 45, 1–9.

Fain, A.R. (1996). A review of the microbiological safety of fresh salads. Dairy, Food and Environmental Sanitation, 16, 146–149.

Fallik, E. (2004). Prestorage hot water treatments (immersion, rinsing and brushing). Postharvest Biology and Technology, 32, 125–134.

Fallik, E. (2007). Heat treatments to control fungal diseases. In: Recent Advances in Alternative Postharvest Technologies to Control Fungal Diseases in Fruits and Vegetables, R. Troncoso-Rojas, M. Tiznado-Hernandez, A. Gonzalez-Leon (eds). Transworld Research Network, Mexico, pp. 21–38.

Fallik, E., Grinberg, S., Gambourg, M., Klein, J.D., Lurie, S. (1995). Prestorage heat treatment reduces pathogenicity of *Penicillium expansum* in apple fruit. Plant Pathology, 45, 92–97.

Fallik, E., Lurie, S. (2006). Thermal control of fungi to reduce postharvest decay. In: Thermal Control of Microbial Contamination, J. Tang, E. Mitcham, S. Wang, S. Lurie (eds). CABI Publishing, pp. 162–181.

Fan, X.T., Annous, B.A., Sokorai, K.J.B., Burke, A., Mattheis, J.P. (2006). Combination of hot-water surface pasteurization of whole fruit and low-dose gamma irradiation of fresh-cut cantaloupe. Journal of Food Protection, 69, 912–919.

Fan, X.T., Niemera, B.A., Mattheis, J.P., Zhuang, H., Olson, D.W. (2005). Quality of fresh-cut apple slices as affected by low-dose ionizing radiation and calcium ascorbate treatment. Journal of Food Science, 70, S143–S148.

Fett, W.E. (2000). Naturally occurring biofilms on alfalfa and other types of sprouts. Journal of Food Protection, 63, 625–632.

Fleming, C.A., Caron, D., Gunn, J.E., Barry, M.A. (1998). A foodborne outbreak of *Cyclospora cayetanensis* at a wedding. Archives of Internal Medicine, 158, 1121–1125.

Fonseca, S.C., Oliveira, F.A.R., Brecht, J.K. (2002). Modelling respiration rate of fresh fruits and vegetables for modified atmosphere packages: a review. Journal of Food Engineering, 52, 99–119.

Fonseca, J.M., Rushing, J.W. (2006). Effect of ultraviolet-C light on quality and microbial population of fresh-cut watermelon. Postharvest Biology and Technology, 40, 256–261.

Food and Drug Administration (1998). U.S. Department of Agriculture, Centers for Disease Control and Prevention, Center for Food Safety and Applied Nutrition, Guide to minimize microbial food safety hazards for fresh fruits and vegetables. Website http://vm.cfsan.fda.gov/~dms/prodguid.html Last accessed October 2007.

Food and Drug Administration (FDA) (2007). U.S. Department of Agriculture; Centers for Disease Control and Prevention, Center for Food Safety and Applied Nutrition, Draft Final Guidance. Guide to minimize microbial food safety hazards for fresh fruits and vegetables. Website http://www.cfsan.fda.gov/~dms/prodguid.html Last accessed October 2007.

Francis, G.A., Thomas, C., O'Beirne, D. (1999). The microbiological safety of minimally processed vegetables. International Journal of Food Science and Technology, 34, 1–22.

Franz, E., Visser, A.A., van Diepeningen, A.D., Klerks, M.M., Termorshuizen, A.J., van Bruggen, A.H.C. (2007). Quantification of contamination of lettuce by GFP-expressing *Escherichia coli* O157, H7 and *Salmonella enterica* serovar Typhimurium. Food Microbiology, 24, 106–112.

Fredlund, H., Back, E., Sjoberg, L., Tornquist, E. (1987). Watermelon as a vehicle of transmission of Shigellosis. Scandinavian Journal of Infectious Diseases, 19, 219–221.

Fux, C.A., Costerton, J.W., Stewart, P.S., Stoodley, P. (2005). Survival strategies of infectious biofilms. Trends in Microbiology, 13, 34–40.

Gálvez, A., Abriouel, H., López, R.L., Omar, N.B. (2007). Bacteriocin-based strategies for food biopreservation. International Journal of Food Microbiology, 120, 51–70.

Gandhi, M., Golding, S., Yaron, S., Matthews, K.R. (2001). Use of green fluorescent protein expressing *Salmonella* Stanley to investigate survival, spatial location, and control on alfalfa sprouts. Journal of Food Protection, 64, 1891–1898.

Gonzalez, R.J., Luo, Y., Ruiz-Cruz, S., Mcevoy, J.L. (2004). The efficacy of sanitizers on the reduction of *E. coli* O157, H7 from shredded carrots under simulated fresh-cut processing conditions. Journal of Food Protection, 67, 2375–2380.

Gorny, J.R. (2006). Microbial contamination of fresh fruits and vegetables. In: Microbiology of Fruits and Vegetables, G.M. Sapers, J.R. Gorny, A.E. Yousef (eds). CRC Press, Taylor and Francis, Boca Raton, FL, USA, pp. 3–32.

Greer, G.G. (2005). Bacteriophage control of foodborne bacteria. Journal of Food Protection, 68, 1102–1111.

Guo, X., Chen, J., Brackett, R.E., Beuchat, L.R. (2001). Survival of salmonellae on and in tomato plants from the time of inoculation at flowering and early stages of fruit development through fruit ripening. Applied and Environmental Microbiology, 67, 4760–4764.

Guo, X., van Iersel, M.W., Chen, J., Brackett, R.E., Beuchat, L.R. (2002). Evidence of association of salmonellae with tomato plants grown hydroponically in inoculated nutrient solution. Applied and Environmental Microbiology, 68, 3639–3643.

Harborne, J.B. (1999). The comparative biochemistry of phytoalexin induction in plants. Biochemical Systematics Ecology, 27, 335–367.

Harrigan, W.F. (1998). Laboratory Methods in Food Microbiology, 3rd edn. Academic Press, Surrey, UK.

Harris, L.J., Farber, J.N., Beuchat, L.R., Parish, M.E., Suslow, T.V., Garrett, E.H., Busta, F.F. (2003). Outbreaks associated with fresh produce, incidence, growth and survival of pathogens in fresh and fresh-cut produce. Comprehensive Reviews in Food Science and Food Safety, 2, 78–141.

Hedberg, C.W., Angulo, F.J., White, K.E., Langkop, C.W., Schell, W.L., Stobierski, M.G., Schuchat, A., Besser, J.M., Dietrich, S., Helsel, L., Griffin, P.M., McFarland, J.W., Osterholm, M.T. (1999). Outbreaks of salmonellosis associated with eating uncooked tomatoes: implications for public health. The Investigation Team. Epidemiology and Infection, 122, 385–393.

Herwaldt, B.L. (2000). *Cyclospora cayetanensis*: a review, focusing on the outbreaks of cyclosporiasis in the 1990s. Clinical Infectious Diseases, 31, 1040–1057.

Herwaldt, B.L., Ackers, M.L. (1997). An outbreak in 1996 of cyclosporiasis associated with imported raspberries. The *Cyclospora* Working Group. New England Journal of Medicine, 336, 1548–1556.

Herwaldt, B.L., Beach, M.J. (1999). The return of *Cyclospora* in 1997: another outbreak of cyclosporiasis in North America associated with imported raspberries. Cyclospora Working Group. Annals of Internal Medicine, 130, 210–220.

Hilborn, E.D., Mermin, J.H., Mshar, P.A., Hadler, J.L., Voetsch, A., Wojtkunski, C., Swartz, M., Mshar, R., Lambert-Fair, M.A., Farrar, J.A., Glynn, M.K., Slutsker, L. (1999). A multistate outbreak of *Escherichia coli* O157, H7 infections associated with consumption of mesclun lettuce. Archives of Internal Medicine, 159, 1758–1764.

Hilborn, E.D., Mshar, P.A., Fiorentino, T.R., Dembek, Z.F., Barrett, T.J., Howard, R.T., Cartter, M.L. (2000). An outbreak of *Escherichia coli* O157, H7 infections and haemolytic uraemic syndrome associated with consumption of unpasteurized apple cider. Epidemiology and Infection, 124, 31–36.

Hirano, S.S., Upper, C.D. (1990). Population biology and epidemiology of *Pseudomonas syringae*. Annual Review of Phytopathology, 28, 155–177.

Hong, S.I., Kim, D. (2004). The effect of packaging treatment on the storage quality of minimally processed bunched onions. International Journal of Food Science and Technology, 39, 1033–1041.

Hora, R., Warriner, K., Shelp, B.J., Griffiths, M.W. (2005). Internalization of *Escherichia coli* O157, H7 following biological and mechanical disruption of growing spinach plants. Journal of Food Protection, 68, 2506–2509.

Huxley, R.R., Lean, M., Crozier, A., John, J.H., Neil, H.A.W. (2004). Effect of dietary advice to increase fruit and vegetable consumption on plasma flavonol concentrations: Results from a randomized controlled intervention trial. Journal of Epidemiology and Community Health, 58, 288–289.

Hyun-Gyun, Y., Bartz, J.A., Schneider, K.R. (2006). The effectiveness of sanitizer treatments in inactivation of *Salmonella* spp. from bell pepper, cucumber, and strawberry. Journal of Food Science, 71, M95–M99.

Islam, M., Doyle, M.P., Phatak, S.C., Millner, P., Jiang, X. (2004a). Persistence of enterohemorrhagic *Escherichia coli* O157, H7 in soil and on leaf lettuce and parsley grown in fields treated with contaminated manure composts or irrigation water. Journal of Food Science, 67, 1365–1370.

Islam, M., Morgan, J., Doyle, M.P., Phatak, S.C., Millner P., Jiang, X. (2004b). Persistence of *Salmonella enterica* serovar Typhimurium on lettuce and parsley and in soils on which they were grown in fields treated with contaminated manure composts or irrigation water. Foodborne Pathogens and Disease, 1, 27–35.

Itoh, Y., Sugita-Konishi, Y., Kasuga, F., Iwaki, M., Hara-Kudo, Y., Saito, N., Noguchi, Y., Konuma, H., Kumagai, S. (1998). Enterohemorrhagic *Escherichia coli* O157, H7 present in radish sprouts. Applied and Environmental Microbiology, 64, 1532–1535.

Jablasone, J., Warriner, K., Griffiths, M.W. (2005). Interactions of *Escherichia coli* O157, H7, *Salmonella typhimurium* and *Listeria monocytogene*s with plants cultivated in a gnotobiotic system. International Journal of Food Microbiology, 99, 7–18.

Jay, J.M. (1992). Modern Food Microbiology, 4th edn. Chapman & Hall, New York, NY, USA.

Johannessen, G.S., Bengtsson, G.B., Heier, B.T., Bredholt, S., Wasteson, Y., Rørvik, L.M. (2005). Potential uptake of *Escherichia coli* O157, H7 from organic manure into crisphead lettuce. Applied and Environmental Microbiology, 71, 2221–2225.

Johnston, L.M., Jaykus, L.A., Moll, D., Martinez, M.C., Anciso, J., Mora, B., Moe, C.L. (2005). A field study of the microbiological quality of fresh produce. Journal of Food Protection, 68, 1840–1847.

Kaper, J.B., Nataro, J.P., Mobley, H.L. (2004). Pathogenic *Escherichia coli*. Nature, Review Microbiology, 2, 123–140.

Karabulut, O.A., Arslan, U., Kuruoglu, G. (2004a). Control of postharvest diseases of organically grown strawberry with preharvest applications of some food additives and postharvest hot water dips. Journal of Phytopathology, 152, 224–228.

Karabulut, O.A., Arslan, U., Kuruoglu, G., Ozgenc, T. (2004b). Control of postharvest diseases of sweet cherry with ethanol and hot water. Journal of Phytopathology, 152, 298–303.

Kinkel, L.L., Wilson, M., Lindow, S.E. (2000). Plant species and plant incubation conditions influence variability in epiphytic bacterial population size. Microbial Ecology, 39, 1–11.

Klein, P., Morris, S.C. (2005). Technological breakthrough in postharvest sanitation treatment with the iodine based Isan process. Acta Horticulturae (ISHS), 687, 131–138.

Kolter, R., Greenberg, E.P. (2006). Microbial sciences: the superficial life of microbes. Nature, 441, 300–302.

Kondo, N., Murata, M., Isshiki, K. (2006). Efficiency of sodium hypochlorite, fumaric acid, and mild heat in killing native microflora and *Escherichia coli* O157, H7, *Salmonella typhimurium* DT104, and *Staphylococcus aureus* attached to fresh-cut lettuce. Journal of Food Protection, 69, 323–329.

Koseki, S., Fujiwara, K., Itoh, K. (2002). Decontaminative effect of frozen acidic electrolyzed water on lettuce. Journal of Food Protection, 65, 411–414.

Koseki, S., Isobe, S. (2006). Effect of ozonated water treatment on microbial control and on browning of iceberg lettuce (*Lactuca sativa* L.). Journal of Food Protection, 69, 154–160.

Koseki, S., Yoshida, K., Kamitani, Y., Isobe, S., Itoh, K. (2004). Effect of mild heat pre-treatment with alkaline electrolyzed water on the efficacy of acidic electrolyzed water against *Escherichia coli* O157, H7 and *Salmonella* on lettuce. Food Microbiology, 21, 559–566.

Koumans, E.H.A., Katz, D.J., Malecki, J.M., Kumar, S., Wahlquist, S.P., Arrowood, M.J., Hightower, A.W., Herwaldt, B.L. (1998). An outbreak of cyclosporiasis in Florida in 1995: a harbinger of multistate outbreaks in 1996 and 1997. American Journal of Tropical Medicine and Hygiene, 59, 235–242.

Koutsoudis, M.D., Tsaltas, D., Minogue, T.D., von Bodman, S.B. (2006). Quorum-sensing regulation governs bacterial adhesion, biofilm development, and host colonization in *Pantoea stewartii* subspecies stewartii. Proceedings of the National Academy of Sciences of the United States of America, 103, 5983–5988.

Kraft, A.A. (1992). Psychrotrophic Bacteria in Foods: Disease and Spoilage. CRC Press, Inc., Boca Raton, FL, USA.

Lafortune, R., Caillet, S., Lacroix, M. (2005). Combined effects of coating, modified atmosphere packaging, and gamma irradiation on quality maintenance of ready-to-use carrots (*Daucus carota*). Journal of Food Protection, 68, 353–359.

Lamikanra, O. (2002). Ultraviolet induced stress response in fresh cut cantaloupe. Phytochemistry, 60, 27–32.

Lamikanra, O., Bett-Garber, K.L., Ingram, D.A., Watson, M.A. (2005). Use of mild heat pre-treatment for quality retention of fresh-cut cantaloupe melon. Journal of Food Science, 70, C53–C57.

Lee, S.Y., Costello, M., Kang, D.H. (2004). Efficacy of chlorine dioxide gas as a sanitizer of lettuce leaves. Journal of Food Protection, 67, 1371–1376.

Leistner, L. (2000). Basic aspects of food preservation by hurdle technology. International Journal of Food Microbiology, 55, 181–186.

Leverentz, B., Conway, W.S., Camp, M.J., Janiesiewicz, W.J., Abuladze, T., Yang, M., Saftner, R., Sulakvelidze, A. (2003). Biocontrol of *Listeria monocytogenes* on fresh-cut produce by treatment with lytic bacteriophages and a bacteriocin. Applied and Environmental Microbiology, 69, 4519–4526.

Leverentz, B., Conway, W.S., Janisiewicz, W., Abadias, M., Kurtzman, C.P., Camp, M.J. (2006). Biocontrol of the food-borne pathogens *Listeria monocytogenes* and *Salmonella enterica* serovar Poona on fresh-cut apples with naturally occurring bacterial and yeast antagonists. Applied and Environmental Microbiology, 72, 1135–1140.

Lin, C.M., Moon, S.S., Doyle, M.P., McWatters, K.H. (2002). Inactivation of *Escherichia coli* O157, H7, *Salmonella enterica* serotype enteritidis, and *Listeria monocytogenes* on lettuce by hydrogen peroxide and lactic acid and by hydrogen peroxide with mild heat. Journal of Food Protection, 65, 1215–1220.

Lopez, V.L., Avendano, V.S., Romero, R.J., Garrido, S., Espinoza, J., Vargas, M. (2005). Effect of gamma irradiation on the microbiological quality of minimally processed vegetables. Archivos Latinoamericanos de Nutricion, 55, 287–292.

López-Rubira, V., Conesa, A., Allende, A., Artés, F. (2005). Shelf life and overall quality of minimally processed pomegranate arils modified atmosphere packaged and treated with UV-C. Postharvest Biology and Technology, 37, 174–185.

Lydakis, D., Aked, J. (2003). Vapour heat treatment of Sultanina table grapes. I: control of *Botrytis cinerea*. Postharvest Biology and Technology, 27, 109–116.

Marquenie, D., Lammertyn, J., Geeraerd, A.H., Soontjens, C., Van Impe, J.F., Nicolai, B.M., Michiels, C.W. (2002). Inactivation of conidia of *Botrytis cinerea* and *Monilinia fructigena* using UV-C and heat treatment. International Journal of Food Microbiology, 74, 27–35.

Martin, D.L., Gustafson, T.L., Pelosi, J.W., Suarez, L., Pierce, G.V. (1986). Contaminated produce – a common source for two outbreaks of *Shigella* gastroenteritis. American Journal of Epidemiology, 124, 299–305.

Martinez-Sanchez, A., Allende, A., Bennett, R.N., Ferreres, F., Gil, M.I. (2006). Microbial, nutritional and sensory quality of rocket leaves as affected by different sanitizers. Postharvest Biology and Technology, 42, 86–97.

Mattheis, J., Fellman, J.K. (2000). Impacts of modified atmosphere packaging and controlled atmospheres on aroma, flavor, and quality of horticultural commodities. HortTechnology, 10, 507–510.

Mercier, J., Lindow, S.E. (2000). Role of leaf surface sugars in colonization of plants by bacterial epiphytes. Applied and Environmental Microbiology, 66, 369–374.

Mintier, A.M., Foley, D.M. (2006). Electron beam and gamma irradiation effectively reduce *Listeria monocytogenes* populations on chopped romaine lettuce. Journal of Food Protection, 69, 570–574.

Mohle-Boetani, J.C., Farrar, J.A., Werner, S.B., Minassian, D., Bryant, R., Abbott, S., Slutsker, L., Vugia, D.J. (for the Investigation Team) (2001). *Escherichia coli* O157 and *Salmonella* infections associated with sprouts in California, 1996–1998. Ann. Intern. Med., 135, 239–247.

Mohle-Boetani, J.C., Reporter, R., Werner, S.B., Abbott, S., Farrar, J., Waterman, S.H., Vugia, D.J. (1999). An outbreak of *Salmonella* serotype Saphra due to cantaloupes from Mexico. Journal Infection and Diseases, 180, 1361–1364.

Monaghan, J.M. (2006). United Kingdom and European approach to fresh produce food safely and security. HortTechnology, 16, 559–562.

Moore, J.E., Cherie, M.B., Kenny, F., Lowery, C.J., Xiao, L., Rao, J.R., Nicholson, V., Watabe, M., Heaney, N., Sunnotel, O., McCorry, K., Rooney, P.J., Snelling, W.J., Dooley, J.S.G. (2007). Detection of *Cryptosporidium parvum* in lettuce. International Journal of Food Science and Technology, 42, 385–393.

Mukherjee, A., Speh, D., Jones, A.T., Buesing, K.M., Diez-Gonzalez, F. (2006). Longitudinal microbiological survey of fresh produce grown by farmers in the upper midwest. Journal of Food Protection, 69, 1928–1936.

Narciso, J., Plotto, A. (2006). A comparison of sanitation systems for fresh-cut mango. HortTechnology, 15, 837–842.

Natvig, E.E., Ingham, S.C., Ingham, B.H., Cooperband, L.R., Roper, T.R. (2002). *Salmonella enterica* serovar Typhimurium and *Escherichia coli* contamination of root and leaf vegetables grown in soils with incorporated bovine manure. Applied and Environmental Microbiology, 68, 2737–2744.

Nguyen-the, C., Carlin, F. (1994). The microbiology of minimally processed fresh fruits and vegetables. Critical Review in Food Science and Nutrition, 34, 371–401.

Obagwu, J., Korsten, L. (2003). Integrated control of citrus green and blue molds using *Bacillus subtilis* in combination with sodium bicarbonate or hot water. Postharvest Biology and Technology, 28, 187–194.

O'Brien, R.D., Lindow, S.E. (1989). Effect of plant species and environmental conditions on epiphytic population sizes of *Pseudomonas syringae* and other bacteria. Phytopathology, 79, 619–627.

Olson, J.C., Jr., Nottingham, P.M. (1980). Temperature. In: *Microbial Ecology of Foods, Vol. 1*, Factors Affecting Life and Death of Microorganisms, International Commission on Microbial Specifications for Foods, Silliker, J. H. (ed.). Academic Press, Inc., New York, NY, USA, , p. 1.

Palou, L., Smilanick, J.L., Crisosto, C.H., Mansour, M.F. (2001). Effect of gaseous ozone exposure on the development of green and blue molds on cold stored citrus fruit. Plant Disease, 85, 632–638.

Palou, L., Smilanick, J.L., Margosan, D.A. (2007). Ozone applications for sanitation and control of postharvest diseases of fresh fruits and vegetables. In: Recent Advances in Alternative Postharvest Technologies to Control Fungal Diseases in Fruits and Vegetables, R. Troncoso-Rojas, M. Tiznado-Hernandez, A. Gonzalez-Leon (eds). Transworld Research Network, Mexico, pp. 39–70.

Pan, J., Vicente, A.R., Martinez, G.A., Chaves, A.R., Civello, P.M. (2004). Combined use of UV-C irradiation and heat treatment to improve postharvest life of strawberry fruit. Journal of the Science of Food and Agriculture, 84, 1831–1838.

Parish, M.E. (1998). Coliforms, Escherichia coli and Salmonella serovars associated with a citrus-processing facility implicated in a salmonellosis outbreak. Journal of Food Protection, 61, 280–284.

Pedras, M.S., Ahiahonu, P.W. (2005). Metabolism and detoxification of phytoalexins and analogs by phytopathogenic fungi. Phytochemistry, 66, 391–411.

Perez-Carrillo, E., Yahia, E.M. (2004). Effect of postharvest hot air and fungicide treatments on the quality of "maradol" papaya (*Carica papaya* L.). Journal of Food Quality, 27, 127–139.

Phillips, C.A., Harrison, M.A. (2005). Comparison of the microflora on organically and conventionally grown spring mix from a California processor. Journal of Food Protection, 68, 1143–1146.

Pingulkar, K., Kamat, A., Bongirwar, D. (2001). Microbiological quality of fresh leafy vegetables, salad components and ready-to-eat salads: an evidence of inhibition of *Listeria monocytogenes* in tomatoes. International Journal of Food Science and Nutrition, 52, 15–23.

Plaza, P., Usall, J., Torres, R., Abadias, M., Smilanick, J.L., Vinas, I. (2004). The use of sodium carbonate to improve curing treatments against green and blue molds on citrus fruits. Pest Management Science, 60, 815–821.

Poubol, J., Izumi, H. (2005a). Shelf life and microbial quality of fresh-cut mango cubes stored in high CO_2 atmospheres. Journal of Food Science, 70, M69–M74.

Poubol, J., Izumi, H. (2005b). Physiology and microbiological quality of fresh-cut mango cubes as affected by high O_2 controlled atmospheres. Journal of Food Science, 70, M286–M291.

Powell, D., Chapman, B. (2007). Fresh threat: what's lurking in your salad bowl? Journal of the Science of Food and Agriculture, 87, 1799–1801.

Prakash, A., Chen, P.C., Pilling, R.L., Johnson, N., Foley, D. (2007). 1% calcium chloride treatment in combination with gamma irradiation improves microbial and physicochemical properties of diced tomatoes. Foodborne Pathogens and Disease, 4, 89–98.

Ragaert, P., Devlieghere, F., Debevere, J. (2007). Role of microbiological and physiological spoilage mechanisms during storage of minimally processed vegetables. Postharvest Biology and Technology, 44, 185–194.

Rayner, J., Veeh, R., Flood, J. (2004). Prevalence of microbial biofilms on selected fresh produce and household surfaces. International Journal of Food Microbiology, 95, 29–39.

Riley, L.W., Remis, R.S., Helgerson, S.D., McGee, H.B., Wells, J.G., Davis, B.R., et al. (1983). Hemorrhagic colitis associated with a rare *Escherichia coli* serotype. New England Journal of Medicine, 308, 681–685.

Rocha, A.M.C.N., Ferreira, J.F.F.C., Silva, A.M.M., Almeida, G.N., Morais, A.M.M.B. (2007). Quality of grated carrot (var. Nantes) packed under vacuum. Journal of the Science of Food and Agriculture, 87, 447–451.

Rodov, V., Ben-Yehoshua, S., Kim, J.J., Shapiro, B., Ittah, Y. (1992). Ultraviolet illumination induces scoparone production in kumquat and orange fruit and improves decay resistance. Journal of American Society for Horticulture Science, 117, 788–792.

Ryu, J.H., Beuchat, L.R. (2005). Biofilm formation by *Escherichia coli* O157, H7 on stainless steel: effect of exopolysaccharide and curli production on its resistance to chlorine. Applied and Environmental Microbiology, 71, 247–254.

Saftner, R.A., Abbott, J.A., Conway, W.S., Barden, C.L. (2003). Effects of 1-methylcyclopropene and heat treatments on ripening and postharvest decay in "Golden Delicious" apples. Journal of the American Society for Horticultural Science, 128, 120–127.

Samish, Z., Etinger-Tulczynska, R., Bick, M. (1962). The microflora within the tissue of fruits and vegetables. Journal of Food Science, 28, 259–266.

Sapers, G.M. (2001). Efficacy of washing and sanitizing methods for disinfection of fresh fruit and vegetable products. Food Technology and Biotechnology, 39, 305–311.

Sapers, G.M. (2006). Washing and sanitizing treatments for fruits and vegetables. In: Microbiology of Fruits and Vegetables, G.M. Sapers, J.R. Gorny, A.E. Yousef (eds). CRC Press, Taylor and Francis, Boca Raton, FL, pp. 375–400.

Schuenzel, K.M., Harrison, M.A. (2002). Microbial antagonists of foodborne pathogens on fresh, minimally processed vegetables. Journal of Food Protection, 65, 1909–1915.

Seo, K.H., Frank, J.F. (1999). Attachment of *Escherichia coli* O157, H7 to lettuce leaf surface and bacterial viability in response to chlorine treatment as demonstrated by using confocal scanning laser microscopy. Journal of Food Protection, 62, 3–9.

Serrano, M., Martinez-Romero, D., Castillo, S., Guillen, F., Valero, D. (2005). The use of natural antifungal compounds improves the beneficial effect of MAP in sweet cherry storage. Innovative Food Science and Emerging Technologies, 6, 115–123.

Seymour, I.J., Appleton, H. (2001). Foodborne viruses and fresh produce. Journal of Applied Microbiology, 91, 759–773.

Shah, N.S., Nath, N. (2006). Minimally processed fruits and vegetables – Freshness with convenience. Journal of Food Science and Technology – Mysore, 43, 561–570.

Sivapalasingam, S., Friedman, C.R., Cohen, L., Tauxe, R.V. (2004). Fresh produce: A growing cause of outbreaks of foodborne illness in the United States, 1973 through 1997. Journal of Food Protection, 67, 2342–2353.

Smilanick, J.L., Aiyabei, J., Mlikota-Gabler, F., Doctor, J., Sorenson, D., Mackey, B. (2002a). Quantification of the toxicity of aqueous chlorine to spores of *Penicillium digitatum* and *Geotrichum citri-aurantii*. Plant Disease, 86, 509–514.

Smilanick, J.L., Margosen, D.M., Mlikota-Gabler, F. (2002b). Impact of ozonated water on the quality and shelf-life of fresh citrus fruit, stone fruit, and table grapes. Ozone: Science and Engineering, 24, 343–356.

Soliva-Fortuny, R.C., Martín-Belloso, O. (2003). New advances in extending the shelf-life of fresh-cut fruits: A review. Trends in Food Science and Technology, 14, 341–353.

Solomon, H.M., Kautter, D.A., Lilly, T., Rhodehamel, E.J. (1990). Outgrowth of *Clostridium botulimun* in shredded cabbage at room temperature under modified atmosphere. Journal of Food Protection, 53, 831–833.

Solomon, E.B., Yaron, S., Mathews, R.K. (2002). Transmission of *Escherichia coli* O157, H7 from contaminated manure and irrigation water to lettuce plant tissue and its subsequent internalization. Applied and Environmental Microbiology, 68, 397–400.

Steele, M., Odumeru, J. (2004). Irrigation water as source of foodborne pathogens on fruit and vegetables. Journal of Food Protection, 67, 2839–2849.

Stoodley, P., Sauer, K., Davies, D.G., Costerton, J.W. (2002). Biofilms as complex differentiated communities. Annual Review of Microbiology, 56, 187–209.

Suparlan-Itoh, K. (2003). Combined effects of hot water treatment (HWT) and modified atmosphere packaging (MAP) on quality of tomatoes. Packaging Technology and Science, 16, 171–178.

Sy, K.V., Murray, M.B., Harrison, M.D., Beuchat, L.R. (2005). Evaluation of gaseous chlorine dioxide as a sanitizer for killing *Salmonella, Escherichia coli* O157, H7, *Listeria monocytogenes*, and yeasts and molds on fresh and fresh-cut produce. Journal of Food Protection, 68, 1176–1187.

Szomolay, B., Klapper, I., Dockery, J., Stewart, P.S. (2005). Adaptive responses to antimicrobial agents in biofilms. Environmental Microbiology, 7, 1186–1191.

Takeuchi, K., Hassan, A.N., Frank, J.F. (2001). Penetration of *Escherichia coli* O157, H7 into lettuce as influenced by modified atmosphere and temperature. Journal of Food Protection, 64, 1820–1823.

Tamblyn, S., deGrosbois, J., Taylor, D., Stratton, J. (1999). An outbreak of *Escherichia coli* O157, H7 infection associated with unpasteurized non-commercial, custom-pressed apple cider – Ontario, 1988. Canada Communicable Disease Report, 25, 113–117.

Tournas, V.H. (2005a). Moulds and yeasts in fresh and minimally processed vegetables, and sprouts. International Journal of Food Microbiology, 99, 71–77.

Tournas, V.H. (2005b). Spoilage of vegetable crops by bacteria and fungi and related health hazards. Critical Reviews in Microbiology, 31, 33–44.

Tzortzakis, N., Singleton, I., Barnes, J. (2007). Deployment of low-level ozone-enrichment for the preservation of chilled fresh produce. Postharvest Biology and Technology, 43, 261–270.

Ukuku, D.O., Bari, M.L., Kawamoto, S., Isshiki, K. (2005). Use of hydrogen peroxide in combination with nisin, sodium lactate and citric acid for reducing transfer of bacterial pathogens from whole melon surfaces to fresh-cut pieces. International Journal of Food Microbiology, 104, 225–233.

Unicomb, L.E., Simmons, G., Merritt, T., Gregory, J., Nicol, C., Jelfs, P., Kirk, M., Tan, A., Thomson, R., Adamopoulos, J., Little, C.L., Currie, A., Dalton, C.B. (2005). Sesame seed products contaminated with *Salmonella*: three outbreaks associated with tahini. Epidemiology and Infection, 133, 1065–1072.

Uyttendaele, M., Neyts, K., Vanderswalmen, H., Notebaert, E., Debevere, J. (2004). Control of *Aeromonas* on minimally processed vegetables by decontamination with lactic acid, chlorinated water, or thyme essential oil solution. International Journal of Food Microbiology, 90, 263–271.

Valero, D., Valverde, J.M., Martinez-Romero, D., Guillen, F., Castillo, S., Serrano, M. (2006). The combination of modified atmosphere packaging with eugenol or thymol to maintain quality, safety and functional properties of table grapes. Postharvest Biology and Technology, 41, 317–327.

Varoquaux, P., Mazollier, J., Albagnac, G. (1996). The influence of raw material characteristics on the storage life of fresh-cut butterhead lettuce. Postharvest Biology and Technology, 9, 127–139.

Vattem, D.A., Mihalik, K., Crixell, S.H., McLean, R.J.C. (2007). Dietary phytochemicals as quorum sensing inhibitors. Fitoterapia, 78, 302–310.

Vicente, A.R., Martinez, G.A., Civello, P.M., Chaves, A.R. (2002). Quality of heat-treated strawberry fruit during refrigerated storage. Postharvest Biology and Technology, 25, 59–71.

Villanueva, M.J., Tenorio, M.D., Sagardoy, M., Redondo, A., Saco, M.D. (2005). Physical, chemical, histological and microbiological changes in fresh green asparagus (*Asparagus officinalis*, L.) stored in modified atmosphere packaging. Food Chemistry, 91, 609–619.

Voetsch, A.C., Van Gilder, T.J., Angulo, F.J., Farley, M.M., Shallow, S., Marcus, R., Cieslak, P.R., Deneen, V.C., Tauxe, R.V. (Emerging Infections Program FoodNet Working Group) (2004). FoodNet estimate of the burden of illness caused by non-typhoidal *Salmonella* infections in the United States. Clinical Infectious Diseases, 38, S127–S134.

Walker, E., Pritchard, C., Forsythe, S. (2003). Hazard analysis critical control point and prerequisite programme implementation in small and medium size food business. Food Control, 14, 169–174.

Waller, J.M. (2002). Postharvest diseases. In: Plant Pathologist's Pocketbook, J.M. Waller, J.M. Lenne, S.J. Waller (eds). CAB International, Oxford, UK, pp. 39–54.

Wang, T., McGregor, S.J., Anderson, J.G., Woolsey, G.A. (2005). Pulsed ultra-violet inactivation spectrum of *Escherichia coli*. Water Research, 39, 2921–2925.

Warriner, K., Ibrahim, F., Dickinson, M., Wright, C., Waites, W.M. (2003). Interaction of *Escherichia coli* with growing salad spinach plants. Journal of Food Protection, 66, 1790–1797.

Watchel, M.R., Whitehand, L.C., Mandrell, R.E. (2002a). Association of *Escherichia coli* O157, H7 with pre-harvest leaf lettuce upon exposure to contaminated irrigation water. Journal of Food Protection, 65, 18–25.

Watchel, M.R., Whitehand, L.C., Mandrell, R.E. (2002b). Prevalence of *Escherichia coli* O157, H7 associated with a cabbage crop inadvertently irrigated with partially treated sewage wastewater. Journal of Food Protection, 65, 471–475.

Wei, C.I., Cook, D.L., Kirk, J.R. (1985). Use of chlorine compounds in the food industry. Food Technology, 39, 107–115.

Wei, C.I., Huang, T.S., Kim, J.M., Lin, W.F., Tamplin, M.L., Bartz, J.A. (1995). Growth and survival of *Salmonella montevideo* on tomatoes and disinfection with chlorinated water. Journal of Food Protection, 58, 829–836.

Wei, H., Brandt, M.J., Wolf, G., Hammes, W.P. (2005). Optimization of acidified warm water treatment to improve the microbiological status and sensory quality of iceberg lettuce. European Food Research and Technology, 220, 168–175.

Weissinger, W.R., Chantarapanont, W., Beuchat, L.R. (2000). Survival and growth of *Salmonella baildon* in shredded lettuce and diced tomatoes, and effectiveness of chlorinated water as a sanitizer. International Journal of Food Microbiology, 62, 123–131.

Wszelaki, A.L., Mitcham, E.J. (2003). Effect of combinations of hot water dips: biological control and controlled atmospheres for control of gray mold on harvested strawberries. Postharvest Biology and Technology, 27, 255–264.

Yasunaga, E. (2006). Postharvest technology for preservation of fresh fruits and vegetables by using controlled and modified atmosphere. In: Advances in Postharvest Technologies for Horticultural Crops, B. Noureddine, S. Norio (eds). Research Signpost, India, pp. 114–130.

Yaun, B.R., Sumner, S.S., Eifert, J.D., Marcy, J.E. (2004). Inhibition of pathogens on fresh produce by ultraviolet energy. International Journal of Food Microbiology, 90, 1–8.

Zagory, D. (1999). Effects of post-processing handling and packaging on microbial populations. Postharvest Biology and Technology, 15, 313–321.

Zhang, G., Ma, L., Doyle, M.P. (2007). *Salmonellae* reduction in poultry by competitive exclusion bacteria *Lactobacillus salivarius* and *Streptococcus cristatus*. Journal of Food Protection, 70, 874–878.

Zhuang, R.Y., Beuchat, L.R., Angulo, F.J. (1995). Fate of Salmonella montevideo on and in raw tomatoes as affected by temperature and treatment with chlorine. Applied and Environmental Microbiology, 61, 2127–2131.

14

Sorting for Defects and Visual Quality Attributes

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I. Background

A. Reasons for sorting

Modern industrialized supply chains have many established criteria and for producers to be competitive, they must meet the specified requirements. Buyers will pay premium prices for fruit and vegetables of uniform size and color. In general, items should not be misshapen or bruised, and should be free of blemishes, diseases and mechanical damage. For exporters, many international and national quarantine regulations must also be met for insects and diseases (see Chapter 9). Product that will be stored for a length of time prior to marketing must also meet criteria for maturity, firmness and damage to ensure storability (see Chapters 15 and 17). These quality specifications have been established primarily to protect members of supply chains and to ensure a saleable product arrives at the consumer.

Consumer perception of quality is highly variable and changes for many reasons, for example, time of year, supply of product, supply of other products and end use (see Chapters 3, 4 and 5). Although initial product quality is determined by the producer, the dynamic parameters of price and quality requirements are established largely by the retailer and consumer (see Chapter 6).

To assist both the seller and the buyer, many public agencies and marketing organizations have developed standards for the grades of most horticultural crops (see Chapter 8). The documents are commonly called "grade standards," and include one or more sets of specifications and tolerances. Compliance with a specific set of requirements in the grade standard enables the lot to be sold as a shipment labeled with the specified grade, for example, US Extra Fancy, Fancy, No. 1 or Utility. When required, a third party inspector evaluates samples from each lot shipped by a seller, before certifying that the lot complies with the grade standard specified.

The application of grade standards in supply chains is essential to codify the quality attributes of a product that are acceptable to:

1. meet some supply chain performance, such as storage or transport performance; or
2. that are considered acceptable to the consumer or buyer.

Many of such attributes have not been tested specifically with consumers, but more often change over time based on experience, and the expert opinion of marketers and others involved in each supply chain. Kusabs et al. (2006) investigated the relationship between sorters of mushrooms and consumers' ratings of the same product. There was little relationship between the two. The sorters were applying a different set of attributes to sort against, which differed from the visual attributes applied by the consumers. Jahns et al. (2001) attempted to use mapping of fuzzy image analysis attributes to predict consumer assessments of quality, and used this approach as a technique to grade product that directly met consumer expectations.

The sorting operation must be viewed in the context of overall postharvest supply chains. It is important to understand how cultural practices and uncontrolled inputs, such as weather, cause variation of quality in products that enter the packing house (see Chapter 20). Likewise, at the time of shipping, it is important to be able to predict the quality of shipments as they progress through the rest of a postharvest supply chain (see Chapter 19). A major function of a packing house is to transform the highly variable product received from the harvesting operation into uniform lots of product for shipments that comply with the requirements of the buyer. The importance of the sorting operation cannot be overstated, since variations in this operation will affect returns for most other parts of postharvest supply chains.

B. Sorting terminology

The following terminology is applied in this chapter. Separation is the removal of non-usable material from usable product. An early operation in packing houses is the separation of debris and inedible items from the flow of marketable product. Separations are generally made with mechanical devices such as sizers, blowers and washers.

Sorting is the segregation of edible or marketable product into distinct quality categories. Sorting of the marketable items is accomplished by both mechanical equipment (sizers or color sorters) and by manual means (visual or tactical). The equipment used for sorting is referred to as a sorting line. People who perform sorting operations are referred to as sorters. Graders are the third-party inspectors who evaluate whether or not the packed lot complies with requirements of a grade standard for a predetermined grade classification. Inspection of samples for this quality control process is more precise than, and differs from, the inspection of product necessary for sorting.

C. Manual sorting equipment

Most sorting operations are still performed by human visual inspection of the product and manual removal of items with defects. Humans have unique abilities for identifying defects and for determining if they exceed prescribed threshold criteria.

A typical sorting operation consists of a continuous flow of product passing in front of one or more stationary sorters (Figure 14.1). Normally, the task of the sorter is to remove items that do not meet the specifications for the lot being shipped. Nonconforming items are placed into a discard flow and items meeting other specifications are placed on separate conveyers that may flow to packing areas for lower quality markets. The design of sorting equipment has a considerable effect on efficiency of the sorter in detecting and removing defective items.

D. Visual perception

The ability of humans to perceive a visual image depends on both physical and cognitive factors (Prussia, 1991). Changes in the color and intensity of light alter the image received by the eye. The method of presenting the product to the sorters also has an important effect on perception. If product speed (either translation or rotation) is too fast, it is not possible to fixate properly on a defect and hence, it is not possible to reach a decision about whether or not the item should be rejected.

Figure 14.1 Typical sorting operation.

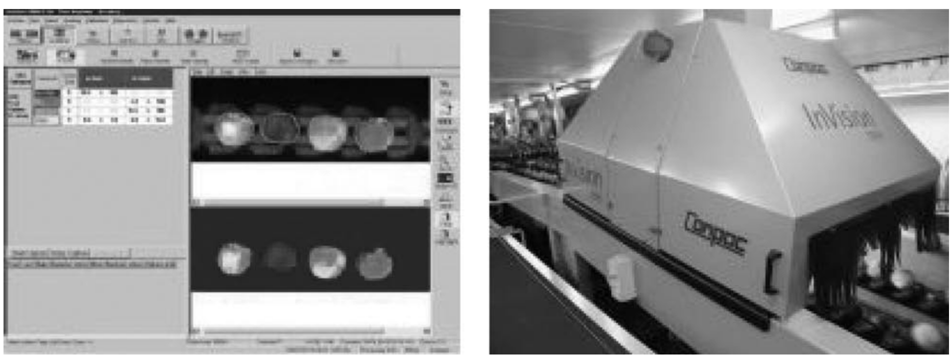

Figure 14.2 Automated sorting system.

Any vision difficulties adversely influence detection of defects. Visual acuity decreases with age, but can be increased by increasing the brightness of the test object. A 60-year-old worker requires about twice the brightness level that a 20-year-old worker needs for equal visual acuity (Luckiesh, 1944). Vision examinations for sorters are useful for determining problems with visual acuity, peripheral vision and color blindness. The inability to concentrate for long periods of time also results in a relaxing of vigilance, which is an important factor in visual perception.

E. Automated sorting

While most sorting operations worldwide are still manual, they are progressively being supplemented with automated sorting, based on computer vision. These systems are typically implemented to perform presorting operations to reduce the number and range of defects that human (manual) sorters need to work with. A typical system is shown in Figure 14.2. Fruit is received after the bin dump and cleaning brushes, and carried on a singulated conveyor under a hood where the fruit is rotated and a camera captures a number of images of the fruit. The images are then processed rapidly, and defects or quality attributes are identified. The fruit are dropped from the conveyor at an appropriate position, based on the decision reached by the image analysis. The high-quality fruit then usually proceeds on past manual sorters prior to sizing and packing. These systems are also often used to presort fruit from the orchard, prior to placement in bins for cool storage.

While the accuracy and range of defects and products that can be graded is limited, the technology offers significant advantages over human sorters as it is generally fast, often more consistent, not prone to fatigue, more objective and becoming progressively lower in cost (Brosnan and Sun, 2002; Tadhg and Da-Wen, 2002, 2004).

Early work in this area (Miller and Delwiche, 1989; Shearer and Payne, 1990; Yang, 1992) focused on techniques for identifying the fruit and descriptions of shape and color. The work has led on to development of very specific algorithms and analyses for much more complex quality traits and defects (Brosnan and Sun, 2002). The analysis techniques are beyond the scope of this chapter, but a range of approaches that have been successfully implemented for fruit and vegetables are described by Graves and Batchelor (2003), Ngan et al. (2003) and Zheng et al. (2006).

The bulk of the reported research relates to apples, which have particularly difficult issues associated with the stem and calyx ends of the fruit (Leemans et al., 2000; Leemans and Destain, 2004; Zhu et al., 2007) which limits the accuracy of detection for russetting, scab and physical damage. More sophisticated lighting and filtering using multi-spectral imaging has also been used, in particular to assist with the detection of bruising (Bennedsen et al., 2005; Xing and de Baerdemaekker, 2005; Kleynen et al., 2005).

Other applications that have been investigated include surface defects on citrus (Miller and Drouillard, 2001; Aleixos et al., 2002) shape and defects on cherries (Rosenberger et al., 2004) and peach defects using NIR (Crowe and Delwiche, 1996).

The accuracy of automated sorting algorithms where reported, for most of these techniques range from 60% to 90%. Often misclassification is not measured, and yet for a commercial operation this can have significant effects, as discussed in Section III. C.

II. Design and operation of manual sorting equipment

The basic sorting operation has developed over a long period of time. Most design and operating conditions have been determined by trial and error for parameters such as table width, table speed, number of sorters and speed of product rotation. Different products place different requirements on the system.

The interrelationship between physical design parameters, the productivity and accuracy of the sorters, and the quality of the product are only partially understood (Prussia and Meyers, 1989), yet the result of the sorting operation has a significant

Table 14.1 Optimal design and operational performances parameters established for selected products by various researchers

Product	Defect type	Defects (%)	Design parameters				Operational parameters		
			Table width (m)	Translation speed (m/min)	Rotation speed (rev/min)	Product rotation (rev/m)	Sorters per table	Fruit per row on table	Fruit per person
Lemons[c]	Actual	25–50	0.5	6.6	22–81	3–13	1	4	4.5
Oranges[c]	Actual	20–60	0.5	5.5	54	9.8	1	4	3.7
Potatoes[c]	Actual	15–40	0.5	9.0	36	3.3	1	3	4.5
Potatoes[d]	Simulated	10–20	0.4[a]	6.7–11.0		5.8	1	4–5	7.0–11.6[b]
Kiwifruit[e]	Actual	10–40	0.65	7.0	20–40	4.9	2–4	4	1.6
Spheres[c]	Simulated	10–30	0.5	6.4–8.5		5.3	1	3–5	4.2–5.6
Ellipsoids[f]	Simulated	10.30	0.5	6.4–8.5		2.5	1	3–5	4.2–56
Apples[g]	Simulated								
	Culls	5	0.24	3.4		4.0	1	2	1.0
	III	5[a]							
	II	10							
Spheres[h]	Simulated	30	0.41	6.6	131	19.9	1	4	5.3
Spheres[i]	Simulated	30	0.41	3.8	19	5.0	1	5	3.0
Oranges[j]	Actual	10.50		9.0	44	4.9	4	3–10	2.0

[a] This value is per sorter
[b] The lower value is at 20% defect level, the higher at 10% defect level
[c] Malcolm and De Garmo (1953)
[d] Hunter and Yaeger (1970)
[e] Bollen (1986a)
[f] Stevens and Gale (1970)
[g] Meyers (1988)
[h] Prussia (1985)
[i] Pasternak et al. (1989)
[j] Three simulated defect grades

effect on much of the rest of a postharvest supply chain. Sorting research has tended to concentrate on large spherical and ellipsoidal products, such as potatoes, apples and citrus. Table 14.1 summarizes design and operational parameters reported by various researchers. Work has concentrated on selected parts of the system with specific objectives, including:

1. the optimal design and operating parameters to achieve high accuracy of reject removal (Malcolm and DeGarmo, 1953; Hunter and Yaeger, 1970);
2. the optimal design and operating parameters to achieve sorter productivity (Bollen, 1986a);
3. the evaluation of a specific piece of equipment (a keypad to identify grades – Stevens and Gale, 1970; performance with fruit flow towards the sorter – Prussia, 1985; Meyers, 1988);
4. determining the relationship between sorter productivity and the quality of the product (Lidror et al., 1978; Pasternak et al., 1989).

To conduct the experiments listed in points 3 and 4 above, the researchers had to make assumptions about, or otherwise determine, the optimum design and operational parameters for their investigation. The applied designs can be assumed to be near-optimal, or at least typical for the particular product of interest.

A. Size of table

A sorting table should be designed at a height that is comfortable for the sorter to reach product on both sides of the table, and it should be easy to deposit rejects on the appropriate belt or in the appropriate chute. The design philosophy is to minimize hand movements, to enable rapid location and removal of defective items. Hand movements should also occur within a comfortable envelope of space. Dreyfus (1967) suggests that the sorters be positioned so that an angle of 45° is measured between the center of the table and the shoulder.

B. Translation speed

Translation speed is the velocity at which products pass the sorter. If the feed rate for incoming items is constant, then changes in translation speed will vary the amount of product on the table at any given time. In others words, translation speed controls the number of fruit per row. If the table rotates the fruit using a static friction drive, then changing translation speed also varies the rotational speed of the product.

Changing the translation speed must be done with caution, since it is unsettling for sorters if the speed is adjusted frequently. However, sorters have the ability to adapt to a wide range of steady speeds. The limiting factors appear to be overflowing the table with product when operating at a low speed, and rotating the fruit too quickly at a high translation speed. Most researchers suggest speeds of 6.5–9.0 meters per minute (Table 14.1).

C. Product loading

The quantity of product is often described in terms of product density on the table (kg/m^2 or $fruit/m^2$) or in terms of number of fruit per row. Loading can be regulated by adjusting the translation speed or the product feed rate. Loading should be regulated to ensure the sorters are capable of maintaining a desired accuracy, and to ensure that sufficient product can be handled when incoming quality has a high reject level. Product loading is generally between three and five fruit per row (Table 14.1), irrespective of table width.

D. Rotational speed

To achieve effective sorting, the product must be rotated in front of the sorter. It is desirable that the fruit is rotated completely at least twice within the immediate field of view. The maximum rotational speed at which sorters can operate effectively is determined partly by the types of defects being removed (Table 14.1) but, in general, rotational speeds above 50 revolutions per minute are detrimental.

To achieve rotary motion on a roller conveyor, the rollers are dragged over stationary rails. The roller rotation causes the product to rotate in the opposite direction. If desired, a powered belt can be installed beneath the rollers, or the rollers may be driven by a chain, to vary rotation speed independently of translation speed.

With the belt stationary, the moving product will have maximum reverse rotational speed. Rotational speed will be zero when the belt is run at the same speed as the roller conveyor. When the belt speed is increased further, the fruit will start to rotate forward. If forward rotation is used, the maximum rotational speed should be maintained below 50 revolutions per minute, as translational and rotational speeds are additive at the product surface.

E. Sorter position

The most efficient sorting operations require two sorters per table for a line carrying products with low levels of defects. A good design allows accommodation of additional sorters in the event of high defect rates in the product. Sorting productivity is reduced if the sorters stand directly opposite each another, since they tend to compete for the same product and do not use the full width of the table properly. Research with kiwifruit on a table 0.8 m wide showed that the proportion of defective fruit removed was 96% when the sorters were staggered, and fell to 68% when the sorters were standing directly opposite each other (Bollen, 1986b).

Research with simulated fruit (Meyers et al., 1990a) reported a 23% improvement in defect detection for sorters positioned at the end of an inspection conveyor, compared with sorters positioned at the sides. Approximately two-thirds of the improvement was shown to result from the ability to see more of the surface area when at the end, rather than when at the side.

F. Lighting

Correct lighting is critical for an efficient sorting operation (Guyer et al., 1994). It improves defect detectability and reduces eye strain. Low intensity light makes perception of contrasts difficult. A study on lighting for fruit sorting by Nicholson (1985) recommended a uniform light level of at least 1000 lux at the table.

Fluorescent tubes are most commonly used. If they are mounted 1.5 meters above the table, there is minimum glare and the whole area is well-lit. For wide tables, it is good practice to mount the tubes perpendicular to the table, since this ensures uniform light levels across the whole table. For narrow tables, tubes mounted parallel to the table provide suitably uniform light. When it is necessary to mount lights at or below eye level to avoid shadowing, the lights should be fitted with deflectors and diffusers to direct a diffuse light onto the table where it is required, and not into the eyes of sorters.

Both Guyer et al. (1994) and Nicholson (1985) also suggest that the surroundings should be well-lit. When sorters look up from the table, their eyes adjust to the light intensity of the background. Background light of a similar intensity helps to reduce eye strain. Neutral-colored walls help reflect diffuse light back onto the table. Sorting products on white belts can produce glare or high reflectivity of incident light. Dark dull belts can ease eye strain and improve the visibility of the product.

If determining product color is important, then it is necessary to use lights that produce a spectrum similar to that of daylight. In an extreme case, green light falling on a red surface will make the surface appear dark to the eye, since most of the light at these wavelengths will be absorbed by the surface. Making accurate decisions based on dark images is difficult. Unfortunately, "cool white" fluorescent tubes have a high intensity, but a blue bias, which makes products appear excessively green.

G. Location of reject chutes and conveyors

Removing rejects or segregating products on a table is physically tiring work, and it is important to reduce hand movements to a minimum. For some crops, it has become habitual to throw rejects across the table. Some sorters prefer this design, but it is more energy-efficient to have narrow chutes directly in front of the sorters or immediately beside them. Conveyors installed above the table usually require extra hand movements, and the conveyor can shadow the table, which also hinders sorting.

H. Defect types

The types of defects have significant effects on the optimum operating parameters. Some of the simulated products shown in Table 14.1 could be sorted at very high throughput rates of 5.3 fruits per second (Meyers et al., 1990b), 4.2–5.6 fruits per second (Malcolm and De Garmo, 1953), and 7.0–11.6 fruits per second (Hunter and Yaeger, 1970). These simulated defects tended to be limited to one or two types, and usually were all of similar size. A real sorting operation encounters a wide range of defect types; sorters must make decisions on the severity of each. This additional decision process results in a significant slowing in potential product throughput.

For the examples shown in Table 14.1 typical throughput rates are reported as 2.0 fruits per second (Pasternak et al., 1989), 1.0 fruits per second (Stevens and Gale, 1970) and 1.6 fruits per second (Bollen, 1986b). Malcom and De Garmo (1953) reported throughputs of 3.7–4.5 fruits per second for actual defects on lemons, oranges and potatoes. The reported trial run time was only 1–2 minutes, and sorters may be able to sustain these levels of activity for short periods.

III. Analysis of sorting operations

To analyze a sorting operation, it is necessary to establish parameters, such as efficiency or accuracy, which may be useful for comparing performance under different conditions. Because of the complexity of sorting, no standard analysis has been established. Simple measures of sorter accuracy have been quoted by many investigators. Often these are called sorting efficiencies. However, they generally relate only to the ability of the sorter to detect and remove a particular product, and are not related to product throughput. Stevens and Gale (1970) discussed inspection efficiency in terms of the proportion of sorting errors in an observed product flow. Malcolm and DeGarmo (1953) defined their inspection efficiency as the proportion of defective product that was removed from a determined quantity of incoming defects.

When analyzing an automated or manual sorting operation, the information directly available includes the throughput, the rate of removal of product, the proportion of defects removed, and the proportion of good fruit removed with the rejects. Sometimes a breakdown by defect type is also possible. This information has been used by various investigators to predict the performance of operations, to provide sorting system design information, and to provide operational information and management tools.

When using a systems approach to postharvest handling, it is useful to be able to predict how a particular operation might function under various conditions. It may be necessary, for example, to predict productivity and staffing levels for various throughput or quality conditions. Many attempts have been made to analyze and describe the sorting operation mathematically; some of these models can be useful in systems analysis.

A. Sorting performance

Sorting performance may be described primarily as a throughput variable, for example, (fruit per second) per sorter, as shown in Table 14.1, or (kilograms per sorter) per hour. Often throughput is correlated with the level of incoming defects, and decreases as some function of increasing defect level. The sorter throughput parameter does not describe the sorter accuracy, and assumes that a prescribed pack out quality and an allowable level of good fruit in the reject flow are being maintained.

Peleg (1985) presents several quality criteria indices to describe the performance of the sorting operation. His description of sorting includes both a sorting accuracy and a product throughput variable. The efficiency is defined as:

$$E_i = \sum (P_{gi,} G_i / P_i Q) \tag{14.1}$$

for i separate quality grades, where E is efficiency, Q is throughput rate of incoming product, G_i is outflow rate sorted into the i^{th} grade, P_i is the proportion of i in the total incoming product flow Q and P_{gi} is the proportion of i in the outflowing grade $G_{i.}$ The most generalized definition includes weighting for the relative monetary value of the different grades of product. The weighted sorting efficiency for an entire operation is defined as:

$$E_w = \sum (P_{gi} G_i / P_i Q) W_i \tag{14.2}$$

where the weighting function is:

$$W_i = K_i P_i / \sum \ (K_i P_i) \tag{14.3}$$

and K_i is the cost fraction of grade i (must be $= \leq 1.0$). In a simple sorting operation, in which the product is either packed or discarded ($i = 1{,}2$; $K_i = 1,\ K_2 = 0$), Equation 14.2 is reduced to:

$$E_w = P_{g1} G_1 / P_1 Q \tag{14.4}$$

The weighted efficiency E_w is equal to the probability of a correctly sorted product being placed in the correct grade of outflowing product.

B. Empirical models

The advantage of developing a model of the sorting operation is the ability to fit a mathematical relationship to some observed or experimental data, and then predict outcomes from other situations (Portiek and Saedt, 1974). In the systems approach it is useful to be able to simulate and evaluate the impacts of different scenarios on whole supply chains.

By examining the condition of a sorting process a one moment, it can be seen that a certain amount of work must be input to achieve a reduction in the quantity of defective product. From studies on the sorting of citrus fruit (Lidror et al., 1978), the following relationship was developed:

$$-kdP_p = P_q dt \qquad (14.5)$$

where t is the sorting work input in terms of inspection time (minutes per 1000 fruit), k is a constant factor that is a function of product type, P_p is the proportion of defective fruit in the product outflow and P_q is the proportion of defective fruit in the incoming product flow. The solution to the equation, which was correlated highly in over 300 experiments, was:

$$t = k\ (P_q - P_p)/P_q \qquad (14.6)$$

with $k = 18$ for citrus. A similar expression is defined by Groocock (1986) as inspection effectiveness for industrial quality management.

In another study on the sorting performance of oranges, Pasternak et al. (1989) determined that the process was described effectively by:

$$P_p = P_q \mathrm{A}_e{}^{-\mathrm{B}t} \qquad (14.7)$$

where A and B are constants that are a function of defect type.

Significant differences were noted between sorting slight defects and sorting severe ones. The model was developed using two sets of constants:

A = 0.86 and B = 0.027 for slight defects,

A = 0.76 and B = 0.078 for severe defects.

These values were determined using a sorting system considered to be operating under optimum sorting conditions. Similar relationships could be established for other sorting operations. Different values of the constants A and B can be generated easily using curve-fitting techniques with observed sorting data. Equation 14.7 can be used in a systems analysis to predict the quantity of defective fruit that will pass on to the packing operation, for a given input defect level and sorting rate. However, this equation does not take into account the quantity of good quality fruit rejected.

C. Signal detection theory

Signal detection theory (SDT) was developed to quantify the effectiveness of systems used for detecting communications signals from background noise (reviewed by Egan, 1975). This has a direct analog with manual and automated image processing-based sorting applications. The ability to detect a signal has been described by two non-dimensional parameters, d' and β. The first parameter gives a measure of the detectability of the signal, and the second represents the criterion (bias) used to identify the signal. SDT was applied in psychology experiments to determine human ability to distinguish a visual signal from a background visual noise (Tanner and Swets, 1954). SDT has numerous applications to visual and other sensory perceptions, to vigilance and to various industrial inspection tasks (Jaraiedi et al., 1986).

The manual sorting operation is analogous to situations in psychology and psychophysics, and SDT is a useful analysis tool for fruit and vegetable sorting operations (Prussia, 1991). Psychology and manual sorting analysts have retained the original communications terminology (Green and Swets, 1966). When attempting to detect a signal, there are two possibilities: a signal-plus-noise stimulus (SN) and a noise-with-no-signal stimulus (N). The two possible responses to a stimulus, "yes" and "no," indicate the observer's belief, or algorithm estimate, that the signal is present or absent. That either response may be in error is always a possibility.

For the general sorting operation, a flow of product passes in front of the sorter, who removes the defective product; the good product is conveyed to the packing area. In automated sorting, defective produce is directed to a reject drop. The incoming mixture of both good and defective product is considered SN; the good product is considered N. The ability of the sorter (or algorithm) to make "yes" and "no" decisions correctly is influenced by the physical parameters of the operation, for example, speed, rotation, fruit density, number of defective fruit, types of defects and lighting. Decisions for manual sorting are also influenced by psychophysical factors, such as sorter sensitivity to perceptual stimulus, sorter alertness and sorter motivation to give one response or the other. A major contribution of SDT is the ability to separate the physical conditions from the psychophysical influences, or the physical from the algorithm performance.

The conditional probability of responding "yes" when a signal is present is termed the hit rate, p(Hit) or p(H), and is calculated by dividing the number of hits by the total number of defective items in the batch sorted. The conditional probability of responding "yes" when a signal is not present is termed the false alarm rate, p(False Alarm) or p(FA), and is calculated by dividing the number of good items that were removed by the total number of good items sorted.

A third possibility is the conditional probability of responding "no" when a signal is present, which is called a p(Miss) or p(M), and is calculated by dividing the number of defective items incorrectly packed by the number of defective items in the batch sorted. The last conditional probability is that of responding "no" when a signal is not present, which is called p(Correct Rejection) or p(CR), and is calculated by dividing the number of good items packed by the total number of good items sorted. For this chapter, the traditional terminology for p(CR) is called p(Correct

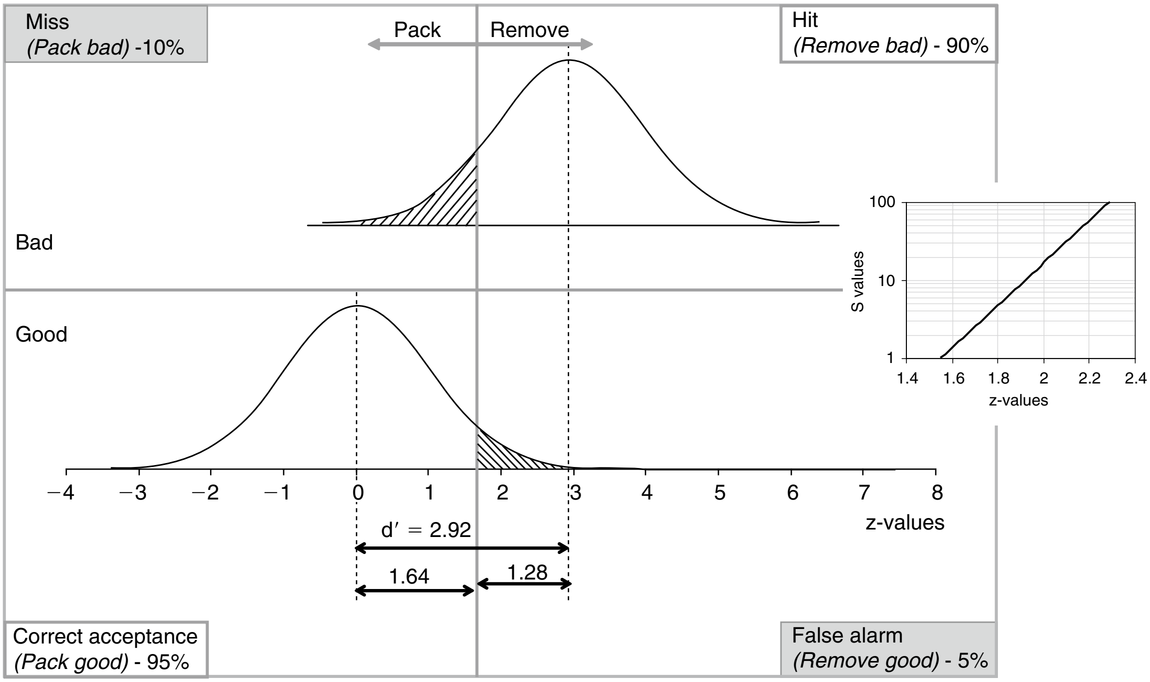

Figure 14.3 Probability distributions for "noise-with-no-signal" (N or good) and "signal-plus-noise" (SN or bad).

Acceptance) or *p*(CA) to better reflect the sorting response of correctly accepting good items for packing.

Since the probabilities are conditional, all four possibilities can be described using only two probabilities, since $p(\mathrm{M}) = 1.0 - p(\mathrm{H})$ and $p(\mathrm{CA}) = 1.0 - p(\mathrm{FA})$. All four responses to the SN and N stimuli are shown graphically in Figure 14.3 where the SN distribution is labeled "Bad" and the N distribution is labeled "Good". Conventional SDT techniques assume that the SN or Bad and N or Good probabilities are distributed normally and are of equal variance as shown in Figure 14.3. The curves are frequency distributions for the intensity of the signal, not for the number of bad items.

The quadrants in Figure 14.3 are defined by the distribution from bad items above the bold horizontal line, and the distribution from good items below the line. The bold vertical line separates the items on the left that are packed, and the ones on the right that are removed. Above the line, the missed items are bad items that get packed, and hits are bad items that are removed. Below the line, the correct acceptance items are good items that are packed, and the false alarms are good items that are removed.

For a particular system in which the physical and operational parameters and the product characteristics do not change, the bad and good distributions do not change. The difference between the normal deviations of the means is described by the parameter d′, the detectability (Freeman, 1973), where z is the standard deviation value or z-value for a normal variate. The relative value of d′ is also important. The easier the detection of defects, the further apart the two distributions will be, and the higher d′ will be. A sorting table or sorting set-up with a higher d′ indicates that the system has the potential to detect and remove more of the defects than those with a lower d′.

An equation for calculating d′ can be determined from the example shown in Figure 14.3 by finding the z-value distances from the mean for the good distribution to the mean for the bad distribution. The example distance of 1.64 from the mean for the good distribution (z = 0) to the vertical set point line (described later) is the z-value for a correct acceptance rate of 95%, which represents the shaded area under the good distribution to the left of the set point. The remaining distance, shown in Figure 14.3 as 1.28, is the distance from the mean for the bad distribution to the set point, and is the z-value for a miss rate of 10% which represents the shaded area under the bad distribution to the left of the set point.

The equation for d′ is the addition of the two distances from the set point line to the means of the two distributions, or the separation of the two distribution means. However, the distance from the mean for the bad distribution must be subtracted, because it is in the opposite direction from the distance from the mean of the good distribution to the set point line. The resulting equation is:

$$d' = z(p(CA)) - z(p(M)) \tag{14.8}$$

Equation 14.8 differs from previously published equations for detectability that show the term $z(p(H))$ subtracted from $z(p(FA))$. The same numerical values result from both equations, because the terms are complements of each other. The terms in Equation 14.8 are used because they represent the physical realities for the distances and areas shown in Figure 14.3. The terms in Equation 14.8 also relate to the economics of the sorting operation. It is important to maximize the number of good items packed, p(CA), and to minimize the number of the bad ones packed, p(M).

The detection performance at a sorting situation may be evaluated visually by using a graph called the receiver operating characteristic (ROC) graph (Figure 14.4), on which p(H) is plotted against p(FA). In manual sorting, p(H) and p(FA) may be varied in some manner, for example, by varying the instructions to the sorters or by adopting some incentive payment scheme. In automated sorting this would be achieved by varying algorithms or algorithm parameters. By varying p(H) and p(FA), it is possible to generate any number of points on an ROC curve that all have the same value for d'. Since the physical parameters of the system (such as speed or rotation) have been unchanged, this curve is characteristic of that operation, which is shown as a unique d' curve for each set of physical conditions. Each sorting system has a curve for each value of p(H) and the corresponding p(FA); these thus are characterized by a detectability curve. The power of SDT is that, after one pair of p(H) and p(FA) values has been determined, it is possible to generate the complete curve.

The second useful descriptor for SDT theory is the criterion likelihood ratio or bias, β, which represents the probability that a decision was based on SN stimuli relative to the probability that the decision was based on N stimuli. For this chapter we

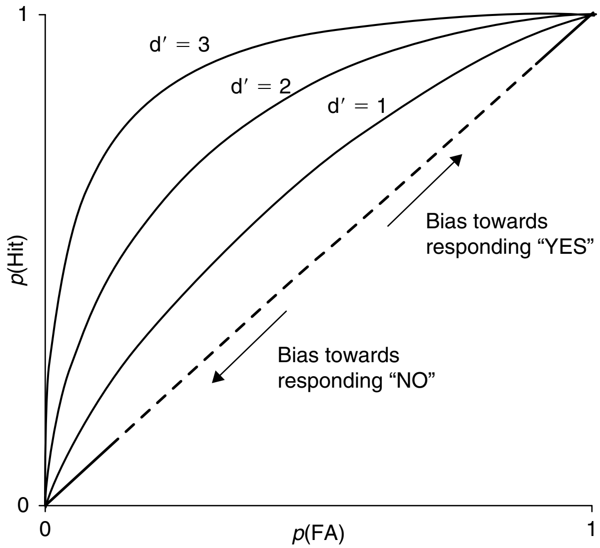

Figure 14.4 Typical receiver operating characteristic plot showing relationships between *p*(hit) and *p*(false alarm) as a family of detectability curves, *d*′.

use the term "set point" to emphasize the purposeful decisions of human sorters and the mechanical or electronic settings established on automated sorting equipment.

The ratio of the two normal density functions simplifies to Equation 14.9 (from Egan, 1975) after changing the *p*(FA) to *p*(CA) and the *p*(Hit) to *p*(M) as required to represent the physical reality in Figure 14.3. The same numeric values result as for previously published equations, because false alarm and correct acceptance rates and hit and miss rates are complements of each other:

$$S = exp\{0.5[z(p(CA))]^2\}/exp\{0.5[z(p(M))]^2\} \quad (14.9)$$

The physical representation of the set point, S, is a description of the cut-off position for an algorithm or that which a sorter sets in his or her own mind. Changes in the set point can be visualized in Figure 14.3 by considering the changes resulting in the four conditional probabilities as the vertical line is moved to the right or left.

The value for S is 1.0 when the distance from the mean for the good distribution to the set point is equal to the distance from the mean for the bad distribution to the set point. At S = 1.0 the numerator and denominator are equal, and the shaded area representing the false alarm rate is equal to the shaded area representing the miss rate (for example when CA = 92.8 and M = 7.2). When S = 1 the values for *z*(CA) and *z*(M) both equal half the value for *d*′.

As the set point moves to the right the values for S become greater than 1.0 because *z*(CA) increases, making the numerator in Equation 14.9 larger. Meanwhile, the denominator in Equation 14.9 decreases as the set point moves toward the mean for the bad distribution. Likewise, the value for S is less than 1.0 as the set point moves to the left of the point where the FA rate is equal to the miss rate.

Any stimulus above this set point is called a signal, regardless of whether it is SN or only N. The set point, S, may be varied by the sorter, and a deliberate change in S results in differing hit and false alarm rates for an otherwise constant sorting system (no change in d'). A low value for S indicates that a considerable amount of N is being accepted as SN, so p(FA) is high. Such a tendency is termed a liberal criterion. A high S implies a low p(FA), and is called a conservative criterion.

Each pair of p(H) and p(FA) has a corresponding d' and S. For a particular system, d' is constant and the values of p(H) and p(FA) will follow this relationship (see relevant lines in Figure 14.4), depending on the value of S. The system parameters, thus, are conveniently separated. The physical description is encapsulated by the value of d' and the psychological factors are described by S. Simulation models using applets are available on the Internet to show interactions of SDT parameters (Bisantz, 1999; Claremont Graduate University, 2005).

In a commercial sorting operations, false alarm rates are normally very low, so it is not possible to generate a full ROC curve through experiments. However, it is necessary to ensure that the theory holds true for the portion of ROC space of interest, as shown in Figure 14.5.

Analyses using SDT highlight the importance of determining both the hit rates and the false alarm rates in the assessment of any sorting operation, which is rarely considered. The resulting detectability and set point values have several useful applications.

Physical design and operational parameters

The detectability, d', can be used to compare the design and operating characteristics of different sorting system set-ups without consideration of sorter bias. For example,

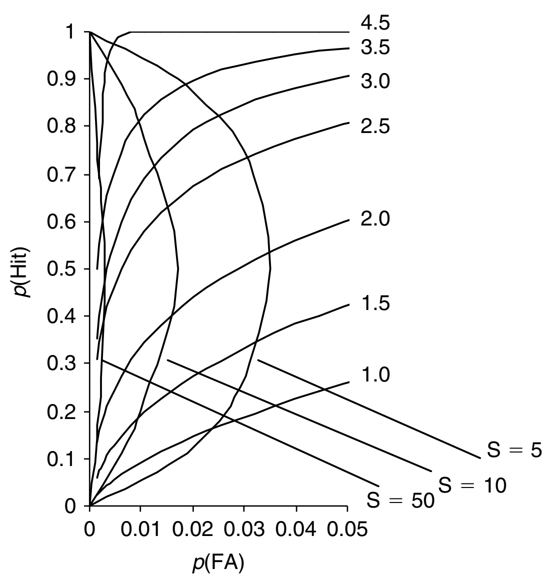

Figure 14.5 Section of receiver operating characteristic space common for sorting operations showing the contour lines for set point, S, superimposed on a family of detectability curves, d'.

fewer false alarms (discarded good items) result when physical changes increase d', and the hit rate, p(H), remains fixed. Operating or design criteria for a particular system also can be optimized by generating d' values using real product for various alterations and modifications.

The advantage of SDT over other techniques of evaluating sorting operations, already discussed, is that d' can be determined by different sorters with products of differing quality in various systems, and still allow comparisons. However, the SDT analysis has some limitations. For example, product quality does have some effect on the sorted behavior, as some defects are easier to identify than others.

Sorter criteria

By calculating S for a sorter, it is possible to determine whether that sorter has a conservative or liberal approach, which could serve as a useful management tool. A conservative approach prevails when the sorters only remove the worst product.

In a commercial operation, the objective is usually to maintain a consistent quality of packed product. If the incoming product quality is poor, it is necessary for the hit rate to be high, whereas if the quality is good, a low hit rate is adequate. The sorters thus are required to vary their own criterion, depending on the incoming quality. Analysis of individual criterion values will determine how effectively each sorter is able to adjust.

Performance of automated sorting

SDT is useful in the analysis of automated sorting systems. As with manual sorting, it is possible to separate out the different aspects of the system. Detectability, d', is generally a measure of the physical design including how well lit the product is, product speed and rotation, camera design and resolution, and number of images captured. The set point, S, is predominantly a measure of the performance of the algorithm. There is some interaction between the two parameters.

Systems analysis

SDT mathematically describes the relationship between hit and false alarm rates. After a value of d' has been determined experimentally, it may be used in a model of the packing house to predict hit and false alarm rates. The analyst also has the ability to use S to vary the behavior of the sorters, and predict the impact of such changes on whole supply chains.

IV. Economics of sorting operations

In many cases, the ability to predict performance of a sorting operation with SDT is useful for management operations on a daily basis. In addition, the usefulness of the model can be extended if it is possible to predict the economic value of potential changes. Models provide a useful tool during planning and design phases, as well as for managing an operation. Economic models are also necessary to evaluate the impact of different sorting scenarios.

One method of optimizing a sorting operation is using the sorting efficiency defined by Peleg (1985), and described by Equation 14.10. Peleg's sorting efficiency requires the proportion of defective product to be known or estimated in both the incoming and the sorted product flows, and monetary values to be assigned to the various grades. The calculated efficiency is weighted according to product value, and allows a comparison of various scenarios. The total value of sorted product, V, is calculated:

$$V = E_w T \nu \tag{14.10}$$

where T is the throughput for sale (e.g. kilogram per hour, ton per season and so forth), E_w is p(CA), and ν is the unit value of the product (e.g. \$ per kilogram, \$ per ton). The returns, represented by total value, can be used in addition to the costs to evaluate various alternatives or can be used as part of a wider system model.

For any marketed product, there will be a payout schedule that is a function of the product amount that is defective. Therefore, the higher the hit rate, the better the returns (Figure 14.6). Every "false alarm" represents a lost item and thus, the value of returns decreases with increasing p(FA).

For a predetermined payment schedule, a payout matrix can be established, as represented in Figure 14.6. The payout must be established for a known incoming fruit quality to specify a hit rate to produce the desired output quality. For example, for

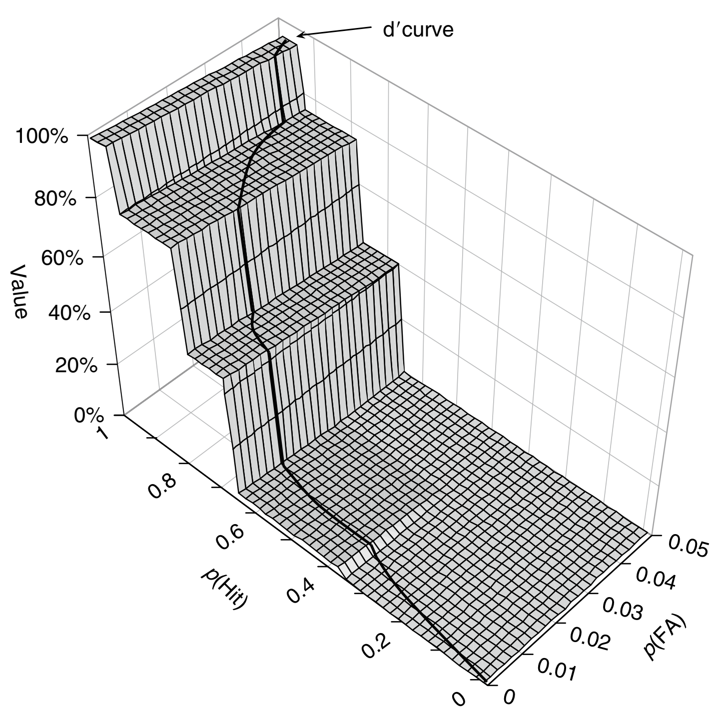

Figure 14.6 Payoff matrix, with receiver operating characteristic plot and d' curve superimposed.

a required output quality of 95% good product, the sorter must maintain a hit rate of 0.53 if 10% defects are incoming, but must have a hit rate of 0.92 if 40% are defects.

If the relationship between p(FA) and p(H) for a particular system is known, or can be determined, this information can be used to determine the relationships between the sorting operation and the returns for product sold, thus combining economic and operational parameters into the same model. The p(H)–p(FA) relationship may be determined from historical data of sorter performance or it may be predicted using SDT.

For the example shown in Figure 14.6, managers might want to know the consequences of advising their sorters to "reduce the number of good fruit in the reject bin" (reduce false alarms) or "reduce the number of defects in the outgoing product" (increase hit rate). If the sorters concentrate on reducing good fruit entering the reject bin (p(FA)), the consequence will be a reduction in the hit rate of defective product; similarly, the consequence of reducing rejects passing into the final pack (p(M)) will be an increase in good fruit entering the reject bin. This situation, as previously discussed, is represented by moving along the d' line shown in Figure 14.6.

If a buyer of quality product pays according to the following schedule:

Grade I	$<$2% defects;
Grade II	$<$10% defects;
Grade III	$<$15% defects;
Grade IV	$<$25% defects;
Will not buy	$>$25% defects;

and the packing house operator has incoming product with 35% defects, then sorters must achieve a hit rate of 0.96 to ensure Grade I product, 0.79 for Grade II, 0.67 for Grade III and 0.38 for Grade IV. Figure 14.6 shows these hit rates.

If the operation is maintaining an average hit rate of 0.8 then, referring to Figure 14.6, "a reduction in the number of good fruit in the reject bin" by lowering p(FA) to 0.015 would result in a reduction of p(H) to below 0.79. The payout schedule cut-off is represented by $p(\mathrm{H}) = 0.79$, therefore, any reduction in the false alarm rate will result in a considerably lower return to the packing house.

The second scenario is to "reduce the number of defects in the outgoing product." If the hit rate was increased to 0.9, the objective would be achieved. However, the increase in p(H) will also result in an increase in false alarms to above 0.02, thus, the return to the packing house will be reduced by the loss of salable fruit. Any changes in the instructions to the sorters will result in a reduction in overall packing house returns in the illustrated situation.

An operator contemplating an upgrade for the system can benefit from applying SDT techniques. The expected performance of some new equipment is an increase in hit rate from 0.82 to 0.95 at a false alarm rate of 0.018. A new d' curve is established for the upgraded system, and represents $p(\mathrm{H}) = 0.92$ and $p(\mathrm{FA}) = 0.02$. Then, if the sorters are suitably instructed, it is possible for the operator to achieve a hit rate of over 0.95 at a false alarm rate of 0.02. The change increases the value of the product and determines whether there is a sufficient return on the capital invested in the upgrade.

V. Summary

This chapter discusses the pivotal importance of the sorting operation to postharvest supply chains. It outlines the approaches researchers have adopted in the past to analyze the operation, and details some of their important recommendations. In addition, the chapter introduces new techniques that are being developed to enable the sorting operation to be described and understood in the context of the overall postharvest supply chains.

Key words
Postharvest, sorting, grading, quality, signal detection theory, supply chain, management.

Bibliography

Aleixos, N., Blasco, J., Navarron, F., Molto, E. (2002). Multispectral inspection of citrus in real-time using machine vision and digital signal processors. Computers and Electronics in Agriculture, 33(2), 121–137.

Bennedsen, B.S., Peterson, D.L., Tabb, A. (2005). Identifying defects in images of rotating apples. Computers and Electronics in Agriculture, 48(2), 92–102.

Bisantz, A.M. (1999). Signal detection theory demonstration. http://www.eng.buffalo.edu/~bisantz/323sdt/sdt_demo.html. Accessed January 2008.

Bollen, A.F. (1986a). Sorting fruit: Systems design and operation. Postharvest Manual. New Zealand Agricultural Engineering Institute/Ministry of Agriculture and Fisheries, Hamilton, New Zealand. Unpublished.

Bollen, A.F. (1986b). How efficient is your packhouse – and its sorting table. N. Z. Kiwifruit, March, 20–21.

Brosnan, T., Sun, D-W. (2002). Inspection and grading of agricultural and food products by computer vision systems: a review. Computers and Electronics in Agriculture, 36(2–3), 193–213.

Claremont Graduate University (2005). d′ as sensitivity. http://wise.cgu.edu/sdtmod/measures4.asp. Accessed January 2008.

Crowe, T.G., Delwiche, M.J. (1996). Real-time defect detection in fruit – part II: An algorithm and performance of a prototype system. Trans. ASAE, 39(6), 2309–2317.

DeGarmo, E.P., Woods, B.M. (1953). Introduction to Engineering Economy. MacMillan, New York.

Dreyfus, H. (1967). Measurement of Man: Human Factors in Design. Whitney Publications, New York, NY, USA.

Egan, J.P. (1975). Signal Detection Theory and ROC Analysis. Academic Press, Orlando, FL, USA.

Freeman, P.R. (1973). Tables of d' and BETA. Cambridge University Press, Cambridge, UK.

Graves, M., Batchelor, B.G. (2003). Machine Vision for the Inspection of Natural Products. Springer-Verlag Inc., New York, NY, USA.

Green, D.M., Swets, J.A. (1966). Signal Detection Theory and Psychophysics. John Wiley & Sons, New York, NY, USA.

Groocock, J.M. (1986). The Chain of Quality, Market Dominance Through Product Superiority (Inspection Effectiveness). John Wiley & Sons, New York, NY, USA.

Guyer, D., Brown, G., Timm, E., Brook, R., Marshall, D. (1994). Lighting systems for fruit and vegetable sorting. Michigan State University, Extension Bulletin, E–2559.

Hunter, J.H., Yaeger, E.C. (1970). Use of a float roll table in potato grading operations. Maine Agricultural Experimental Station, Orono, ME, USA, Bulletin No. 690.

Jahns, G., Moller-Nielsen, H., Paul, W. (2001). Measuring image analysis attributes and modelling fuzzy consumer aspects for tomato quality grading. Computers and Electronics in Agriculture, 31(1), 17–29.

Jaraiedi, M., Toth, G.J., Aghazadeh, F., Herrin, G.D. (1986). Modeling of decision making behavior of inspectors. Trends Ergonomics, III, 351–357.

Kleynen, O., Leemans, V., Destain, M.F. (2005). Development of a multi-spectral vision system for the detection of defects on apples. Food Eng., 60(1), 41–49.

Kusabs, N.J., Trigg, L., Bollen, A.F., Holmes, G. (2006). Objective measurement of mushroom quality relative to industry inspectors. Int. J. Postharvest Technol. and Innov., 1(2).

Leemans, V., Destain, M.F. (2004). A real-time grading method of apples based on features extracted from defects. Food Engineering, 61(1), 83–89.

Leemans, V., Destain, M.F., Magein, H. (2000). Quality fruit grading by colour machine vision: Defect recognition. Acta Hort., 517, 405–412.

Lidror, A., Roll, Y., Siv, S. (1978). Citrus fruit sorting parameters influencing manual work rate. Proc. Int'l. Soc. Citriculture, 20, 115–116.

Luckiesh, M. (1944). Light, Vision, and Seeing. Van Nostrand Reinhold, New York, NY, USA.

Malcolm, D.G., DeGarmo, E.P. (1953). Visual inspection of products for surface characteristics in grading operations. USDA Marketing Research, Report No. 45. U.S. Govt. Printing Office, Washington, DC, USA.

Meyers, J.B. (1988). Improving dynamic visual inspection performance. Masters Thesis, Dept of Agric. and Biol. Eng., University of Georgia, Athens, GA, USA.

Meyers, J.B., Jr., Prussia, S.E., Thai, C.N., Sadosky, T.L., Campbell, D.J. (1990a). Visual inspection of agricultural products moving along sorting conveyors. Trans. ASAE, 33(2), 367–372.

Meyers, J.B., Jr., Prussia, S.E., Karwoski, C.J. (1990b). Signal detection theory for optimizing dynamic visual inspection performance. Appl. Eng. Agric., 6(4), 412–417.

Miller, M.K., Delwiche, M.J. (1989). A color vision system for peach grading. Trans. ASAE, 32(4), 1484–1490.

Miller, W.M., Drouillard, G.P. (2001). Multiple feature analysis for machine vision grading of Florida citrus. Applied Engineering in Agriculture, 17(5), 627–633.

Ngan, P., Penman, D., Bowman, C. (2003). On-line automated visual grading of fruit: practical challenges. In: Machine vision for the inspection of natural products, M. Graves, B. Batchelor (eds). Springer-Verlag Inc., New York, NY, USA, pp. 215–239.

Nicholson, J.V. (1985). Colour and light for the inspection table. SIRTEC Publication No. 1., New Zealand Department of Scientific and Industrial Research, Wellington, New Zealand.

Pasternak, H., Lidror, A., Engel, H. (1989). The effect of the incidence of defect on orange inspection time. Can. Agric. Eng., 31(2), 131–134.

Peleg, K. (1985). Produce Handling, Packaging, and Distribution. AVI, Westport, CT, USA.

Portiek, J.H., Saedt, A.P.H. (1974). An analytic and a descriptive model for the potato sorting process. J. Agr. Eng. Res., 19, 189–198.

Prussia, S.E. (1985). Visually sorting at ergonomically designed workstations. ASAE Paper No. 85–1618. Am. Soc. Agric. Eng., St. Joseph, Michigan.

Prussia, S.E. (1991). Dynamic visual inspection. In: Module 9 of Human Factors, D.L. Roberts, W.I. Becker (eds). Am. Soc. Agric. Eng., St. Joseph, MI, USA.

Prussia, S.E., Meyers, J.B., Jr. (1989). Ergonomics for improving visual inspection at fruit packinghouses. Acta Hort., 258, 357–364.

Rosenberger, C., Emile, B., Laurent, H. (2004). Calibration and quality control of cherries by artificial vision. Journal of Electronic Imaging, 13(3), 539–546.

Shearer, S.A., Payne, F.A. (1990). Color and defect sorting of bell pepper using machine vision. Trans. ASAE, 33(6), 2045–2050.

Stevens, G.N., Gale, G.E. (1970). Investigations into the feasibility of semi-automatic quality inspection of fruit and vegetables. J. Agr. Eng. Res., 15(1), 52–64.

Tadhg, B., Da-Wen, S. (2002). Inspection and grading of agricultural and food products by computer vision systems – a review. Computers and Electronics in Agriculture, 36(2–3), 193–213.

Tadhg, B., Da-Wen, S. (2004). Improving quality inspection of food products by computer vision. Food Eng., 61(1), 3–16.

Tanner, W.P., Swets, J.A. (1954). A decision-making theory of visual detection. Psychol. Rev., 61, 283–288.

Xing, J., De Baerdemaeker, J. (2005). Bruise detection on "Jonagold" apples using hyperspectral imaging. Postharvest Bio. and Technol., 37(2), 152–162.

Yang, Q. (1992). The potential for applying machine vision to defect detection in fruit and vegetable grading. Agr. Eng., 47(3), 74–79.

Zheng, C., Da-Wen, S., Liyun, Z. (2006). Recent developments and applications of image features for food quality evaluation and inspection – a review. Trends in Food Sci. and Technol., 17(12), 642–655.

Zhu, B., Jiang, L., Tao, Y. (2007). Three-dimensional shape enhanced transform for automatic apply stem-end/calyx identification. Optical Eng., 46(1).

15

Non-destructive Evaluation: Detection of External and Internal Attributes Frequently Associated with Quality and Damage

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I. Introduction

While most commercial quality classification systems for fruit and vegetables are based on the external aspect (color, size, absence of blemishes, etc.) there is an increasing interest in also incorporating internal quality attributes. Consumers now demand fruit and vegetables which not only look nice, but also taste good, have an appropriate texture, are free of contaminants and contain sufficient nutritional and health-promoting substances. Until recently, destructive techniques were used to measure these properties. An obvious disadvantage of such techniques is that the fruit is lost after the measurement, so that only quality inspection at the batch, rather than at the individual fruit level, is feasible. However, during the last decade several novel systems have been developed to measure quality attributes non-destructively. Several of them are now commercially available as desktop units or mounted on a grading line, so that quality control of individual fruit becomes feasible. Additional advantages are the fact that no sample pretreatments are required for non-destructive techniques, the absence of waste after the measurement, and often the measurement speed.

The objective of this chapter is to give an overview of some recent developments in non-destructive quality measurements. We will focus on systems to measure external appearance, internal defects, firmness, taste and aroma.

II. External appearance

The external appearance is the main quality aspect each consumer is confronted with when buying food products. Historically, human perception of the product's appearance has been the main "instrument" to qualify aspects like color, blemishes, gloss, shape and size. The main developments seen in assessing visual quality are related to moving away from subjective qualitative consumer evaluation by developing objective quantitative instrumental techniques. The first step was the introduction of color charts and other reference charts to standardize the evaluation process. The next step was the development of instrumental techniques to replace human vision. An additional benefit of introducing such quantitative instrumental techniques is that the quality attributes can be interpreted as continuous variables, which allows the use of increasingly sophisticated statistical and numerical modeling techniques to analyze and interpret the data (Hertog et al., 2007).

A. Color

The color of any object depends heavily on the nature of its illuminating light source; in the absence of light, as an extreme, color is nonexistent. The properties of color distinguishable by the human eye are hue, saturation and brightness. While spectral colors can be correlated to wavelength one-to-one, the perception of compound light, consisting of multiple wavelengths, is much more complicated. Many different combinations of wavelengths can produce the same color perception.

The color of a food product is the combined result of both its structure, affecting the scattering and reflectance properties of the food, and its pigmentation, affecting the absorption properties of the food. Small structural changes affecting the scattering properties of the food may induce larger changes in color than can be attributed to simple changes in pigment concentrations (Macdougall, 1982).

Trichromatic colorimeters and spectrophotometers are commercially available to take single spot color measurements under standardized lighting conditions expressing color in units of one of the standardized color spaces (ASTM, 2000). The L*a*b* color space or the HCS (hue, chroma, saturation) color spaces are widely used in fruit or vegetable applications. Computer imaging systems have been developed that measure color of the whole product's surface using digital cameras, incorporating possible spatial variation. In this configuration images can be rapidly processed and used for online color sorting systems (Liao et al., 1992; Tao et al., 1995). However, careful calibration is required. Almost all manufacturers of sorting lines now provide online color inspection stations.

B. Blemishes

With the ongoing developments in computer vision, imaging techniques have been developed as an inspection tool for quality assessment of a variety of food products to recognize objects, to measure shape characteristics and to identify external defects. These techniques have been successfully applied to fruit (Abbott et al., 1997; Throop et al., 2005), meat (Swatland, 1995) and poultry (Park et al., 1998), and have also resulted in harvesting systems for fruit production (Kondo et al., 1996; Bulanon et al., 2002; Van Henten et al., 2002). The ongoing development in hardware, going from grayscale cameras to color systems and multispectral or hyperspectral imaging techniques, has further contributed to the development of more sophisticated recognition systems to detect blemishes before they might even become visible to the human eye. Blemishes studied include rots, bruises, flyspecks, scabs and molds, fungal diseases and soil contamination (Mehl et al., 2004). The base for any of these inspection techniques is to take multiple monochromatic images of the food objects at different wavelengths, and to search for those wavelengths at which the blemish of interest shows a characteristic absorption behavior different from the unblemished tissue. By combining data for different wavelengths using multivariate techniques, the detection of blemishes can be further improved.

III. Internal defects

Internal disorders in horticultural products are not revealed by external visual symptoms. Non-destructive and non-invasive monitoring techniques are beneficial to investigate the occurrence and development of internal disorders. Two non-destructive tomographic techniques have been applied for the direct structural and 3-D detection of internal defects in horticultural products: X-ray computed tomography (X-ray CT) and magnetic resonance imaging (MRI). While MRI has recently been shown to be applicable for online detection of internal defects, X-ray CT has the advantage of obtaining very high resolution images of the plant material's cellular and subcellular structure. These two techniques, and how they have been used in the scientific literature, are discussed further. Other methods for internal quality evaluation are reviewed by Butz et al. (2005).

A. Magnetic resonance imaging

^{1}H MRI employs static magnetic fields and radio frequencies in order to obtain images of proton mobility in biological systems. The proper radio frequency will rotate its magnetic moment by 90°. After removal of the radio frequency, energy relaxation results in a signal in the receiver. The energy loss depends on the environment surrounding the nucleus, leading to different but characteristic relaxation times. By applying magnetic field gradients in 3 directions, 2- and 3-dimensional images can be created (Butz et al., 2005). Basically, the signal comes from the aqueous fraction in the sample and is, therefore, mainly used to measure water content and profiles in products non-destructively (Nguyen et al., 2006).

MRI has been applied for the detection of core breakdown in Bartlett pears (Wang and Wang, 1989), the detection of void spaces, worm damage and bruises in fruit (Chen et al., 1989), quantitative NMR imaging of kiwifruit during growth and ripening (Clark et al., 1998a), the study of watercore dissipation in Braeburn and Fuji apples (Clark et al., 1998b; Clark and Richardson, 1999), the study of watercore and its distribution in Red Delicious apples (Wang et al., 1988) and woolly breakdown in nectarines (Sonego et al., 1995). Gonzalez et al. (2001) and Clark and Burmeister (1999) studied the progression of internal browning in Fuji and Braeburn apples, respectively, stored under disorder-inducing conditions. Lammertyn et al. (2003a,b) and Hernandez-Sanchez et al. (2007) used MRI to study browning and core breakdown in pear. Core breakdown in Conference pears is a storage disorder which is characterized by brown discoloration of the tissue and development of cavities, and which cannot be detected by the consumer from the external appearance at the time of purchase. MRI was able to differentiate between unaffected tissue, brown tissue and cavities (Figure 15.1). The area percentage brown tissue per slice increased with the diameter of the pear, but was systematically underestimated by 6%, compared to the actual slices (Lammertyn et al., 2003b). The area percentage cavity corresponded very well to the actual amount. At the macroscopic level, fast low angle shot MR images were acquired for pears on a sorting line, and discriminated for internal breakdown according to histogram characteristics (Hernandez-Sanchez et al., 2007). Up to 96% of pears were correctly classified.

B. X-ray computed tomography

X-ray tomography is based on X-ray radiography. An X-ray beam is radiated towards the sample and the transmitted beam is recorded by a detector. The level of transmission of these rays depends mainly on the mass density and mass absorption coefficient of the material (Maire et al., 2001; Salvo et al., 2003). The resulting image is superimposed information (projection) of a volume in a 2-D plane. The classical way

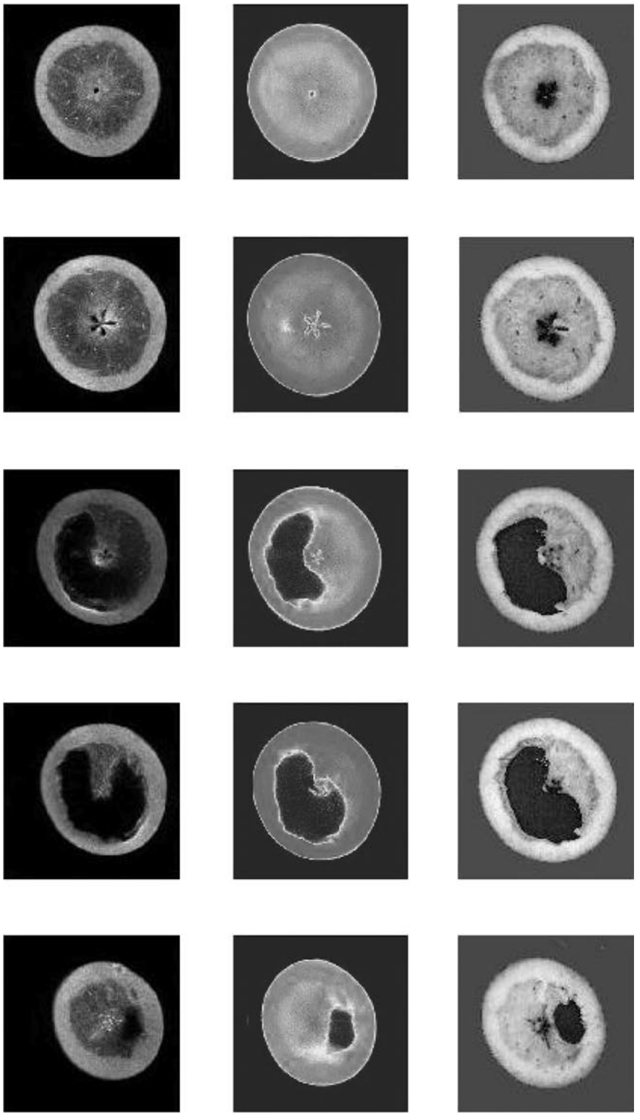

Figure 15.1 Comparative overview of the corresponding X-ray CT scans (left), MRI images (middle) and actual photographs (right) of core breakdown of pear tissue. Sound tissue, brown tissue and cavities are light gray, dark gray and black in the CT scans, and light orange, dark orange and blue in the MRI scans, respectively. There is a good correspondence between the different images. Source: Lammertyn et al. (2003b), reproduced with permission from Elsevier Science Ltd.

to get 3-D information is to perform a large number of radiographs, while rotating the sample between 0° and 180°. The filtered back-projection algorithm can then be used to reconstruct the volume of the sample from these radiographs (Herman, 1980). X-ray CT allows visualization and analysis of the architecture of cellular plant materials with a resolution down to a few micrometers, and without sample preparation or chemical fixation (van Dalen et al., 2003; Maire et al., 2003; Lim and Barigou, 2004; Mendoza et al., 2007). X-rays are shortwave radiations which can penetrate through plant tissue. Due to the high moisture content in fruit and vegetables, water dominates X-ray absorption. Defects that affect the density and the water content can therefore be visualized by X-ray imaging. Compared to 2-D radiography used in medicine and linescan radiography applied on grading machines, X-ray computer tomography (CT) is the most powerful technique from the horticultural research point of view, since two and three dimensional images can be reconstructed from the accumulated data to study internal physical and physiological processes. Generally, there are different sources to perform X-ray tomography. The first one uses the divergent beam produced by a microfocus X-ray tube, and the second one uses synchrotron radiation (Salvo et al., 2003).

Most internal disorders, such as woolliness in nectarines, hollow heart in potato, watercore in apples and spongy tissue in mango, affect the density and water content of the internal tissue and hence, are detectable by means of X-ray measurements (Brecht et al., 1991; Tollner et al., 1992; Thomas et al., 1993; Sonego et al., 1995; Schatzki et al., 1997; Barcelon et al., 1999). Lammertyn et al. (2003a,b) used X-ray CT to study the development of core breakdown disorder in Conference pears (Pyrus communis cv. Conference). After image processing of X-ray tomography slices of pears (Figure 15.1, left series of images), it was possible to measure the breakdown development non-destructively (in terms of area percentage of affected and unaffected tissue, as well as the cavity and core area per slice) during storage measured on actual slices (Figure 15.1, right series of images) with an underestimation of 12%. MRI was proposed as a better method to follow core breakdown during postharvest storage (Figure 15.1, middle series of images) (Lammertyn et al., 2003b). The advantage of X-ray CT is, however, its better resolution over MRI. Recently, as the resolution of the method is constantly improving, X-ray CT has been applied to study the fine structures of horticultural products at the scale of only a few microns (Kuroki et al., 2004; Mendoza et al., 2007). For *in vivo* observations, high resolution submicron tomography has so far only been achieved on relatively dry or hard biological samples, such as plant seeds (Stuppy et al., 2003; Cloetens et al., 2006). It is expected to be applicable also to moist plant materials, such as fruits and vegetables.

IV. Firmness

Firmness is traditionally measured by means of a Magness–Taylor (MT) penetrometer. The penetrometer test simulates the mastication of fruit tissue in the mouth, and the MT firmness incorporates several mechanical properties, including the elastic, shear and rupture properties of the fruit tissue. The test is to some extent sensitive to the operator, and the MT firmness may be position-dependent. The search for an alternative non-destructive firmness procedure for horticultural products has resulted in several techniques which allow use of the same principles under laboratory and online conditions (De Ketelaere et al., 2003). Sensors based on low-mass impact and acoustic impulse response are among the different technologies developed, and are commercially available and most widely used. These are briefly discussed below.

A. Impact analysis

Impact analysis is a simple and quick method for determining local fruit properties. De Baerdemaeker et al. (1982) and Rohrbach et al. (1982) attempted to use either time domain or frequency domain characteristics of the impact force as a firmness indicator for a wide variety of fruits and vegetables. Nahir et al. (1986) reported that the characteristics of the impact response of dropping tomatoes on a rigid surface are highly correlated with both fruit weight and fruit firmness. Delwiche et al. (1987) found that impact characteristics derived from the time signal of peaches striking a rigid surface were highly correlated with the elastic modulus and penetrometer values of the fruit. A problem inherent in this technique is the fact that impact characteristics are highly dependent on the mass and radius of curvature of the fruit. A large variation in these parameters affects the accuracy of the technique. A different approach was suggested by Chen et al. (1985) who impacted the fruits with a small spherical impactor of known mass and radius of curvature. The deceleration of the impactor was related to fruit firmness (Chen et al., 1985; Chen and Ruiz-Altisent, 1996; Garcia-Ramos et al., 2003). The advantage of this technique is that the impact response is independent of the fruit mass, and less sensitive to its radius of curvature. The technique was further investigated by Jaren et al. (1992) and Correa et al. (1992) for different fruit. Ruiz-Altisent et al. (1993) used the impact device to sort apples, pears and avocados, while Molto et al. (1996) used maximum impact force as criterion for sorting oranges, mandarins and peaches. De Ketelaere et al. (2001, 2006a) used this technique to analyze apples and tomatoes, and compared their results to acoustic measurements that are discussed below.

B. Acoustic impulse response measurements

The analysis of the acoustic fruit response to mechanical impulse in the frequency domain detects internal properties of the whole fruit, including firmness (Abbott et al., 1968; Finney and Norris, 1968; Cooke, 1972; Shmulevich et al., 1996; De Ketelaere et al., 2001, 2006b). Excitation of the fruit can be performed by a shaker (Peleg, 1993) or by impact excitation (Schotte et al., 1999). The fruit's response can be captured by an accelerometer (Peleg, 1993), a piezoelectric sensor (Galili et al., 1993) or a microphone (De Ketelaere et al., 2004). A computer which is hooked up to the transducer derives the frequency response spectrum from the time domain signal by means of a fast Fourier transform. A firmness index $F = f^2m^{2/3}$ is typically calculated, where f is the first resonance frequency (in Hertz) and m is the mass of the fruit (in kilograms) (Schotte et al., 1999).

The resonant frequencies and dynamic behavior of simply shaped objects (sphere, axisymmetric spheroid) are well-understood, and several studies have been carried out on various kinds of near-spherical agricultural objects, such as apples (Chen and De Baerdemaeker, 1993), peaches (Verstreken and De Baerdemaeker, 1994), melons (Chen et al., 1996) and tomatoes (Langenakens et al., 1997). However, if the fruit shape is far from spherical, as in pears, Jancsók et al. (2001) have shown that an adapted firmness index which also includes a measure of shape S (e.g. the length/diameter ratio) is more appropriate:

$$F = \frac{1}{aS + b} f^2 m^{2/3}$$

where a and b are constants. As the authors only considered Conference pears, it is not clear whether the constants a and b depend on the species/cultivar.

As the firmness index is related to the elastic properties of the fruit only, it is fundamentally different from the MT firmness. This is illustrated in Figure 15.2, where the firmness index of tomato is shown versus the compression force and the MT firmness (Hertog et al., 2004). As the compression force (force required to compress the tomato fruit over a well-defined distance) essentially measures the elastic properties, a relatively good relationship with the firmness index was obtained (Figure 15.2a). On the other hand, a poor relationship was obtained between firmness index and MT firmness (Figure 15.2b). Shmulevich et al. (2003) compared a Magness–Taylor device, a commercially available low mass impact device and an acoustic device for apple firmness evaluation. They found that the correlation between low mass impact and acoustic firmness sensing was reasonably high (r = 0.83–0.93), while correlations with Magness–Taylor were low (r = 0.43–0.60). Golding et al. (2005) also reported moderate correlations between Magness–Taylor and non-destructive sensor technologies (r = 0.62 for an acoustic sensor and 0.82 for a low mass impact sensor). Similar conclusions were drawn by Valero and Crisosto (2004).

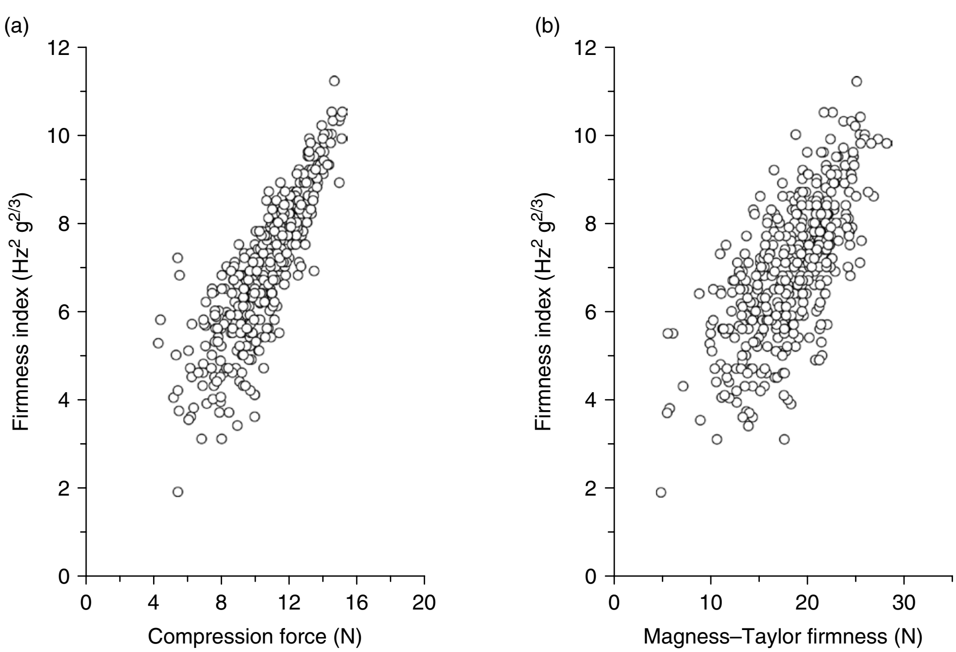

Figure 15.2 Firmness index versus compression force (a) and Magness–Taylor firmness (b) for tomato fruit. Data from: Hertog et al. (2004).

De Ketelaere et al. (2006a) compared a commercial low mass impact sensor to a commercial acoustic sensor, and reported that the acoustic sensor is preferable for firm products, while for soft products the low mass impact sensor has advantages. It is believed that this lack of documentation about the comparison of techniques, together with the different physical backgrounds and related units, are the main reasons obstructing the rapid adoption of non-destructive firmness sensors in industry and among postharvest researchers.

In conclusion, with the commercial availability of these non-destructive sensors nowadays, and the proof of their ability to sense firmness and firmness changes of fruit with very different properties, time might have come to consider these non-destructive techniques as new standards for fruit firmness evaluation, replacing the older destructive standard. However, in order to overcome the issues of comparison of technologies, there is a clear need for standardization of non-destructive firmness sensing of fruit and vegetables (De Ketelaere et al., 2006a).

V. Taste components

Taste is defined as the sensation perceived through the tongue when exposed to certain classes of chemicals. Receptors have been identified for at least five taste attributes: sweet, acid, salt, bitter and umami. The latter attribute represents “savoriness” which is related to the presence of glutamates. While in fruit sweetness and acidity are the most important taste attributes, in vegetables other attributes may also be important.

Taste attributes are typically measured through refractometry (sweetness), titration (acidity), HPLC (bitter and umami components) and atomic absorption (salts). These techniques all require destructive sampling. Non-destructive techniques for taste components are often based on the interaction of fruit or vegetable tissue with near-infrared (NIR) radiation (wavelength range from 780 to 2500 nm).

A. Near-infrared spectroscopy

In NIR spectroscopy the fruit or vegetable is irradiated with near-infrared light, and the reflected or transmitted radiation is measured at a single or multiple spots on the surface of the fruit. While the radiation penetrates the fruit, its spectral characteristics change through wavelength-dependent reflection, scattering and absorption processes. This change depends on the chemical composition of the fruit, including its sugar and acid content, as well as its light scattering properties, which are related to its microstructure and hence, texture. Some typical near-infrared reflectance spectra of different fruit species are shown in Figure 15.3. The near-infrared spectrum of fruit and vegetables is dominated by the absorption bands of water and therefore, advanced multivariate statistical techniques, such as partial least squares regression, are required to extract the required information from the usually convoluted spectra (Nicolaï et al., 2007a).

The penetration depth of NIR radiation in fruit or vegetable tissue is limited. Lammertyn et al. (2000) found a penetration depth of up to 4 mm in the 700–900 nm range and between 2 and 3 mm in the 900–1900 nm range for apple. In a different

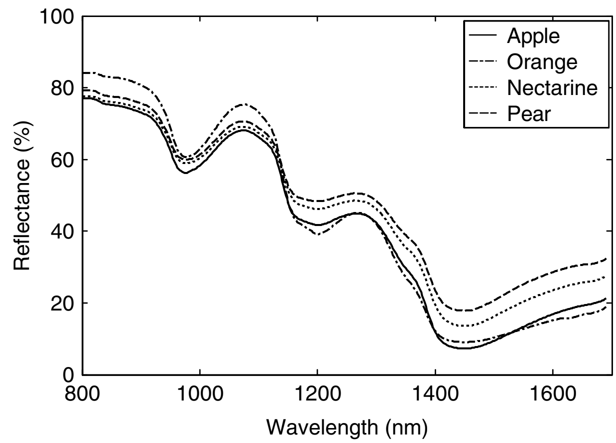

Figure 15.3 Typical NIR reflectance spectra of some fruit. The NIR reflectance spectra were recorded using a Corona 45 VIS/NIR diode array spectrophotometer (Carl Zeiss Jena Gmbh, Jena, Germany). From: Nicolaï et al. (2007), reproduced with permission from Elsevier Ltd.

optical configuration, Fraser et al. (2001) showed that the penetration depth in apple in the 700–900 nm range was at least 25 mm, while it became less than 1 mm in the 1400–1600 nm range. The limited penetration depth decreases the accuracy of NIR-based measurements of internal quality attributes of thick-skinned fruit such as citrus. Transmission measurements, on the other hand, need very high light intensities which can easily burn the fruit surface and alter its spectral properties.

A drawback of NIR spectroscopy is that, for each fruit species and cultivar, a new calibration model is required, which should be based on large datasets incorporating different orchards, seasons, cultivation systems, etc. (Peirs et al., 2003b). The prediction accuracy also depends on temperature (Peirs et al., 2003a). Finally, the calibration models depend on the spectrophotometer, so that model transfer, even between different spectrophotometers of the same brand and type, is not straightforward.

NIR spectroscopy has been used to measure the SSC of various fruit, including apple (Lammertyn et al., 1998), apricot (Carlini et al., 2000), cherry (Lu, 2001), kiwifruit (McGlone and Kawano, 1998), mandarin (Kawano et al., 1993), melon (Guthrie et al., 1998) and peach (Slaughter, 1995). The root mean squared error of prediction (RMSEP) is typically 0.5–1.0°Brix. Acidity in fruit is much more difficult to measure by means of NIR spectroscopy, although some reports have been published in which a reasonable accuracy was obtained (e.g. Peirs et al., 2002). Mehinagic et al. (2004) developed a calibration model to predict sensory attributes of apple directly from NIR reflectance spectra. A full account of NIR applications in fruit and vegetables is given by Nicolaï et al. (2007a).

Fruit grading lines equipped with NIR sensing devices are now commercially available from Aweta (IQA, www.aweta.nl), Greefa (iFA, www.greefa.nl), Mitsui-Kinzoku (www.mitsui-kinzoku.co.jp), Sacmi (F5, www.sacmi.it), TasteMark (www.taste-technologies.com) and others.

B. Multi- and hyperspectral imaging systems

Most applications of NIR spectroscopy which are described in the literature essentially rely on spot measurements. Peiris et al. (1999) however, observed a circumferential variation of up to 2% Brix for the SSC in a variety of fruit; the radial and proximal to distal variation was even larger. Several authors have therefore used multispectral (a few wavelengths) or hyperspectral (a continuous range of wavelengths) imaging systems to inspect the surface, rather than only a single spot on the fruit. In such systems (e.g. Martinsen and Schaare, 1998) lines of spatial information with a full spectral range per spatial pixel are captured sequentially, to complete a volume of spatial–spectral data. This is usually achieved by means of a spectrograph, which disperses an incoming line of radiation into a spectral and spatial matrix which is captured by the camera. The horizontal and vertical pixels on the camera capture spatial and spectral information, respectively. Such a system hence, provides full spectral information at every spatial position. The object must be moved step-wise under the camera by means of an actuator, while at each step a line is scanned, but this is not necessarily a disadvantage when the system is mounted on a grading line on which the fruit is physically transported anyway. Novel developments include focal plane array cameras, in combination with liquid crystal tunable filters (LCTF), acousto-optical tunable filters (AOTF) or other monochromatic principles which allow for much quicker acquisition speeds (Bearman and Levenson, 2001). Multi- and hyperspectral systems have been used to visualize the SSC distribution in kiwifruit (Martinsen and Schaare, 1998) and melons (Sugiyama, 1999; Long and Walsh, 2006).

C. Spatially and time-resolved spectroscopy

A typical reflectance or transmittance spectrum of fruit contains information about absorption, as well as scattering properties. Absorption is related to the presence of chemical components, while scattering is related to the microstructure and hence, the texture of the tissue. Several authors have attempted to develop techniques to measure absorption and scattering properties separately (Tu et al., 1995, 2000; McGlone et al., 1997). In spatially-resolved reflectance spectroscopy the fruit is irradiated with a light beam. Because of local scattering the reflected spot is actually larger than the cross section of the light beam. Lu (2004) used broadband light in the range 688–940 nm, and related some features of the reflected spot to firmness and soluble solids content of apple. He obtained a standard error of prediction (SEP) of about 6 N for Magness–Taylor firmness (Lu, 2004), and 0.78% Brix for the soluble solids content (SSC). In time-domain reflectance spectroscopy, series of very short (pico or femto second) NIR light pulses are pumped into the fruit, using a tunable laser or a solid-state laser array (Cubeddu et al., 2001). The detector is positioned at some distance from the light entry point. Depending on the scattering properties of the tissue, the photons may follow a complicated path in the tissue, and it may take more or less time to reach the detector. As a result, the detector will measure a photon time of flight distribution from which, based on light diffusion theory, the absorption and scattering coefficient as a function of wavelength can be measured. These coefficient spectra can then be correlated to internal quality attributes. By comparing classical

NIR reflectance measurements of pear with the corresponding absorption and scattering coefficient spectra obtained through TRS, Nicolaï et al. (2007a) showed that NIR reflectance is, in fact, dominated by scattering, which does not change much with wavelength. So far the obtained correlations between absorption and scattering spectra and quality attributes such as SSC or firmness have been low (Valero et al., 2004) to non-existent (Nicolaï et al., 2007b), most probably due to instrument drift or the limited wavelength range ($\leq$1030 nm) considered in the experiments. More research is required in this area.

VI. Aroma

Aroma analysis is traditionally done by means of gas chromatography-mass spectrometry (GC-MS). In this technique the headspace of the product is first sampled, either directly using a gas syringe or via a concentration technique, such as purge and trap or solid-phase microextraction (SPME). The latter technique, in particular, has become very popular because it is simple, cheap and relatively straightforward to automate. After injection in the GC, the headspace is separated into its different volatile components. For identification purposes, every eluting component is transferred to a mass spectrometer where it is fragmented into a mass spectrum. The component can then be identified through a mass spectrum library search. While GCMS remains the standard aroma analysis technique to date, it requires skilled personnel, and the analysis time is too long for routine fruit aroma analyses.

A. Headspace fingerprinting mass spectrometry (HFMS)

Unlike in normal GCMS, in headspace fingerprinting mass spectrometry (HFMS) the headspace of a sample is injected directly into the ionization chamber of a mass spectrometer, without prior chromatographic separation (Shiers et al., 1999). This is typically implemented by means of a short capillary column which is operated at an elevated temperature so that a broad, featureless peak is obtained. The spectrum resulting from simultaneous ionization and fragmentation of the mixture of molecules introduced can be considered as a fingerprint of the actual aroma. Typically vials with juice are loaded into an autosampling system equipped with an SPME injector. While the technique is much faster than traditional GCMS – samples can be analyzed every 2–5 minutes, depending on the headspace equilibration time required – headspace equilibration and extraction time and temperature must be controlled carefully to obtain reproducible results. A disadvantage of the technique is that it is unable to take into account variable odor thresholds. While for some products this may not be a problem, it certainly is when the headspace contains thiols or amines which have a very low odor threshold. HFMS has been used successfully to measure ripeness of apples (Saevels et al., 2004), and the aroma profile of tomato cultivars in a quality system (Berna et al., 2004). Recently, the evolution of aroma production in strawberries during super-atmospheric oxygen storage was monitored using HFMS (Berna et al., 2007).

Other techniques to speed up gas chromatography analysis have been developed. In fast GC, a capillary column with a very small diameter is used in combination with a sensitive detector. The column temperature is often established using resistive heating, which allows very fast heating rates. Mondello et al. (2004) achieved an analysis time of 3.3 minutes for citrus essential oil, which represented an analysis speed gain of almost 14. Applications to rapid aroma screening of horticultural products remain to be identified.

B. Electronic noses

Electronic nose systems are sensor arrays which mimic the operation of a human nose. When an atmosphere loaded with volatile components flows over it, each sensor generates a signal. The combined signal of all sensors is then statistically related to, e.g. the response of a human taste panel. Sensors that rely on chemical properties of the target molecule, whether it can adsorb at a particular surface or be oxidized or reduced, have been developed for a variety of analytes. Popular at present are sensors based on the conduction of semiconductors, such as tin oxide, or polymers such as polypyrrole (Gardner and Bartlett, 1994; Di Natale et al., 2000). More sensitive are sensors that "weigh" impinging molecules, such as piezoelectric crystals and surface acoustic wave devices.

In horticulture, electronic noses have been successful in monitoring the aroma of melons (Benady et al., 1995), pears (Oshita et al., 2000), peaches (Molto et al., 1999), nectarines (Di Natale et al., 2001) and tomatoes (Maul et al., 1998; Berna et al., 2004). Most research has focused on classification of cultivars or evaluation of changes of the aroma profile during maturation and ripening. Measuring the headspace of apples has been an interesting challenge for electronic noses, since aroma is an important maturity indicator that correlates well with consumer acceptance (Brezmes et al., 2001). Hines et al. (1999) and Young et al. (1999) used an electronic nose to measure ripeness of apples. Aroma changes in apples during shelf life and the optimal picking date were successfully determined non-destructively using an electronic nose by Saevels et al. (2003, 2004). Berna et al. (2004) investigated the effect of shelf life and cultivar on the aroma of tomato using a quartz microbalance electronic nose system. These authors also correlated tomato aroma measured using an electronic nose successfully with sensory properties and consumer preference (Berna et al., 2005a,b).

An important step in miniaturization and cost reduction was made by Rakow and Suslick (2000), who developed a 2-D array of metalloporphyrins as sensor elements for the visual identification of a wide range of olfactants and even weakly-ligating solvent vapors. The color of the sensors change depending on the absorbed volatile molecules, and the resulting 2-D fingerprint can be measured with a scanner. While this technology has, as far as we know, not been used in postharvest applications, it opens up the possibility of low-cost, disposable electronic nose sensors. The New Zealand company ripeSense® (www.ripesense.com) has taken this idea and developed a disposable sensor which reacts to the aromas released by the fruit as it ripens. The sensor is initially red, and graduates to orange and finally yellow. The sensor can be integrated into a package and gives the consumer an idea of the ripeness of the fruit. It can be assumed that similar sensors will emerge within the next couple of years.

VII. Conclusions

Many novel non-destructive systems have become available to measure internal quality attributes of fruit and vegetables. Some of them, in particular vibration and impact-based techniques for measuring firmness, as well as NIR spectroscopy for measuring soluble solids content, are now implemented on grading lines. As a consequence, grading based on internal quality attributes, rather than external appearance becomes possible, and this is expected to radically change the way fresh fruit is commercialized.

However, many problems remain to be solved. It is clear that a successful commercial implementation of these techniques will depend on the reliability of the measurements, their correlation with existing techniques and their price.

Key words
Fruit, vegetable, quality, non-destructive, measurement, firmness, appearance, aroma, taste.

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Bibliography

Abbott, J.A., Bachman, G.S., Childers, R.F., Fitzgerald, J.V., Matusik, F.J. (1968). Sonic technique for measuring texture of fruit and vegetables. Food Technology, 22, 101–112.

Abbott, J.A., Lu, R., Upchurch, B.L., Stroshine, R.L. (1997). Technologies for non-destructive quality evaluation of fruits and vegetables. Horticultural Reviews, 20, 1–120.

ASTM (2000). Standards on color and appearance measurements, 6th edn. American Society for Testing and Materials, Philadelphia, PA, USA.

Barcelon, E.G., Tojo, S., Watanabe, K. (1999). X-ray CT imaging and quality detection of peach at different physiological maturity. Transactions of the ASAE, 42, 435–441.

Bearman, G., Levenson, R. (2001). Biological imaging spectroscopy. Available online at http://hdl.handle.net/2014/11729.

Benady, M., Simon, J.E., Charles, D.J., Miles, G.E. (1995). Fruit ripeness determination by electronic sensing of aromatic volatiles. Transactions of the ASAE, 38, 251–257.

Berna, A.Z., Buysens, S., Di Natale, C., Grun, I.U., Lammertyn, J., Nicolaï, B.M. (2005a). Relating sensory analysis with electronic nose and headspace fingerprint MS for tomato aroma profiling. Postharvest Biology and Technology, 36, 143–155.

Berna, A.Z., Geysen, S., Li, S., Verlinden, B., Lammertyn, J., Nicolaï, B.M. (2007). Headspace fingerprint mass spectrometry to characterize strawberry aroma at super atmospheric oxygen conditions. Postharvest Biology and Technology, 46, 230–236.

Berna, A.Z., Lammertyn, J., Buysens, S., Di Natale, C., Nicolaï, B.M. (2005b). Mapping consumer liking of tomatoes with fast aroma profiling techniques. Postharvest Biology and Technology, 38, 115–127.

Berna, A.Z., Lammertyn, J., Saevels, S., Di Natale, C., Nicolaï, B.M. (2004). Electronic nose systems to study shelf life and cultivar effect on tomato aroma profile. Sensors and Actuators B-Chemical, 97, 324–333.

Brecht, J.K., Shewfelt, R.L., Garner, J.C., Tollner, E.W. (1991). Using X-ray-computed tomography to non-destructively determine maturity of green tomatoes. Hortscience, 26, 45–47.

Brezmes, J., Llobet, E., Vilanova, X., Orts, J., Saiz, G., Correig, X. (2001). Correlation between electronic nose signals and fruit quality indicators on shelf-life measurements with Pinklady apples. Sensors and Actuators B-Chemical, 80, 41–50.

Bulanon, D.M., Kataoka, T., Ota, Y., Hiroma, T. (2002). Segmentation algorithm for the automatic recognition of Fuji apples at harvest. Biosystems Engineering, 83, 405–412.

Butz, P., Hofmann, C., Tauscher, B. (2005). Recent developments in noninvasive techniques for fresh fruit and vegetable internal quality analysis. Journal of Food Science, 70, R131–R141.

Carlini, P., Massantini, R., Mencarelli, F. (2000). Vis-NIR measurement of soluble solids in cherry and apricot by PLS regression and wavelength selection. Journal of Agricultural and Food Chemistry, 48, 5236–5242.

Chen, H., De Baerdemaeker, J. (1993). Finite-element-based modal analysis of fruit firmness. Transactions of the ASAE, 36, 1827–1833.

Chen, H., De Baerdemaeker, J., Bellon, V. (1996). Finite element study of the melon for non-destructive sensing of firmness. Transactions of the ASAE, 39, 1057–1065.

Chen, P., McCarthy, M.J., Kauten, R. (1989). NMR for internal quality evaluation of fruits and vegetables. Transactions of the ASAE, 32, 1747–1753.

Chen, P., Ruiz-Altisent, M. (1996). A low-mass impact sensor for high-speed firmness sensing of fruits. Proceedings of the Agricultural Engineering International Conference 96, AGENG 96, Madrid, Spain, 23–26 September, paper 96F–003.

Chen, P., Tang, S., Chen, S. (1985). Instrument for testing the response of fruits to impact. ASAE Paper 75–3537, ASAE, St. Joseph, MI, USA.

Clark, C.J., Burmeister, D.M. (1999). Magnetic resonance imaging of browning development in "Braeburn" apple during controlled-atmosphere storage under high CO_2. Hortscience, 34, 915–919.

Clark, C.J., Drummond, L.N., MacFall, J.S. (1998a). Quantitative NMR imaging of kiwifruit (Actinidia deliciosa) during growth and ripening. Journal of the Science of Food and Agriculture, 78, 349–358.

Clark, C.J., MacFall, J.S., Bieleski, R.L. (1998b). Loss of watercore from "Fuji" apple observed by magnetic resonance imaging. Scientia Horticulturae, 73, 213–227.

Clark, C.J., Richardson, C.A. (1999). Observation of watercore dissipation in "Braeburn" apple by magnetic resonance imaging. New Zealand Journal of Crop and Horticultural Science, 27, 47–52.

Cloetens, P., Mache, R., Schlenker, M., Lerbs-Mache, S. (2006). Quantitative phase tomography of Arabidopsis seeds reveals intercellular void network. Proceedings of the National Academy of Sciences of the United States of America, 103, 14626–14630.

Cooke, J.R. (1972). Interpretation of resonant behavior of intact fruits and vegetables. Transactions of the ASAE, 15, 1075–1080.

Correa, P., Ruiz-Altisent, M., de la Plaza, J.L. (1992). Physical parameters in relation to physiological changes of avocado during ripening (20°C) and cold storage (6°C) in different conditions. Proceedings of the Agricultural Engineering International Conference 92, AGENG 92, Uppsala, Sweden, 1–4 June, paper 9211–16.

Cubeddu, R., D'Andrea, C., Pifferi, A., Taroni, P., Torricelli, A., Valentini, G., Dover, C., Johnson, D., Ruiz-Altisent, M., Valero, C. (2001). Non-destructive quantification of chemical and physical properties of fruits by time-resolved reflectance spectroscopy in the wavelength range 650–1000 nm. Applied Optics, 40, 538–543.

De Baerdemaeker, J., Lemaitre, L., Meire, R. (1982). Quality detection by frequency-spectrum analysis of the fruit impact force. Transactions of the ASAE, 25, 175–178.

De Ketelaere, B., Howarth, M.S., Crezee, L., Lammertyn, J., Viaene, K., Bulens, I., De Baerdemaeker, J. (2006a). Postharvest firmness changes as measured by acoustic and low-mass impact devices: a comparison of techniques. Postharvest Biology and Technology, 41, 275–284.

De Ketelaere, B., Lammertyn, J., Molenberghs, G., Desmet, M., Nicolaï, B., De Baerdemaeker, J. (2004). Tomato cultivar grouping based on firmness change, shelf life and variance during postharvest storage. Postharvest Biology and Technology, 34, 187–201.

De Ketelaere, B., Lammertyn, J., Molenberghs, G., Nicolaï, B., De Baerdemaeker, J. (2003). Statistical models for analyzing repeated quality measurements of horticultural products. Model evaluations and practical example. Mathematical Biosciences, 185, 169–189.

De Ketelaere, B., Ruiz-Altisent, M., Correa, E., De Baerdemaeker, J., Barreiro, P. (2001). Reliability of vibration measurements and impact response characteristics for the quality assessment of tomatoes. Proceedings of the 6th International Symposium on Fruit, Nut and Vegetable Production Engineering, Potsdam, Germany, 11–14 September, pp. 487–492.

De Ketelaere, B., Stulens, J., Lammertyn, J., Cuong, N.V., De Baerdemaeker, J. (2006b). A methodological approach for the identification and quantification of sources of biological variance in postharvest research. Postharvest Biology and Technology, 39, 1–9.

Delwiche, M.J., Mcdonald, T., Bowers, S.V. (1987). Determination of peach firmness by analysis of impact forces. Transactions of the ASAE, 30, 249–254.

Di Natale, C., Macagnano, A., Martinelli, E., Proietti, E., Paolesse, R., Castellari, L., Campani, S., D'Amico, A. (2001). Electronic nose based investigation of the sensorial properties of peaches and nectarines. Sensors and Actuators B-Chemical, 77, 561–566.

Di Natale, C., Mantini, A., Macagnano, A., Paolesse, R., D'Amico, A. (2000). The application of an electronic nose to the analysis of post-harvested fruits. Proceedings of the 14th European Conference on Solid-State Transducers, Eurosensors XIV, Copenhagen, Denmark, 27–30 August, pp. 61–62.

Finney, D.D., Norris, K.H. (1968). Instrumentation for investigating dynamic mechanical properties of fruits and vegetables. Transactions of the ASAE, 11, 94–97.

Fraser, D.G., Kunnemeyer, R., McGlone, V.A., Jordan, R.B. (2001). Near infra-red (NIR) light penetration into an apple. Postharvest Biology and Technology, 22, 191–194.

Galili, N., Rosenhouse, G., Mizrach, A. (1993). Ultrasonic technique for fruit and vegetable quality evaluation. Proceedings of the 4th International Symposium on Fruit, Nut and Vegetable Production Engineering, Valencia-Zaragoza, Spain, 22–26 March, pp. 281–289.

Garcia-Ramos, F.J., Ortiz-Canavate, J., Ruiz-Altisent, M., Diez, J., Flores, L., Homer, I., Chavez, J.M. (2003). Development and implementation of an on-line impact sensor for firmness sensing of fruits. Journal of Food Engineering, 58, 53–57.

Gardner, J.W., Bartlett, P.N. (1994). A brief history of electronic noses. Sensors and Actuators B-Chemical, 18, 211–220.

Golding, J.B., Spohr, L., Newman, S., Tanner, D.J., Orszulok, E., Smale, N., Graves, C., McGlasson, W.B. (2005). Non-destructive assessment of peach and nectarine firmness. ISHS Acta Horticulturae, 687, International Conference Postharvest Unlimited Downunder 2004, pp. 261–270.

Gonzalez, J.J., Valle, R.C., Bobroff, S., Viasi, W.V., Mitcham, E.J., McCarthy, M.J. (2001). Detection and monitoring of internal browning development in "Fuji" apples using MRI. Postharvest Biology and Technology, 22, 179–188.

Guthrie, J.A., Wedding, B., Walsh, K.B. (1998). Robustness of NIR calibrations for soluble solids in intact melon and pineapple. Journal of Near Infrared Spectroscopy, 6, 259–265.

Herman, G.T. (1980). Image Reconstruction from Projections. Academic Press, New York, NY, USA.

Hernandez-Sanchez, N., Hills, B.P., Barreiro, P., Marigheto, N. (2007). An NMR study on internal browning in pears. Postharvest Biology and Technology, 44, 260–270.

Hertog, M.L.A.T.M., Ben-Arie, R., Róth, E., Nicolaï, B.M. (2004). Humidity and temperature effects on invasive and non-invasive firmness measures. Postharvest Biology and Technology, 33, 79–91.

Hertog, M.L.A.T.M., Lammertyn, J., De Ketelaere, B., Scheerlinck, N., Nicolaï, B.A. (2007). Managing quality variance in the postharvest food chain. Trends in Food Science & Technology, 18, 320–332.

Hines, E.L., Llobet, E., Gardner, J.W. (1999). Neural network based electronic nose for apple ripeness determination. Electronics Letters, 35, 821–823.

Jancsók, P., Clijmans, L., Nicolaï, B.M., De Baerdemaeker, J. (2001). Investigation of the effect of shape on the acoustic response of Conference pears by finite element modelling. Postharvest Biology and Technology, 23, 1–12.

Jaren, C., Ruiz-Altisent, M., Perez de Rueda, R. (1992). Sensing physical stage of fruit by their response to non-destructive impacts. Proceedings of the Agricultural Engineering International Conference 92, AGENG 92, Uppsala, Sweden, 1–4 June, paper 9211–113.

Kawano, S., Fujiwara, T., Iwamoto, M. (1993). Non-destructive determination of sugar content in satsuma mandarine using near-infrared (NIR) transmittance. Journal of the Japanese Society for Horticultural Science, 62, 465–470.

Kondo, N., Nishitsuji, Y., Ling, P.P., Ting, K.C. (1996). Visual feedback guided robotic cherry tomato harvesting. Transactions of the ASAE, 39, 2331–2338.

Kuroki, S., Oshita, S., Sotome, I., Kawagoe, Y., Seo, Y. (2004). Visualization of 3-D network of gas-filled intercellular spaces in cucumber fruit after harvest. Postharvest Biology and Technology, 33, 255–262.

Lammertyn, J., Dresselaers, T., Van Hecke, P., Jancsok, P., Wevers, M., Nicolaï, B.M. (2003a). Analysis of the time course of core breakdown in "Conference" pears by means of MRI and X-ray CT. Postharvest Biology and Technology, 29, 19–28.

Lammertyn, J., Dresselaers, T., Van Hecke, P., Jancsok, P., Wevers, M., Nicolaï, B.M. (2003b). MRI and X-ray CT study of spatial distribution of core breakdown in "Conference" pears. Magnetic Resonance Imaging, 21, 805–815.

Lammertyn, J., Nicolaï, B., Ooms, K., De Smedt, V., De Baerdemaeker, J. (1998). Non-destructive measurement of acidity, soluble solids, and firmness of Jonagold apples using NIR-spectroscopy. Transactions of the ASAE, 41, 1089–1094.

Lammertyn, J., Peirs, A., De Baerdemaeker, J., Nicolaï, B. (2000). Light penetration properties of NIR radiation in fruit with respect to non-destructive quality assessment. Postharvest Biology and Technology, 18, 121–132.

Langenakens, J., Vandewalle, X., De Baerdemaeker, J. (1997). Influence of global shape and internal structure of tomatoes on the resonant frequency. Journal of Agricultural Engineering Research, 66, 41–49.

Liao, K., Reid, J.F., Paulsen, M.R., Ni, B. (1992). Knowledge based color discrimination of corn kernels. ASAE Paper 923579, ASAE, St. Joseph, MI, USA.

Lim, K.S., Barigou, M. (2004). X-ray micro-computed tomography of cellular food products. Food Research International, 37, 1001–1012.

Long, R.L., Walsh, K.B. (2006). Limitations to the measurement of intact melon total soluble solids using near infrared spectroscopy. Australian Journal of Agricultural Research, 57, 403–410.

Lu, R. (2001). Predicting firmness and sugar content of sweet cherries using near-infrared diffuse reflectance spectroscopy. Transactions of the ASAE, 44, 1265–1271.

Lu, R.F. (2004). Prediction of apple fruit firmness by near-infrared multispectral scattering. Journal of Texture Studies, 35, 263–276.

Macdougall, D.B. (1982). Changes in the color and opacity of meat. Food Chemistry, 9, 75–88.

Maire, E., Salvo, L., Blandin, J.J., Ludwig, W., Létang, J.M. (2001). On the application of X-ray microtomography in the field of material science. Advanced Engineering Materials, 3, 546.

Maire, E., Fazekas, A., Salvo, L., Dendievel, R., Youssef, S., Cloetens, P., Letang, J.M. (2003). X-ray tomography applied to the characterization of cellular materials. Related finite element modeling problems. Composites Science and Technology, 63, 2431–2443.

Martinsen, P., Schaare, P. (1998). Measuring soluble solids distribution in kiwifruit using near-infrared imaging spectroscopy. Postharvest Biology and Technology, 14, 271–281.

Maul, F., Sargent, S.A., Balaban, M.O., Baldwin, E.A., Huber, D.J., Sims, C.A. (1998). Aroma volatile profiles from ripe tomatoes are influenced by physiological maturity at harvest: An application for electronic nose technology. Journal of the American Society for Horticultural Science, 123, 1094–1101.

McGlone, V.A., Abe, H., Kawano, S. (1997). Kiwifruit firmness by near infrared light scattering. Journal of Near Infrared Spectroscopy, 5, 83–89.

McGlone, V.A., Kawano, S. (1998). Firmness, dry-matter and soluble-solids assessment of postharvest kiwifruit by NIR spectroscopy. Postharvest Biology and Technology, 13, 131–141.

Mehinagic, E., Royer, G., Symoneaux, R., Bertrand, D., Jourjon, F. (2004). Prediction of the sensory quality of apples by physical measurements. Postharvest Biology and Technology, 34, 257–269.

Mehl, P.M., Chen, Y.R., Kim, M.S., Chan, D.E. (2004). Development of hyperspectral imaging technique for the detection of apple surface defects and contaminations. Journal of Food Engineering, 61, 67–81.

Mendoza, F., Verboven, P., Mebatsion, H.K., Kerckhofs, G., Wevers, M., Nicolaï, B. (2007). Three-dimensional pore space quantification of apple tissue using X-ray computed microtomography. Planta, 226, 559–570.

Molto, E., Selfa, E., Ferriz, J., Conesa, E., Gutierrez, A. (1999). An aroma sensor for assessing peach quality. Journal of Agricultural Engineering Research, 72, 311–316.

Molto, E., Selfa, E., Pons, R., Fornes, I. (1996). Non-destructive measuring of firmness using impact sensors. Proceedings of the Agricultural Engineering International Conference 96, AGENG 96, Madrid, Spain, 23–26 September, paper 96F–014.

Mondello, L., Casilli, A., Tranchida, P.Q., Costa, R., Dugo, P., Dugo, G. (2004). Fast GC for the analysis of citrus oils. Journal of Chromatographic Science, 42, 410–416.

Nahir, D., Schmilovitch, Z., Ronen, B. (1986). Tomato grading by impact force response. ASAE Paper 86–3028, ASAE, St. Joseph, MI, USA.

Nguyen, T.A., Dresselaers, T., Verboven, P., D'hallewin, G., Culeddu, N., Van Hecke, P., Nicolaï, B.M. (2006). Finite element modelling and MRI validation of 3D transient water profiles in pears during postharvest storage. Journal of the Science of Food and Agriculture, 86, 745–756.

Nicolaï, B.M., Beullens, K., Bobelyn, E., Peirs, A., Theron, K.I., Lammertyn, J. (2007a). Non-destructive measurement of fruit and vegetable quality by means of NIR spectroscopy. Postharvest Biology and Technology, 46, 99–118.

Nicolaï, B.M., Verlinden, B.E., Desmet, M., Saevels, S., Theron, K., Cubeddu, R., Pifferi, A., Torricelli, A. (2007b). Time-resolved and continuous wave NIR reflectance spectroscopy to predict firmness and soluble solids content of Conference pears. Postharvest Biology and Technology, 47, 68–74.

Oshita, S., Shima, K., Haruta, T., Seo, Y., Kawagoe, Y., Nakayama, S., Takahara, H. (2000). Discrimination of odors emanating from "La France" pear by semi-conducting polymer sensors. Computers and Electronics in Agriculture, 26, 209–216.

Park, B., Chen, Y.R., Nguyen, M. (1998). Multi-spectral image analysis using neural network algorithm for inspection of poultry carcasses. Journal of Agricultural Engineering Research, 69, 351–363.

Peiris, K.H.S., Dull, G.G., Leffler, R.G., Kays, S.J. (1999). Spatial variability of soluble solids or dry-matter content within individual fruits, bulbs, or tubers: Implications for the development and use of NIR spectrometric techniques. Hortscience, 34, 114 and 118.

Peirs, A., Scheerlinck, N., Nicolaï, B.M. (2003a). Temperature compensation for near infrared reflectance measurement of apple fruit soluble solids contents. Postharvest Biology and Technology, 30, 233 and 248.

Peirs, A., Scheerlinck, N., Touchant, K., Nicolaï, B.M. (2002). Comparison of Fourier transform and dispersive near-infrared reflectance spectroscopy for apple quality measurements. Biosystems Engineering, 81, 305–311.

Peirs, A., Tirry, J., Verlinden, B., Darius, P., Nicolaï, B.M. (2003b). Effect of biological variability on the robustness of NIR models for soluble solids content of apples. Postharvest Biology and Technology, 28, 269–280.

Peleg, K. (1993). Comparison of non-destructive and destructive measurement of apple firmness. Journal of Agricultural Engineering Research, 55, 227–238.

Rakow, N.A., Suslick, K.S. (2000). A colorimetric sensor array for odour visualization. Nature, 406, 710–713.

Rohrbach, R.P., Franke, J.E., Willits, D.H. (1982). A firmness sorting criterion for blueberries. Transactions of the ASAE, 25, 261–265.

Ruiz-Altisent, M., Jaren, C., Correa, P. (1993). Fruit quality sensing: post harvest ripeness. Proceedings of the 4th International Symposium on Fruit Nut and Vegetable Production Engineering, Valencia-Zaragoza, Spain, 22–26 March, pp. 211–222.

Saevels, S., Lammertyn, J., Berna, A.Z., Veraverbeke, E.A., Di Natale, C., Nicolaï, B.M. (2003). Electronic nose as a non-destructive tool to evaluate the optimal harvest date of apples. Postharvest Biology and Technology, 30, 3–14.

Saevels, S., Lammertyn, J., Berna, A.Z., Veraverbeke, E.A., Di Natale, C., Nicolaï, B.M. (2004). An electronic nose and a mass spectrometry-based electronic nose for assessing apple quality during shelf life. Postharvest Biology and Technology, 31, 9–19.

Salvo, L., Cloetens, P., Maire, E., Zabler, S., Blandin, J.J., Buffiere, J.Y., Ludwig, W., Boller, E., Bellet, D., Josserond, C. (2003). X-ray micro-tomography an attractive characterisation technique in materials science. Nuclear Instruments & Methods in Physics Research Section B-Beam Interactions with Materials and Atoms, 200, 273–286.

Schatzki, T.F., Haff, R.P., Young, R., Can, I., Le, L.C., Toyofuku, N. (1997). Defect detection in apples by means of X-ray imaging. Transactions of the ASAE, 40, 1407–1415.

Schotte, S., De Belie, N., De Baerdemaeker, J. (1999). Acoustic impulse-response technique for evaluation and modelling of firmness of tomato fruit. Postharvest Biology and Technology, 17, 105–115.

Shiers, V., Adechy, M., Squibb, A. (1999). A new mass spectrometry-based electronic nose for headspace characterisation. In: Electronic noses and sensor array based systems; design and application. Proceedings of the 5th International Symposium on Olfaction and the Electronic Nose, Baltimore, MD, USA, 27–30 September 1998, pp. 289–295.

Shmulevich, I., Galili, N., Howarth, M.S. (2003). Non-destructive dynamic testing of apples for firmness evaluation. Postharvest Biology and Technology, 29, 287–299.

Shmulevich, I., Galili, N., Rosenfeld, D. (1996). Detection of fruit firmness by frequency analysis. Transactions of the ASAE, 39, 1047–1055.

Slaughter, D.C. (1995). Non-destructive determination of internal quality in peaches and nectarines. Transactions of the ASAE, 38, 617–623.

Sonego, L., Benarie, R., Raynal, J., Pech, J.C. (1995). Biochemical and physical evaluation of textural characteristics of nectarines exhibiting woolly breakdown – NMR imaging, X-ray computed-tomography and pectin composition. Postharvest Biology and Technology, 5, 187–198.

Stuppy, W.H., Maisano, J.A., Colbert, M.W., Rudall, P.J., Rowe, T.B. (2003). Three-dimensional analysis of plant structure using high-resolution X-ray computed tomography. Trends in Plant Science, 8, 2–6.

Sugiyama, J. (1999). Visualization of sugar content in the flesh of a melon by near-infrared imaging. Journal of Agricultural and Food Chemistry, 47, 2715–2718.

Swatland, H.J. (1995). On-line evaluation of meat. Technomic Publishing Company, Inc., Lancaster, PA, USA.

Tao, Y., Heinemann, P.H., Varghese, Z., Morrow, C.T., Sommer, H.J. (1995). Machine vision for color inspection of potatoes and apples. Transactions of the ASAE, 38, 1555–1561.

Thomas, P., Saxena, S.C., Chandra, R., Rao, R., Bhatia, C.R. (1993). X-ray-imaging for detecting spongy tissue, an internal disorder in fruits of Alphonso mango (Mangifera-Indica L). Journal of Horticultural Science, 68, 803–806.

Throop, J.A., Aneshansley, D.J., Anger, W.C., Peterson, D.L. (2005). Quality evaluation of apples based on surface defects: development of an automated inspection system. Postharvest Biology and Technology, 36, 281–290.

Tollner, E.W., Hung, Y.C., Upchurch, B.L., Prussia, S.E. (1992). Relating X-ray absorption to density and water-content in apples. Transactions of the ASAE, 35, 1921–1928.

Tu, K., De Busscher, R., De Baerdemaeker, J., Schrevens, E. (1995). Using laser beam as light source to study tomato and apple quality non-destructively. Proceedings of the Food Processing Automation IV Conference, Chicago, IL, USA, 3–5 November, pp. 528–536.

Tu, K., Jancsok, P., Nicolaï, B., De Baerdemaeker, J. (2000). Use of laser-scattering imaging to study tomato-fruit quality in relation to acoustic and compression measurements. International Journal of Food Science and Technology, 35, 503–510.

Valero, C., Crisosto, C.H. (2004). Relation between destructive and non-destructive bench top firmness measurements on peaches, nectarines and plums. Central Valley Postharvest News Letter, 13, 5–6.

Valero, C., Ruiz-Altisent, M., Cubeddu, R., Pifferi, A., Taroni, P., Torricelli, A., Valentini, G., Johnson, D.S., Dover, C.J. (2004). Detection of internal quality in kiwi with time-domain diffuse reflectance spectroscopy. Applied Engineering in Agriculture, 20, 223–230.

van Dalen, G., Blonk, H., van Aalst, H., Hendriks, C.L. (2003). 3-D imaging of foods using X-ray microthomography. GIT Imaging & Microscopy, 3, 18–21.

Van Henten, E.J., Hemming, J., Van Tuijl, B.A.J., Kornet, J.G., Meuleman, J., Bontsema, J., Van Os, E.A. (2002). An autonomous robot for harvesting cucumbers in greenhouses. Autonomous Robots, 13, 241–258.

Verstreken, E., De Baerdemaeker, J. (1994). Evolution of maturity of peaches: non-destructive firmness measurement from the acoustic impulse response. International Agrophysics, 8, 469–473.

Wang, C.Y., Wang, P.C. (1989). Non-destructive detection of core breakdown in Bartlett pears with nuclear magnetic-resonance imaging. Hortscience, 24, 106–109.

Wang, S.Y., Wang, P.C., Faust, M. (1988). Non-destructive detection of watercore in apple with nuclear magnetic-resonance imaging. Scientia Horticulturae, 35, 227–234.

Young, H., Rossiter, K., Wang, M., Miller, M. (1999). Characterization of Royal Gala apple aroma using electronic nose technology-potential maturity indicator. Journal of Agricultural and Food Chemistry, 47, 5173–5177.

16

Stress Physiology and Latent Damage

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I. Introduction

Once a commodity has been harvested, only the best postharvest procedures will maintain quality. In virtually all cases, fresh produce quality is set at harvest, and then inevitably declines during the postharvest lifetime. The number and type of stresses will vary, depending on handling conditions after its removal from the plant or tree. These conditions include water stress due to moisture loss, temperature stress from storage conditions, anaerobic stress if the product is stored in a modified or controlled atmosphere, biotic stress from pathogens present at harvest or that enter small wounds during the postharvest sorting, and mechanical stress from transport, sorting and packing (see also Chapters 14, 15 and 18). The ability to monitor the response of products to stress, including handling conditions, is important in designing the best postharvest management procedures.

Understanding the underlying mechanisms that made a fruit or vegetable sensitive to stress helps to design treatments to minimize the adverse effects of the stress or to modify the postharvest procedures to prevent development of symptoms. Differences in susceptibility among and within species provide geneticists and physiologists with models to study the cellular and molecular basis of tissue response. Cellular and molecular approaches lead to the development of postharvest handing and storage methods that maintain quality without stress, and to the development of postharvest stress-resistant cultivars.

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II. Types of postharvest stress

Stress is usually categorized by environmental (abiotic) factors or biological (biotic) factors that induce injury and quality degradation. Fruits and vegetables are exposed to several types of stress as they pass through the handling system from farm to consumer. Some types of stress are induced intentionally, such as temperature change and controlled atmosphere use, while others are unintentional, such as impact stress during harvest and handling. In addition, stresses that the product experiences in the field or orchard can manifest in damage once the product has been harvested. The category of stress evident after harvest includes stress from direct sunlight, mineral deficiency, and latent infections of pathogens that invade during the development of a fruit or vegetable and are quiescent until after the product is harvested.

A. Abiotic stress

Abiotic stresses are those caused by the environment, either during growing conditions or after harvest. Descriptions of specific stress forms follow.

Stress from preharvest and harvest conditions

Sun scald

Fruit and vegetables that are exposed to direct sunlight can develop sun scald. The temperature of a fruit exposed to sun is 5 to 10°C higher than the surrounding air (Woolf et al., 2000). Fruits do not have the numbers of stomata that are present in leaves, which prevent the leaves from heating, and by water vapor loss cause evaporative cooling. In most cases, sun scald will be apparent in the field and appear as bleaching or yellowing on the product. The damage can be serious and cause the thermal death of epidermal and sub-epidermal cells, which results in a necrotic spot. Thermal death has been reported to affect many fruits and vegetables, including apples, blueberries, citrus, grapes, lychee, peppers and tomatoes. In many cases it results from plants' exposure to additional stresses, such as water stress or insect or pathogen attack. As a result, the leaves are wilted or missing, thus exposing the fruit to the sun. Pruning can ensure that fruit are shaded by leaves which can prevent sun scald, since UV-B radiation is needed for its induction (Schrader et al., 2003). Other means of preventing damage to healthy plants include shade netting, evaporative cooling and covering the plant or fruit with a protective layer of white kaolin (Gindaba and Wand, 2005). Bagging the fruit can also help reduce sun scald, although in direct sunlight fruit can be affected by heat stress. In most crops, sorting at harvest will remove the damaged fruits. However, in the case of apples, this type of stress will develop further in storage as latent damage.

Apple fruit affected at harvest will be culled. However, if the sun scald damage is light and the area affected small, the fruit will be harvested and stored. During storage this light area becomes brown, detracting from the fruit quality following storage (Figure 16.1). The development of the brown pigmentation is not dependent on oxygen and not decreased by controlled atmosphere (CA) storage (Lurie et al., 1991).

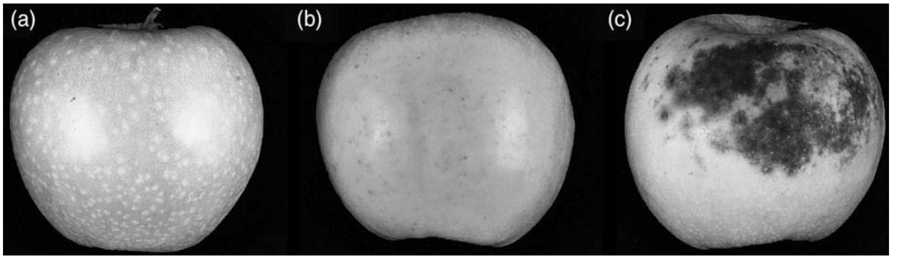

Figure 16.1 Sun scald on apples: (a) an apple with light sun scald at harvest; (b) severe sun scald at harvest is shown as yellow peel which would not be stored; (c) light sun scald which darkened in storage to a brown color.

No effective measures for prevention have been found. It may be caused by non-enzymatic condensation of amino acids and reducing sugars to a brown compound (Lurie et al., 1991).

Mineral imbalance or deficiency

Proper irrigation and fertilization of a crop can have important consequences for its postharvest quality. Irrigation is often increased as harvest time approaches to enhance fruit size. Fruit size enhancement is applied to pome and stone fruits, as well as grapes. The increase in irrigation has the effect of diluting the cellular contents of the fruit. The dilution is generally not important for fruit immediately destined for the market, but if the fruit is designated for storage it may impact negatively on quality after storage. Larger fruit tend to be more sensitive to storage disorders than smaller fruit of the same cultivar. Among the minerals that have been found to be involved in postharvest problems are nitrogen, calcium, phosphorus, zinc and boron. Over-fertilizing with nitrogen fertilizers will lead to fruits that soften very quickly and have less storage potential than fruits with lower levels of nitrogen.

Calcium is thought to be the most important mineral element in determining fruit quality. It seems to be especially important in apples, where it has been shown to reduce metabolic disorders. Calcium in adequate amounts helps to maintain apple fruit firmness, and decreases the incidence of physiological disorders such as water core, bitter pit and internal breakdown. Postharvest decay may also be reduced by increasing the calcium content of apples.

Calcium has a number of roles in plant tissue. It is an important part of the plant cell wall, and binds together strands of pectin helping to maintain fruit firmness (Figure 16.2a). It is also involved in membrane stabilization, and acts as a signal molecule to activate many cellular processes. Calcium is transported by the xylem, and once cell division ceases and cell expansion begins, very little additional calcium enters the fruit tissue. As fruits increase in size, the calcium is diluted and may fall below a critical level. In some cases, it is not the absolute level of calcium in the tissue, but the ratio of calcium to potassium, or to potassium and magnesium, that are associated with the development of latent disorders in storage. A number of storage disorders have been attributed to suboptimum levels of calcium in fruits besides apples, including vascular and flesh browning in avocados, peel pitting in kiwifruit,

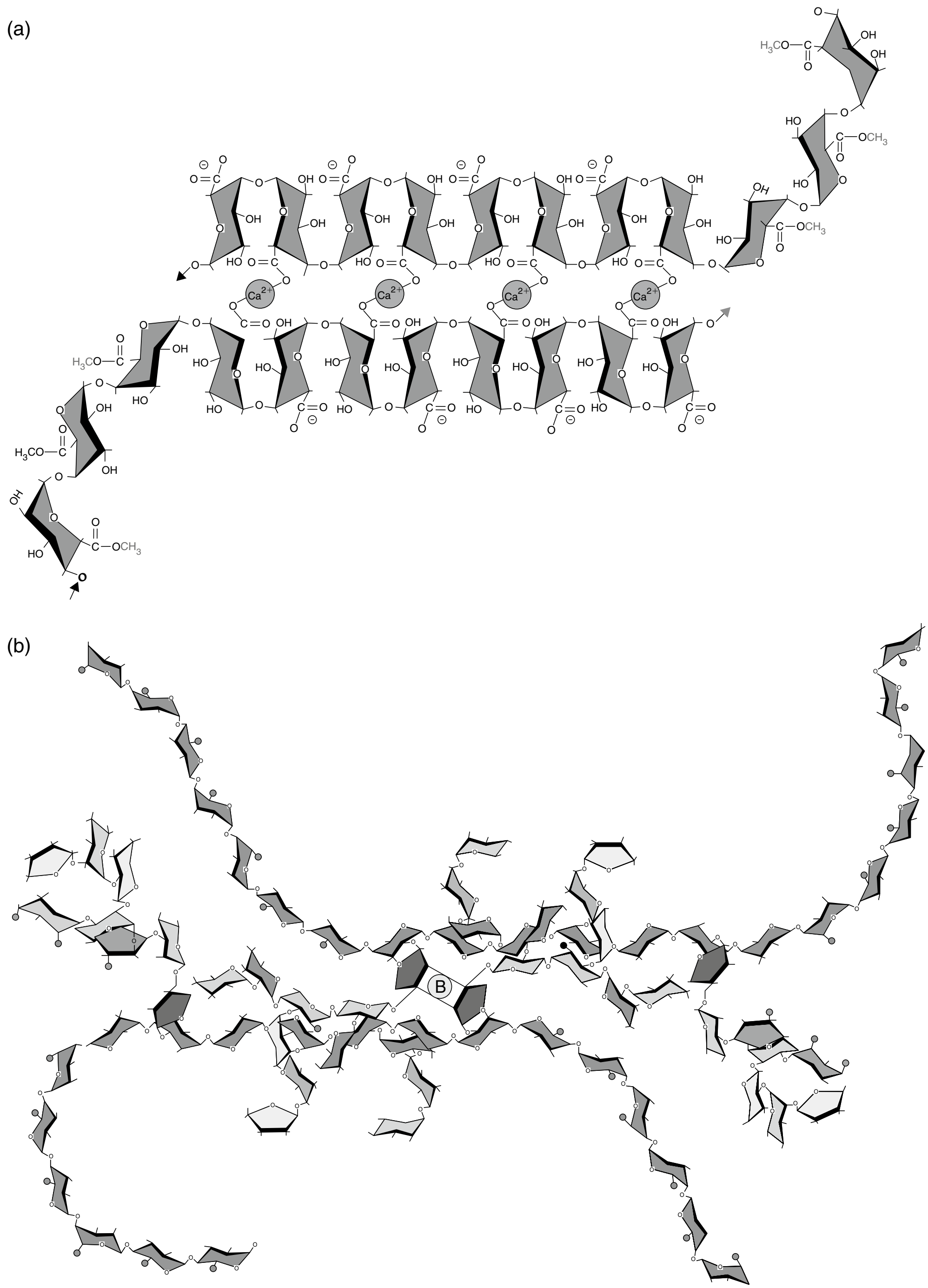

Figure 16.2 Two forms of pectic polysaccharides that require minerals for structure. (a) Calcium-pectate interactions in the cell wall. Homogalacturonic acid forms “egg box” junctions, with calcium bridging two anti-parallel chains. (b) Boron-pectate interactions. Rhamnogalacturan II is a complex polymer with four distinct side groups containing several different kinds of sugars and linkages. Monomers of rhamnogalacturan monomers can dimerize as boron di-diesters with apiose residues.

blossom end browning in persimmon, internal breakdown in plums and blossom end rot in tomatoes. Except for tomatoes, all of these are latent problems that develop during fruit storage.

Boron is a micronutrient that can cause latent damage in storage if its concentration is too low and other problems if it is too high in the fruit tissue. It is necessary as a cofactor for some enzymes, and it is also found in the pectin of the cell wall in a structure called rhamnolgalacturan II (Figure 16.2b). The latter is a unique epitope in the cell walls, where unusual neutral sugars are bound together by a boron atom. Boron deficiency is associated with brown heart in Conference pears, and with pitting in other fruit, including apples.

Bruising and wounding

Fruits and vegetables can be damaged during their development on the plant or tree. Wind can cause abrasions by rubbing the fruit or vegetable against other parts of the plant, while insects can cause damage which, even if it is repaired by the fruit or vegetable, will leave a scar. Harvest practices often contribute to additional wounding by the fruits or vegetables coming in contact with each other or with the sharp edges of harvesting containers. Harvest is the stage when the fruit or vegetables may be bruised when placed in picking containers or emptied from these into large bins. Bruising causes compression of layers of cells, and when the elastic limit of the cell wall has been exceeded, the cell walls rupture, releasing the contents of the cell into the air-filled intercellular spaces.

Bruising is a particularly serious problem on cherries due to impact during harvest or sorting. The bruises develop as pits on the fruit surface during storage or distribution (Figure 16.3). Generally, the fruit is hydrocooled to reduce fruit respiration and metabolic activity rapidly. It was found that cold fruit (0°C) were more sensitive to impact damage than warmer fruit (5°C) (Stow et al., 2004). This is due to the physical properties of cell walls that are affected by temperature; stiffness is greater at lower temperatures and cell walls are less flexible and more susceptible to pressure damage (Herppich et al., 2005).

Tomato fruit has been used as a model to study bruising, because it is a soft fruit and easily bruised by impact damage. The occurrence of bruising depends on two main factors: the direct mechanical damage to the tomato, and the presence and subsequent action of unregulated cell wall modifying enzymes. Bruising is considered to be a two-step process, in which mechanical damage occurs first, and then enzymatic degradation of the affected tissue, including cell walls, takes place. The enzymatic degradation could result in a rapid enzymatic breakdown of the cell wall polysaccharides, observed as soft spots (bruises) on the fruit. A comparative biochemical analysis of the bruised and intact tissue of green, pink, light red and red tomatoes showed that a mechanical impact results in an immediate loss of cell wall material only in the riper fruit. Differences in the pectin and neutral sugar content in bruised and sound mature green and pink fruits were not significant, whereas pectin and neutral sugar content in bruised orange- and red-ripe fruits was lower compared to the sound fruits. No immediate enzymatic wall disassembly was observed in the early stages of ripening. However, orange- and red-ripe fruits showed depolymerization of the pectin

Figure 16.3 Pitting on sweet cherries.

and hemicellulosic components. The studies revealed that, in the case of mechanically damaged fruit, polysaccharide-digesting enzymes are responsible for the rapid breakdown of the cell wall (Van Linden et al., 2003; Van Linden and Baerdemaeker, 2005). The breakdown results in soft spots on the fruit. No bruises will form without enzymatic digestion of the cell wall. In another study of induced bruising, researchers found that fruit dropped a number of times from a height of 10 centimeters had lower respiration, lower soluble solids and ascorbic acid, and higher titratable acidity, chlorophyll and decay than control fruits (Kaaya and Njoroge, 2004). These dropped fruit had lower eating quality.

In addition to changes in the taste parameters of soluble solids and titratable acidity, the aroma of the tomato fruit is altered by bruising. Individual volatile profiles of the pericarp and locule tissue in bruised fruit were significantly different from those of corresponding tissues in undropped, control fruit, notably: trans-2-hexenal from pericarp tissue; 1-penten-3-one, cis-3-hexenal, 6-methyl-5-hepten-2-one, cis-3-hexenol and 2-isobutylthiazole from locule tissue (Moretti et al., 2002). Alteration of volatile profiles was most pronounced in the locule tissue, which was more sensitive to internal bruising than the other tissues. Changes observed in the volatile profiles appear to be related to disruption of cellular structures. Panelists were able to distinguish between bruised and unbruised fruits, which indicated that internal bruising caused by impact significantly altered tomato flavor and aroma (Moretti and Sargent, 2000).

Wounding and cracking involve breakage of cells and release of their contents into the intercellular spaces. The release induces a whole range of catabolic processes, including enzymatic digestion of membranes. Wounded strawberry fruit produces a diverse group of volatile compounds, including aldehydes, alcohols and esters derived from the lipoxygenase (LOX) and hydroperoxide lyase (HPL) pathways involved in membrane breakdown. Some of the breakdown products are volatiles, such as trans-2-hexanal, which is derived from α-linolenic acid (18:3). The level of total lipid 18:3 in the fruit increased 2-fold in response to wounding. At 10 minutes after wounding, fruit exhibited a 25% increase in LOX activity, and a doubling of HPL. Thus, during the first 10-minute period after wounding, free 18:3 substrate availability and the activity of two key enzymes, LOX and HPL, changed in a manner consistent with increased volatile biosynthesis, particularly trans-2-hexanal and cis-3-hexanal (Myung et al., 2006). These volatiles are important in plant–pathogen interaction.

The volatile production that is the product of lipid oxidation can generate off-flavors. Off-flavor production in legumes, such as garden peas, is a particular problem, due to high levels of lipoxygenase found in the seeds. The lipid oxidation pathway is triggered in response to tissue wounding, which occurs during mechanical harvesting of peas in the field. Bruised peas develop strong off-flavors within a few hours. Studies have shown that antioxidants are consumed during lipid oxidation, and vitamin C, an important micronutrient, is decreased in wounded or bruised peas (Dornenburg and Davies, 1999).

Stress in storage

Chilling injury

The most frequent treatment applied to fresh fruits and vegetables to maintain their quality following harvest is temperature management, including the cold chain, where the temperature of the product is reduced rapidly after the harvest to stabilize it, and then the low temperature conditions are maintained until it reaches the consumers. The freezing point of fruits and vegetables is below the freezing point of water, for example, apples will freeze about −1.5°C, bananas at about −0.8°C, mangoes at about −1°C, grapes at about −2.2°C and dates at about −16°C. The actual freezing point will vary between cultivars, or even within a cultivar, depending on the conditions in which the produce is grown. The reason is that the freezing point is determined by the soluble solids dissolved in the cell sap, and this varies among different fruits and vegetables. Generally, the lower the temperature the longer the storage life, as long as the temperature is above the level at which the fruit is likely to freeze. However, certain commodities are subject to chilling injury (Table 16.1). Chilling injury is a temperature-associated physiological disorder which a product develops when exposed to low temperatures. Chilling injury may be apparent as failure to ripen in climacteric fruit, different forms of external or internal tissue discoloration, or predisposition to microorganism infection (Figure 16.4). The susceptibility to chilling injury is influenced by factors such as time of exposure to a chilling injury inducing temperature, cultivar and the preharvest conditions of the crop. The exact

Table 16.1 Recommended commercial storage conditions of fruits and vegetables

Commodity	Maximum storage and shelf life (days)	Optimum storage temperature (°C)
Anona	14–28	14
Avocado	14–28	2–6
Banana	7–28	13
Bean	3–10	7
Carambola	30–45	5
Cucumber	10–14	12
Eggplant	10–14	10
Grapefruit	28–42	12
Guava	14–21	10
Lemon	30–180	12
Lychee	21–35	5
Mango	14–40	12
Melon	7–14	5–10
Onion	30–180	14
Orange	21–84	3–6
Papaya	7–21	12
Pepper	12–18	7
Pineapple	14–36	10
Pomegranate	28–56	6
Potato	60–120	4–14
Prickly pear	14–35	5
Squash	84–150	12
Sweet potatoes	28–180	14
Tangarine & mandarin	17–28	3
Tomato	7–14	12
Watermelon	14–35	14
Zucchini	5–10	7

mechanism by which chilling injury affects a product has not been fully determined. It has been shown to be concerned with loss of membrane integrity and ion leakage from cells and changes in enzyme activity, but exactly why some crops are susceptible and some resistant is unknown. However, the commodities that are susceptible are generally those that originated from tropical or subtropical areas of the world.

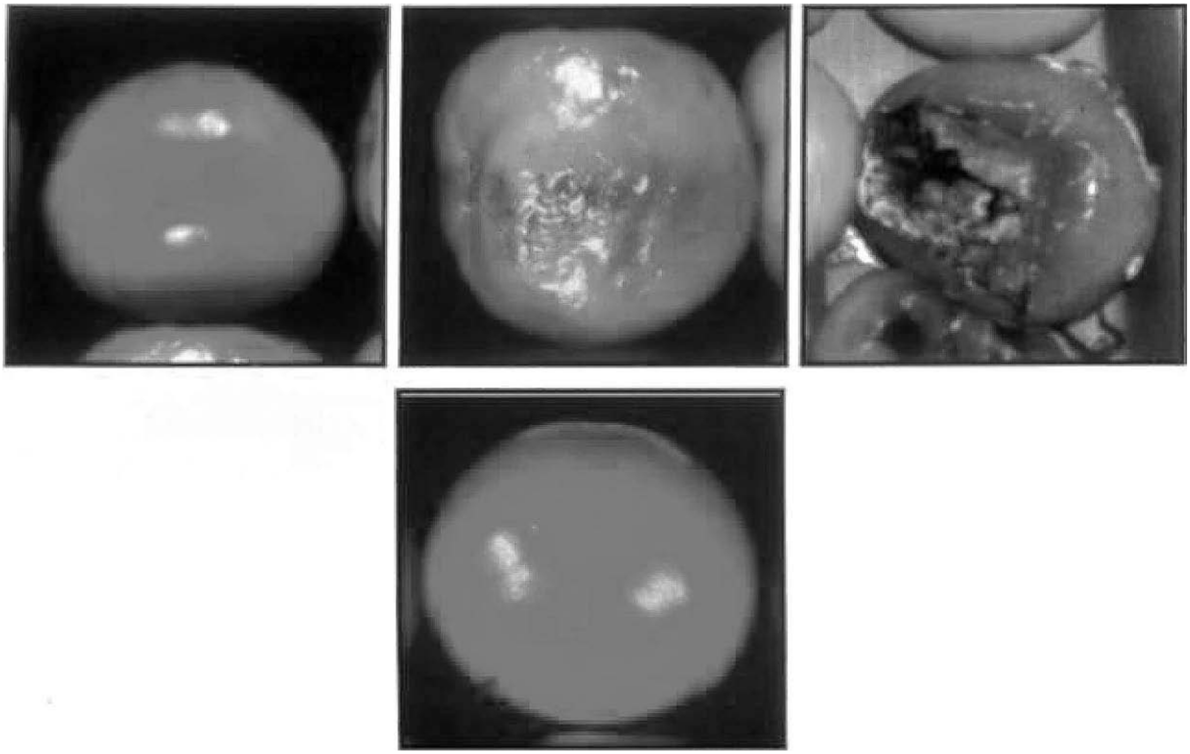

Figure 16.4 Chilling injury symptoms on tomatoes. Left: irregular ripening causes blotchy color development. Center: pitting development due to collapse of underlying cells. Right: increased decay development. Below: a red ripe tomato with no chilling injury.

A model proposed in 1973 suggested that changes in membrane permeability, associated with a membrane lipid physical phase transition from a flexible liquid–crystalline to a solid–gel structure, is the primary event associated with chilling injury (Lyons, 1973). This is now thought to be one factor contributing to plant tissue's ability to sense chilling temperature, but is not the only factor in all products. In the case of citrus fruits, it has been suggested that the sensitivity of Fortune mandarins to chilling injury is related to the inability to modify its membrane components, because the increase in unsaturated fatty acids (which help maintain a flexible liquid–crystalline structure) occurs after the onset of chilling injury (Mulas et al., 1996). However, manipulations that reduced chilling injury did not change the membrane lipid composition. A part of the damage appears to be due to oxidative stress. There have been a number of reports indicating the involvement of oxidative stress in chilling-induced damage of different fruits and vegetables, and antioxidative enzyme activation due to various temperature or storage manipulations is correlated with reduced chilling injury.

Because damage is caused by a combination of time and temperature, there are a number of manipulations that can be instituted to delay chilling injury on sensitive commodities. Temperature manipulation is one method. The lowering of temperature gradually, over a number of days, can reduce the risk of injury in a number of fruits, including avocados, citrus and tomatoes. Holding the commodity at an intermediate temperature can also help prevent injury. Citrus that is held for a few days at 16°C is less susceptible to chilling injury at low temperature. Other procedures include delaying cooling for 48 hours or warming fruit for 14 hours every few weeks. Both procedures are effective on peaches and nectarines, which are generally stored at 0°C, but which develop a form of chilling injury after three or four weeks in storage. The delay in cooling or breaking of the cold chain allows them to be stored longer at 0°C with no chilling injury. Citrus fruit can also benefit from intermittent warming.

In addition to temperature manipulations, there are methods to increase the resistance to stress in the fruit or vegetable. Stress will induce the synthesis and accumulation of a number of stress proteins that protect plant tissues from other stresses. A short anaerobic treatment, a high temperature stress (above 37°C), and UV irradiation all have been found to induce resistance to chilling injury. They all induce the synthesis of groups of proteins, anaerobic stress, heat shock or pathogenesis response that grant cross-protection to low temperature. In citrus, heat treatment of Fortune mandarins increased the activities of the antioxidative enzymes superoxide dismutase, catalase and ascorbate peroxidase, and protected fruits against chilling, indicating the participation of oxidative stress in the development of chilling injury (Sala and Lafuente, 2000). In addition, a comparison of gene expression in cold-stressed fruit to those given a prestorage heat treatment showed that some genes relevant to the transcriptional and translational apparatus of tissues were enhanced by the heat treatment. This result supports the suggestion that the protective effect of stress treatments may be related to an increased transcription capacity and the ability of cells to recover from early stages of cell damage (Want et al., 2001). Controlled atmosphere or modified atmosphere also delay chilling injury development by depressing general tissue metabolism.

Controlled and modified atmosphere

Altering the atmosphere around a stored commodity by lowering the level of oxygen and raising the level of carbon dioxide was first developed for apple storage in the 1920s. It is still a major method of storing both apples and pears, to make these fruit available year-round. No other commodities have been found to be as amenable to controlled atmosphere storage for such a long time, but many other fruits are stored for shorter periods of a few months. These include kiwifruit, persimmons and plums. In recent years, the use of modified atmosphere packaging has expanded. This technique encloses the fruit or vegetable inside a polymeric film of known permeability to water vapor, carbon dioxide and oxygen. The respiration of the product raises the level of carbon dioxide and reduces oxygen. Products stored in modified atmosphere packaging can be held in this manner through storage and shipping, in contrast to controlled atmosphere, where a storage room is opened and the fruit shipped in regular air storage.

Exposing harvested products to low oxygen and high carbon dioxide can be beneficial or harmful, depending on the concentrations of theses gases, temperature, exposure duration and commodity. Beneficial effects include disease control, insect disinfestation, alleviation of chilling injury, inhibition of browning and yellowing of commodities and of other physiological disorders. However, storage of a commodity in reduced oxygen and elevated carbon dioxide causes stress. On the one hand, respiration and metabolic activity are decreased under these conditions. On the other hand, the exposure of horticultural products to oxygen levels below and/or carbon dioxide levels above their optimum tolerable range can cause the initiation or aggravation of certain physiological disorders, irregular ripening, increased susceptibility to decay, off-flavor development and eventually, a loss of the product. Even apples which store well for extended periods in proper conditions of oxygen and carbon dioxide will develop disorders if stored in too high a carbon dioxide concentration. These disorders include peel scalding and the development of internal browning and air pockets (Figure 16.5).

Even if a product does not show visible signs of damage, the response of plant tissues to low oxygen or high carbon dioxide is the initiation of ethanolic fermentation. In this pathway, acetaldehyde is produced through pyruvate decarboxylation catalyzed by pyruvate decarboxylase. The acetaldehyde is reduced to ethanol by the enzyme alcohol dehydrogenase. Ethanol is usually the major product in most low oxygen stressed fruit, but in some tissues part of the ethanol is converted into ethyl acetate. In high carbon dioxide stress the ratio of ethanol to acetaldehyde was 2:1 compared to 50:1 in low oxygen stress (Ke et al., 1994).

Relative humidity

The amount of water vapor in the air can greatly affect the quality of fruit and vegetables. Too low relative humidity (RH) will cause cracking or shriveling of the product as water is lost from the tissue (Figure 16.6). The generally recommended levels of 85% to 95% RH for storage of fresh produce represent a compromise to prevent excessive weight loss, while providing some control of microbial spoilage. Too high RH will cause condensation of water on the surface of the commodity, and encourage the development of decay organisms. Condensation affects many modified atmosphere packaging methods. A study of tomatoes found that, in a flow-through system of 2% oxygen, the fruit remained saleable for 40 days, compared to 15 days in a package with the same oxygen concentration (Shirazi and Cameron, 1992). The limiting factor in the package was decay due to high in-package RH.

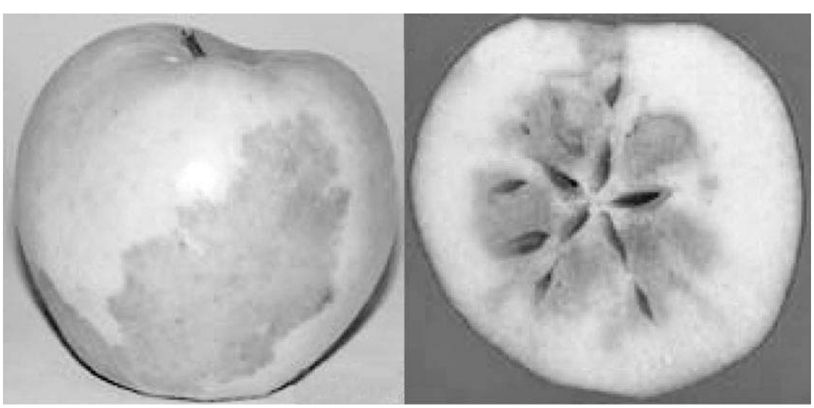

Figure 16.5 Carbon dioxide injury on apples held in controlled atmosphere. Left: scalding of the apple peel. Right: flesh browning a cavity development.

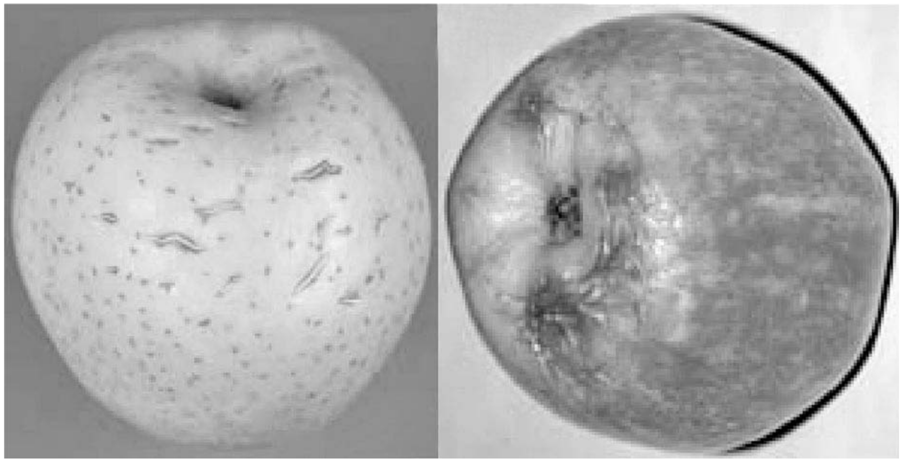

Figure 16.6 Water loss from apples due to low humidity in storage. Left: cracking of the fruit peel. Right: shriveling on some of the surface area of the fruit.

Even when stored at optimal RH, commodities lose weight over time due to both transpiration and respiration. The weight loss is equivalent to water loss. The amount of weight that a commodity can lose before visible damage is apparent ranges from 3% to 6% of its harvest weight. However, with water loss comes water stress of the tissue, and this stress can accelerate ripening and senescence. Stored tomatoes and cucumbers at low RH (60%) elevated ethylene and respiration, compared to storage at 80% and 95% RH. The consequence was faster ripening of the tomatoes, including fruit reddening and softening, and faster senescence of the cucumbers, including peel yellowing and tissue softening. Bananas ripened faster in low RH and produced higher levels of ACC (the intermediate of ethylene), as well as ethylene. In apples stored in low RH ethylene production increased, and the volatiles of ripe apples, mainly acetate esters, were enhanced.

B. Biotic stress

Stress caused by microorganisms is generally due to infection by either fungi or bacteria. Infections can occur at any time during the growing season, from flowering onwards. If the pathogen can develop on unripe fruit then this fruit will not reach maturity or enter the marketing chain. However, many microorganisms can be present on the surface of a commodity and only begin to develop as the fruit or vegetable begins to ripen or senesce. In addition, some fungi will begin to develop on an unripe commodity and become quiescent or latent until better conditions for development are present.

Latent or quiescent infections

Postharvest fungal pathogens exploit three main routes to penetrate the host tissue: through wounds occurring during growth, through natural openings such as lenticels and stem ends, and by direct breaching of the cuticle of the commodity. In many cases a fungus will enter the unripe fruit tissue and then remain inactive until the harvested fruit ripens. The penetration may go unnoticed by the fruit, or may elicit rapid defense processes that can limit fungal development. The period from infection to activation of fungal development and symptom expression is called the quiescent stage (Prusky and Lichter, 2007). After harvest and during ripening, the mechanisms that protect unripe fruit from fungal development become nonfunctional, and the quiescent fungus begins to develop and cause decay.

The fruit's natural preformed and inducible antifungal molecules or defense responses constitute a major barrier to the quiescent pathogen. An example of complex host- and fungus-mediated metabolism of antifungal compounds is the case of *Colletotrichum gloeosporioides* on avocado fruit. *C. gloeosporioides* spores can adhere to and germinate on the surface of avocado and send a germ tube through the cuticle of the fruit. But the fungus does not initiate decay until the avocado fruit begins to ripen. The spread of the fungus is inhibited by a high concentration of an antifungal diene. The diene compound decreases as the fruit matures, due to both the activity of avocado lipoxygenase, and the activity of a fungal enzyme that breaks down an inhibitor of lipoxygenase, leading to increased lipoxygenase activity (Guetsky et al., 2005). In grapes, quiescent infections of *Botrytis cinerea* occur because fungal development is inhibited by high levels of phenolic compounds (Goetz et al., 1999).

Prevention of quiescent infections is very difficult, because most preharvest treatments will not penetrate into the fruit or vegetable to destroy the pathogen. The best way of preventing the pathogen development is to maintain the fruit or vegetable in an unripe or non-senescent state, because the conditions are not optimal for pathogen development.

Infections after harvest

The types of microorganisms present on fresh produce can vary widely. Before harvest they can come from dust or soil, air, irrigation water, insects or animals. After harvest they can be in the air, containers or packing line of a packing house or store room. Once present, microorganisms subsist on the fruit through biotrophy, in which nutrients, carbohydrates, proteins and minerals are obtained from the living host cells. However, growth is limited by intrinsic properties of the particular fruit or vegetable, as well as storage conditions. In general fungi, because of their resistance to acidity, are the predominant organisms on fruits, while aerobic bacteria and fungi can develop on fruit and vegetables.

Although microorganisms will be present on all commodities, most microbes are innocuous and do not cause damage or decay. Only a small group of bacteria and fungi can invade the tissue of fresh fruits and vegetable and cause spoilage. In the colonization of fruit and vegetable hosts and the development of decay, postharvest fungal pathogens switch from biotrophy to necrotrophy, in which nutrients are obtained from dead host cells (Perfect et al., 1999). Opportunistic fungi will be present on the surface of the product in an inactive mode, waiting for wounding, ripening or senescence. In ripening or senescent products fungi will easily initiate necrotrophic development. Thus, the storage methods that delay or prevent ripening or senescence will also prevent the development of fungal pathogens. Low temperatures will inhibit most bacterial and fungal development, although among bacteria

Pseudomonas fluorescens can grow at close to 0°C, and among the fungi *Botrytis cinarea* can germinate and develop at 0°C. Preventing free water on the stored commodity will also inhibit decay development. Most fungi need a certain level of water activity to germinate, and in adverse conditions will remain as spores. Controlled or modified atmospheres also have fungistatic effects. Carbon dioxide levels of 3% or higher will inhibit the development of *Alternaria alternata*, which attacks numerous fruits, and low oxygen also inhibits the development of many fungi. In addition, some of the treatments that raise resistance to chilling injury can either kill fungal and bacterial spores, or induce resistance in the commodity to microbe invasion. Such treatments include a UV stress and a high temperature stress (Fallik, 2004; Shama, 2007).

However, once fruit or vegetables are in the marketing chain or displayed in the store, the microorganisms that were unable to develop under storage conditions are released from inhibition, and can cause extensive losses. This is in contrast to chemical fungicides, which will have an impact after storage, as well as during storage. There are very few fungicides (or bacteriocides) permitted for postharvest use, because there are fears of elevated residue levels and affects on human health. Therefore, the proper method of storage is essential to minimize losses at the retail level.

III. Implications for quality management

The implications for fruit and vegetable quality management are clear from the description of the preharvest and postharvest stresses detailed above. A comprehensive or systems approach can help control quality losses that will occur if all stages of production and marketing are not optimal. There are increasingly sophisticated monitoring methods to determine the quality of commodities at different stages, both during development and after harvest. In the orchard or field, optimum irrigation and fertilization can be monitored by instruments that simultaneously determine soil water content, leaf and air temperature, air RH, fruit growth and temperature, stem water potential and other measurements. These can be remotely monitored and used to optimize irrigation and fertilization regimes. On the sorting line, following harvest there is increasing use of non-destructive measurements to examine commodity quality, in addition to human observation and culling. Cameras can scan the commodity as it rotates on the line and sort by color, and identify fruit with blemishes; weighing cups will sort by size or weight; near-infrared instruments can determine soluble solids content or internal disorders; while acoustic methods can determine the firmness of a commodity. These methods and others are still in development for more and more commodities, and will increasingly be used to deliver products of uniform quality. The expected problems of a commodity can be analyzed and systems developed to minimize quality loss. For example, many crops need to undergo quarantine treatment when they are exported from the Mediterranean area to other parts of the world where Mediterranean fruit fly is a quarantine pest. One method to eliminate the pest is a storage period of 16 days at 1.1°C, which will kill the fly. However, many subtropical crops, such as citrus, cannot be held for so long at that temperature without developing chilling injury. A systems approach would utilize prestorage treatments to reduce the sensitivity of the crop to low temperature. With regard to temperature, understanding and monitoring the ripeness of a fruit can allow decisions to be made about the best temperature for storage. Early-season subtropical fruits are more sensitive to low temperature than late-season, while less mature fruits are also more sensitive than riper fruits. Understanding the differences in sensitivity allows tomatoes of varying ripeness to be stored at dissimilar temperatures without damage. Avocados from mid- and late-season harvests can also be stored and shipped at a lower temperature than the early-season fruits, with no quality loss.

Another example is carbon dioxide damage that can develop on some apple cultivars if they are exposed immediately after harvest to a controlled atmosphere. However, a procedure whereby the apples are stored for a period of time in regular air before controlled atmosphere is imposed can alleviate this problem. Dynamic controlled atmosphere is a new technique where oxygen is lowered to below 1% and the fruit monitored by either a fluorescent measurement, respiration or ethanol production. The fruit are held just above the oxygen point where anaerobic fermentation will occur. Proponents of this method of storage claim that apples stored in this manner are of higher quality with regard to firmness, aroma and other nutritional aspects than apples stored in normal controlled atmosphere.

If the major problem of a commodity is weight loss and shriveling, a systems approach would evaluate various methods of maintaining high humidity around the commodity without encouraging decay development. Two methods are enclosure in a polymer film that has higher permeability to water vapor than to carbon dioxide or water, or storage in a room with humidity control with a system where the water droplets are extremely small and charged so that they do not coalesce into drops that will condense on the commodity. This can maintain RH close to saturation, but the commodity remains dry.

There are continuing developments and improvements in postharvest monitoring and storage techniques. These need to be integrated into an overall procedure for each fruit and vegetable taking into account the weaknesses and strengths of each commodity. The end result will be better quality and healthier products for the consumer.

Key words
Abiotic stress, biotic stress, bruising, chilling injury, decay, latent infection, mineral deficiency, relative humidity, sun scald.

Bibliography

Dornenburg, H., Davies, C. (1999). The relationship between lipid oxidation and antioxidant content in postharvest vegetables. Food Rev. Int., 15, 435–453.

Fallik, E. (2004). Postharvest hot water treatments (immersion, rinsing and brushing). Postharvest Biol. Technol., 32, 125–134.

Gindaba, J., Wand, S.J.E. (2005). Comparative effects of evaporative cooling, kaolin particle film, and shade net on sunburn and fruit quality in apples. HortScience, 40, 592–596.

Goetz, G., Fkyeral, A., Metais, N., Kunhiz, M., Tabacchi, R., Pezet, R., Pont, V. (1999). Resistance factors to grey mould in grape berries: identification of some phenolics inhibitors of *Botrytis cinerea* stilbene oxidase. Phytochem., 52, 759–767.

Guetsky, R., Kobile, I., Wang, X., Perlman, N., Gollop, N., Avila-Quezada, G., Hadar, I., Prusky, D. (2005). Metabolism of the flavonoid epicatechin by laccase of *Colletotrichum gloeosporioides* and its effect on pathogenicity on avocado fruits. Phytopath., 95, 1341–1348.

Herppich, W.B., Herold, B., Landahl, S., Galindo, F.G., Geyer, M. (2005). Effects of temperature on produce texture and water status. Acta Hort., 687, 235–242.

Kaaya, A.N., Njoroge, C.K. (2004). The effect of physical damage on respiration, chemical and physical parameters in tomato (*Lycopersicon esculentum*) fruit. African J. Food Sci. Technol., 4, 2–10.

Ke, D., Yahia, E., Mateos, M., Kader, A.A. (1994). Ethanolic fermentation of "Bartlett" pears as influenced by ripening stage and atmospheric composition. J. Arem. Soc. Hort. Sci., 119, 976–982.

Lurie, S., Pesis, E., Ben-Arie, R. (1991). Darkening of sunscald on apples in storage is a non-enzymatic and non-oxidative process. Postharvest Biol. Technol., 1, 119–125.

Lyons, J.M. (1973). Chilling injury in plants. Annu. Rev. Plant Physiol., 24, 445–466.

Moretti, C.L., Sargent, S.A. (2000). Changes in the flavor and aroma of tomatoes caused by impact. Sci. Agricola, 57, 385–388.

Moretti, C.L., Baldwin, E.A., Sargent, S.A., Huber, D.H. (2002). Internal bruising alters aroma volatile profiles in tomato fruit. HortScience, 37, 378–382.

Mulas, M., Lafuente, M.T., Zacarias, L. (1996). Chilling effects on fatty acid composition of flavedo lipids in stored "Fortune" mandarines. Adv. Hort Sci., 2, 85–90.

Myung, K., Hamilton-Kemp, T.R., Archbold, D.D. (2006). Biosynthesis of trans-2-hexenal in response to wounding in strawberry fruit. J. Agric. Food Chem., 54, 1442–1448.

Prusky, D., Lichter, A. (2007). Activation of quiescent infections by postharvest pathogens during transition from biotriphic to necrotrophic stage. FEMS Microbiol. Lett., 268, 1–8.

Sala, J.M., Lafuente, M.T. (2000). Catalase enzyme activity is related to tolerance of mandarine fruits to chilling. Postharvest Biol. Technol., 20, 81–89.

Schrader, L., Zhang, J.G., Sun, J.S. (2003). Environmental stresses that cause sunburn of apple. Acta Hort., 618, 397–405.

Shama, G. (2007). Process challenges in applying low doses of ultraviolet light to fresh produce for eliciting beneficial hormetic responses. Postharvest Biol. Technol., 44, 1–8.

Stow, J.R., Jameson, J., Senner, K. (2004). Storage of cherries: the effects of rate of cooling, store atmosphere and store temperature on storage and shelf-life. J. Hort. Sci. Technol., 79, 941–946.

Tromp, J., Webster, A.D., Wertheim, S.J. (2005). Fundamentals of temperate zone fruit production. Academic Press, NY.

Van Linden, V., de Baerdemaeker, J. (2005). The phenomenon of tomato bruising: where biomechanics and biochemistry meet. Acta Hortic., 682, 925–932.

Van Linden, V., Labavitch, J., de Baerdemaeker, J. (2003). Bruising mechanism in tomato fruit: concerted biomechanical and enzymatic action. Commun. Agric. Applied Biol. Sci., 68, 11–15.

Wang, C.Y., Bowen, J.H., Weir, I.E., Allan, A.C., Ferguson, I.B. (2001). Heat induced protection against death of suspension cultured apple fruit cells exposed to low temperature. Plant Cell Environ., 24, 1199–1207.

Woolf, A., Wexler, A., Prusky, D., Kobiler, I., Lurie, S. (2000). Direct sunlight influences postharvest temperature responses and ripening of five avocado cultivars. J. Amer. Soc. Hort. Sci., 125, 370–376.

17

Measuring Quality and Maturity

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I. Quality and acceptability

Quality is defined by the buyer (Kramer and Twigg, 1970; Shewfelt, 1999) and perception of the quality of a product changes as it travels through the handling system. The grower buys seeds or plants of a selected cultivar, as well as a series of inputs (water, fertilizer or pest protection) that will help provide a good yield at a level of quality acceptable to the first buyer. Quality of a fresh product early in the postharvest system (at packing houses or warehouses) is usually evaluated against grades and standards. Such grades and standards tend to be based on attributes that can be readily determined visually – color, size, shape and absence of defects. Visual sorting and grading operations use these attributes to determine the acceptance or rejection of shipments of a fresh product.

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For any given lot of a fresh crop, a grade can be established at harvest, usually at the packing facility. Theoretically, the grade of that lot will not change, but the condition of the commodity will alter during handling and storage as the product senesces. Perishability of a commodity is a function of how rapidly the condition of the product deteriorates under a given commercial storage regime.

Maturity of a crop is an assessment of physiological development. Physiological maturity is described as the stage of development when a plant or plant part will continue ontogeny even if detached, whereas commercial maturity is defined as the stage of development when a plant or plant part possesses the prerequisites for utilization by consumers for a particular purpose (Watada et al., 1984). Maturity of a crop at harvest directly affects the color and size of an item, and thus its grade. Other important quality characteristics such as texture, flavor and nutrient content, as well as perishability and susceptibility to adverse handling and storage conditions, are a function of harvest maturity.

Although grade and condition are the primary factors influencing buying decisions for fresh items from the farmer to the consumer, the consumer uses different criteria to judge quality. Quality attributes can be divided into purchase quality and consumption quality. Purchase quality is composed of those characteristics that are important to the consumer when deciding whether to buy a particular commodity and which item(s) to select. Purchase attributes may include color, size, shape, absence of defects, firmness to the touch and aroma. Consumption quality consists of those characteristics assessed by the consumer to determine how much that item is liked during eating. Consumption attributes include flavor (taste and aroma) and mouthfeel. In addition to purchase and consumption quality there are other hidden attributes, such as wholesomeness, nutritional value and safety. These attributes are considered hidden because they cannot be readily detected by visual inspection or by consumption, but require sophisticated analysis. Perception of these hidden attributes plays an important role in the consumer purchase decision.

Quality characteristics constitute part of a wider range of factors leading to food acceptability that is defined as "the level of continued purchase or consumption by a specified population" (Land, 1988). Extrinsic attributes or other factors that affect acceptability include packaging, price, marketing practices and merchandising techniques. More detailed descriptions of food acceptability (Thomson, 1988; Meiselman, 2006) and quality measurement (Shewfelt and Brückner, 2000) are the subjects of other books. This chapter focuses on the intrinsic attributes of a fruit or vegetable that affect its acceptability, and places measurement of maturity and quality in a systems context.

II. Commodity-specific quality attributes

A set of characteristics important to consumer acceptance is associated with each fresh fruit or vegetable. Broccoli should be green, but green peaches are rejected. Celery should be crisp and crunchy, but strawberries are expected to be soft and succulent. Bland flavors are associated with lettuce and potatoes, but are not desirable in tomatoes and blueberries.

Determining characteristics that are important for consumer acceptance is not as easy as it might seem. Few investigators determine consumer acceptability of specific fruits and vegetables in their research. More consumer acceptance studies have been performed on the tomato than on any other fresh commodity (Stern et al., 1994; Malundo et al., 1995; Auerswald et al., 1999; Sinesio et al., 2000; Causse et al., 2002). Research establishes that external factors (particularly firmness to the touch, with uniform but not fully ripe color) are of primary importance in tomato purchase. Unfortunately, a single test does not establish acceptance once and for all, since consumer tastes change with time and are influenced by cultural factors. Carefully planned studies identify specific target markets. For example, yellow kiwifruit appeal to a specific segment, but not to others (Jaeger et al., 2003). Apples are segmented by variety (Shewfelt, 2000), region (Hampson and Quamme, 2000) and safety concerns (Baker and Crosbie, 1994).

Despite good intentions to serve the consumer, the grower must satisfy the immediate buyer (packer or distributor) to stay in business. Most packers, wholesale distributors and retail sales operators buy fruits and vegetables on the basis of grades and standards, as mentioned earlier. Many postharvest systems are therefore biased toward purchase quality attributes that are closer to grades and standards. When designing specifications for quality management programs of a specific commodity, attributes must be selected that can be used to predict both purchase and consumption quality as perceived by the consumer, as well as being readily quantifiable throughout the handling system (Shewfelt, 1999). Techniques should be identified or developed for each attribute that would provide a single number on a linear scale to distinguish clearly between products of acceptable and unacceptable quality. Instrumental techniques are usually preferred to any other methods if they are rapid and provide reproducible results. Non-destructive instrumental methods are preferred to destructive ones, since they decrease waste and permit repeated measures on the same items over time. Chemical methods are usually preferred to sensory techniques, primarily for reproducibility. For some products, no instrumental or chemical analyses are available that adequately predict consumer response. In these cases, objective scales are developed for a commodity and items are evaluated by an expert judge. Ayala-Zavala et al. (2004) describe a scale for spoilage of strawberries, and Rennie et al. (2001) use a quality scale for lettuce. At a minimum, the use of any technique must be validated by its relationship to sensory perception of small, experienced, or trained panels. When possible, these attributes should be tested to determine their ability to predict consumer acceptability in large, untrained panels.

When evaluating a system, quantification of key attributes should be made at major points in the handling system. A technique that is dependent on a single expensive instrument bound to a particular location is not useful. Quick, reliable, reproducible methods that can be performed by available personnel at each critical step are ideal. Clearly written quality specifications, coupled with defined actions for specific circumstances, are beneficial. Monitoring quality attributes should start as close to the field as practicable. The earlier in the handling system a problem can be detected the greater are the chances for taking corrective action to minimize economic losses.

For example, if a quality check reveals that a harvested crop is deteriorating more rapidly than normal a decision can be made to:

1. expedite shipping and handling to market and distribute it directly to consumers while the quality is still acceptable;
2. grade and sort items to save those that will be able to withstand normal handling and discard those that will not; or
3. stop shipment immediately and discard the lot before any additional input costs are incurred.

Some postharvest operations collect additional product at each sampling step, and partition the sample into sub-samples that will be analyzed immediately and those that will be stored under anticipated handling conditions. This practice helps to increase the chances of detecting potential problems while they are still manageable, and can provide insight into whether a problem is the result of inferior product or abusive handling conditions. Use of temperature recorders during transport or in storage rooms and of time-temperature indicators on the boxes of fresh product can also provide information about temperature abuse.

III. Sample collection and preparation

Part of any quality specification includes the number of samples and the frequency of collection. Requirements for individual commodities vary widely; specific recommendations are beyond the scope of this book. Factors that must be considered are normal fruit-to-fruit variation within a lot, seasonal and regional variability, degree of precision needed to predict acceptability and the capabilities of the analytical facilities. A compromise must be reached between collecting so few samples that resultant information is meaningless, and collecting more samples than can be analyzed accurately. Sampling plans should enhance the chances of detecting fruit-to-fruit variation in the lot at the expense of detecting variation in the methodology, such as by increasing the number of fruit analyzed but not duplicating measures on the same fruit. Two-tiered sampling plans are also useful, in which a certain result triggers more detailed sampling.

All quality management programs must be well-grounded in statistics, from the development of sampling schedules to the interpretation of results. Statistical methods cannot merely be added on to a fully developed management program, but must be integrated thoroughly into the entire process. Pitfalls to be avoided include:

1. under-collection of data so no valid conclusions can be drawn;
2. over-collection of data to answer questions that are not relevant to management problems;
3. subtle changes in collection techniques that invalidate the results; and
4. failure to appreciate and account for the dynamic changes that occur in senescing plant tissue.

Once specifications, including sampling schedules, have been established, every effort must be made to provide the necessary equipment, supplies and personnel at each sampling location. A full commitment to the quality program is needed to reap any benefits. Any scaling-back of monitoring efforts must be done only after a careful assessment of the implications of the changes.

IV. Maturity

Maturity at harvest is an important factor affecting quality perception and the rate of change of quality during postharvest handling. Thus, it is critical to obtain measures of maturity. An ideal maturity index can be measured non-destructively (Bergevin et al., 1995; Olmo et al., 2000; Nelson, 2003; Butz et al., 2005), is different at distinct levels of maturity and does not change with time of storage. Unfortunately, few such ideal measures exist. Maturity indices can be determined in many ways, including estimation of the duration of development; measurement of size, weight, or density; physical attributes such as color (Choi et al., 1995; Ferrer et al., 2005), firmness (Edan et al., 1997) and moisture or solids content; other chemical attributes such as starch, sugar, or acid content; or morphological evaluation. Development of such indices can help separate maturity effects from storage and handling effects, thus permitting more effective predictive modeling.

Maturity can be assessed in some crops by morphological examination. Most notably, mature green tomato fruit can be subdivided into four distinct physiological stages that cannot be distinguished by external visual evaluation. By slicing the fruit however, and looking at internal morphology, the stages can be distinguished by observing locular gel formation (Table 17.1). The difference in ripening to breaker stage in fruit not treated with exogenous ethylene is only 2–3 days for stage M4 and more than 16 days for stage M1 (Brecht, 1987).

Although the effects of maturity at harvest on quality and storage stability of numerous commodities are widely accepted, the use of maturity indices to separate maturity effects from handling effects has not been exploited sufficiently. Two techniques are available to quantify maturity effects:

- separate maturity into discrete classes and plot the change in a particular quality attribute of each class as a function of storage time;

Table 17.1 Scoring of "mature green" tomatoes based on visual evaluation of sliced fruit (Brecht, 1987)

Score	Gel formation	Color change
M1	None	None
M2	Observed in at least one but not all locules	None
M3	Observed in all locules	None
M4	Observed in all locules	Red coloration in one or more locules, but none on fruit surface

- treat maturity as a continuous variable and plot change in a particular quality attribute at distinct steps in the handling process as a function of the maturity index.

An example of maturity class plots, shown in Figure 17.1, is the interaction of maturity and cultivar on soluble solids development in kiwifruit during postharvest storage. In this specific case, harvesting Merced and Solano at a more advanced stage of maturity is more critical than harvesting Butte at a particular stage. Maturity specifications must be evaluated carefully under commercial conditions and might require some adjustment, but the process puts maturity evaluation on a much more solid scientific basis than does the generally accepted earlier-is-better approach.

An example of a maturity index as a continuous, dependent variable for summer squash is shown in Figure 17.2. In this specific case, a hue angle of 92° is the optimal hue for sensory color acceptance, indicating that a squash with an external length of 15 centimeters from proximal to distal end will have the best color acceptance within this defined system, which consists of 10 days from harvest to sale. Such plots provide a clearer picture of the optimal maturity range than the maturity class plots, but they must be viewed with some caution. Use of continuous indices is preferable when the index is highly accurate and can be measured precisely, and the relationship of maturity and quality is highly correlated. Both techniques are dependent on how closely the defined test system mirrors actual handling conditions. It can be seen that changes in storage duration within the system could have profound effects on recommended maturity levels. For example, shorter periods between harvest and sale would permit the sale of more mature (>15 cm) squash at optimal maturity, but might limit the sale of smaller squash that could be perceived as too green.

V. Measuring quality

A. Visual evaluation

Visual evaluation of quality characteristics by an expert judge, despite limitations, is still a widely used and accepted technique. Numerical scales for specific attributes are available for commodities when no chemical or physical measure is available that relates to a specific purchase characteristic (Gilles and Toivonen, 1995). Such scales are treated as objective measures, but they suffer from many of the problems of sensory analysis without having many of the safeguards of those techniques:

- Scoring is subject to variability by expert judges.
- It is almost impossible to “blind” the judge to treatments, particularly when the same samples are evaluated over time in a storage study.
- The full range of the scales is rarely used, since studies are usually stopped when the sample drifts into the lower (poor quality) end of the scale.
- Results tend to be analyzed assuming linearity of the scale, although no clear evidence exists in many cases that points on the scale are at equal intervals.

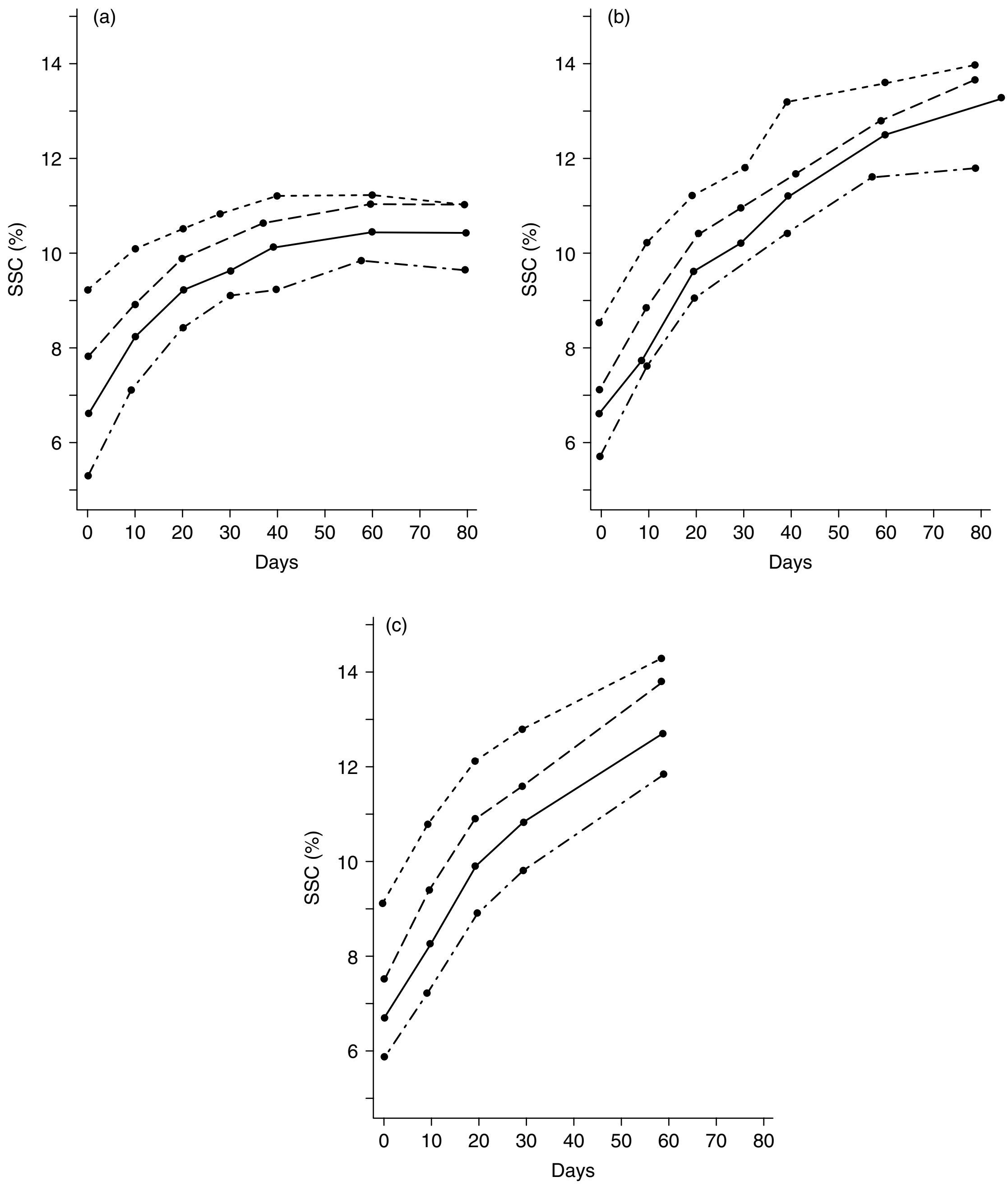

Figure 17.1 Effect of cultivar (A, Butte; B, Merced; C, Solano) and harvest maturity (1, –·–; 2, ——; 3, – –; 4, - -) on soluble solids development (SSC) in kiwifruit stored for 80 days at 0°C. Reprinted with permission from Crisosto et al. (1984). Am. Soc. Hort. Sci. 109(4), 584–587.

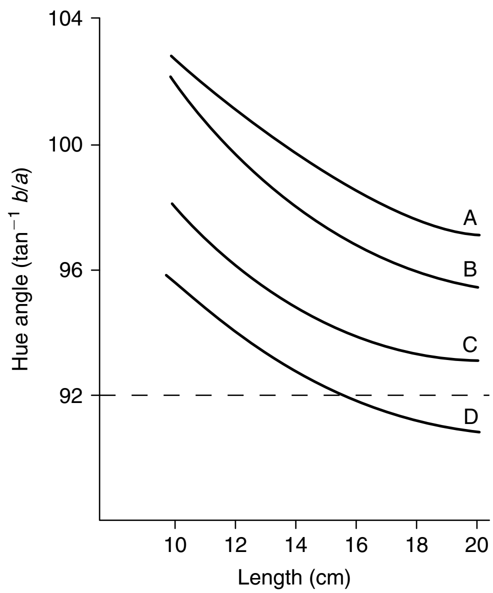

Figure 17.2 Effect of maturity (external length from proximal to distal end) and simulated handling step (A, packing house departure 1 day postharvest; B, wholesale warehouse arrival after 2 days at 5°C; C, wholesale warehouse departure after 4 days at 10°C; D, retail sale after 3 days at 10°C) on hue angle of summer squash. Hue angle of 92° was considered optimal by a sensory panel (— —).

On the other hand, an experienced judge can detect subtle changes well before any differences can be detected by instruments or sensory panels. Sample variability within a treatment, the short length of most storage studies (which frequently span weekends), and large sample size requirements prevent the use of sensory panels in experimental studies or for routine quality control checks.

When faced with the need to use a visual evaluation technique or another sense (such as smell) to evaluate quality without consumption, these guidelines are recommended:

- When possible, use a previously published scale so that results can be related to previous studies.
- Evaluate only those characteristics that relate directly to purchase quality attributes of the intended end use of the product.
- Select as the expert judge someone who has little or no detailed knowledge of the design of the study and no stake in the results (i.e. not the graduate student who designed the study).
- Use the same judge throughout each study or, in a quality control environment, minimize the number of judges. When possible, have two or more judges independently evaluate each item.
- Periodic discussions should be held to refresh the judge(s) on definitions of key terms. (These discussions, however, should never be conducted in the middle of an ongoing experiment in which it is essential to maintain consistency of interpretation.)

- The scale should be evaluated for its ability to predict likeability by an untrained consumer panel (30 or more panelists) for both the specific attribute(s) and overall acceptability.

B. Color

Measurement of color is an important means of quality assessment of food products. Although color of fruits and vegetables is an external manifestation of composition and form of plant pigments, a simple compositional analysis of extracted pigments does not necessarily predict visual impact. Fruit ripening and vegetable yellowing frequently involve the unmasking of yellow-to-orange xanthophylls and carotenes by the disappearance of chlorophyll (Chan and Ramaswamy, 2002). A direct measure of chlorophyll concentration however, is a poor predictor of the visual impact of broccoli color (Toivonen and Sweeny, 1998). Anthocyanins are the primary pigments in blueberries, present in the fruit in metal–ion complexes. When extracted however, the pigment is red with little resemblance to the purple coloration of whole fruit (Boulton, 2001). Coloration of anthocyanins is highly dependent on the intracellular environment, particularly pH (Holcroft and Kader, 1999). Traditional spectrophotometric methods for total anthocyanins (Prior et al., 1998), betalains (Fernández-López and Almela, 2001), chlorophyll (Gitelson and Merzlyak, 1997) and carotenoids are being replaced by HPLC methods that separate individual pigments. Published HPLC separation methods exist for anthocyanins (Wu and Prior, 2005), betalains (Fernández-López and Almela, 2001), carotenoids and chlorophylls (Almela et al., 2001).

Measurement of changes in pigments is important in understanding the physiology of ripening and senescence. In measuring changes in visual impact however, it is more important to detect physical changes in the appearance. Although appearance is a function of more than just color, and there are instruments available to detect these other factors (Voss, 1992), this discussion will focus on color measurement. Many color scales have been developed, but the predominant scale used for fruits and vegetables is the Hunter "Lab" or its variant CIE L*a*b*. For most applications, either scale provides meaningful information. Since most investigators are switching to the CIE L*a*b* system, it is the scale of choice. For the sake of simplicity, the following discussion refers to Lab.

In selecting color-measuring equipment, careful attention must be paid to the specific applications desired and the range of commodities or products to be tested. In the experimental stage, sample orientation and light aperture are critical. These factors are described in detail elsewhere (Clydesdale, 1991) and are not covered in this chapter.

The most frequent error in color measurement is the use of Lab results directly without conversion to hue, value and chroma. The primary reason food scientists use food colorimeters is that the readings are related to human color perception, which influences consumer acceptance of the product. Humans and colorimeters "see" color differently. Humans see the color of a product in terms of its lightness, hue (color name such as red, blue, or green) and chroma (brightness or saturation) by integrating some very complex signals into these three components. Colorimeters do not have the capacity to integrate directly, and thus must break the signal down into a

Table 17.2 Hypothetical example to demonstrate difference in yellowness of Golden Delicious apples as perceived by humans and instruments[1]

Apple	*L*	*a*	*b*	*b/a*	Hue angle
R	35	−5.0	+10.0	−2.00	120
S	35	−10.0	+12.5	−1.25	130
T	35	0	+7.5	4	90

[1]See text for explanation of abbreviations used.

simpler construct. Instruments "see" color in terms of lightness (L), red-green character in the absence of yellow or blue components (a) and yellow-blue character in the absence of red or green components (b). L, a, and b measures are machine language, whereas hue, chroma and lightness are terms that relate to human perception. Fortunately, we can convert the machine language, through some rather simple mathematical calculations, to numbers that have relevance to humans.

As soon as the specific terms of hue (for example, red or yellow) are used, different things are being said in machine and human terms. To the machine, an increase in yellowness is signaled by an increase in the magnitude of $+b$, whereas in human terms an increase in yellowness is signaled by the closeness of the hue angle ($\tan^{-1} b/a$) to 90°. Thus in human terms, the yellowness of a sample can increase even if the $+b$ reading decreases, as long as the $+a$ reading exhibits a greater decrease. Likewise, the yellowness of a sample can decrease even if the $+b$ reading increases, if the $+a$ reading exhibits a greater increase.

In the example shown in Table 17.2 and Figure 17.3, apple S is more yellow than apple R, which is in turn more yellow than apple T to the instrument. In terms of human perception however, the ranking of yellowness of the samples is just the opposite. Differences in chroma may also affect human perception in this case, but hue is usually more important in the perception of fruit and vegetable quality.

Although color is related primarily to maturity or purchase quality, it may also contribute to consumption quality. Johnson and Clydesdale (1982) show that dark colored beverages are perceived to be sweeter than lighter-colored counterparts presented with the same flavorings and sugar concentration. Flesh color of many fruits and vegetables may not be observed until the time of consumption, and may provide a different quality perception than external color. When measuring flesh color, the sample should be measured as soon after cutting the fruit as possible to avoid changes due to browning or desiccation. In addition, it is a good practice to clean any juice from the sample port between measurements. Other non-invasive techniques to measure fruit and vegetable appearance use radiant energy (Butz et al., 2005) or computer vision (Brosnan and Sun, 2004).

C. Texture

Firmness is the primary textural attribute measured in fruits and vegetables. Firmness is usually measured by destructive puncture tests, including handheld Effegi

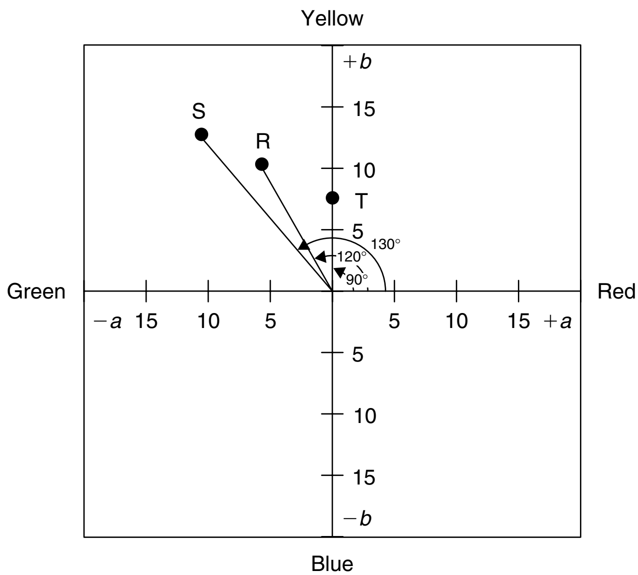

Figure 17.3 Illustration of the misleading conclusions drawn on use of "+b" readings to determine yellowness of a sample.

(Volz et al., 2003) and mechanized Instron tests (White et al., 2004). An indication of firmness is obtained by the force necessary to cause penetration of a standard probe a specified distance into the product. These tests are being replaced by more non-destructive tests (Macnish et al., 1997; Sugiyama et al., 1998; Cho and Han, 1999; Hung et al., 1999; De Ketelaere and De Baerdemaeker, 2001; Butz et al., 2005; Gomez et al., 2005). Non-destructive tests are particularly effective in sorting fruit by firmness, but may not be as effective in measurement in quality monitoring during handling and storage (Abbott, 2004). Sensory evaluation of apples was most likely to be predicted by puncture tests than other methods evaluated (Harker et al., 2002).

As in color measurement, sample presentation for textural analysis is important. The size of the surface area for puncture or deformation, the geometry of the sample, the means of support, and the interaction of the instrument and the sample all affect results. In puncture tests, a decision must be made about whether the peel should be retained or removed. In analyzing tomatoes, the peel is usually retained, but in analyzing peaches it is more often removed. Temperature of the samples can affect measurements and should be standardized. Penetration instruments yield data about firmness as a force. Thus the SI unit of force, the Newton (N), should be used to report all results; probe diameter must also be reported. For more details on measurement of food texture, see Bourne (2002).

D. Flavor

Chemical analysis of fruit and vegetable composition is used primarily to estimate consumption quality and hidden attributes. Sweetness is a function of sugar concentration and sourness a function of acidity. Consumer perception of sweetness or sourness is related to the ratio of sugars and acids, but the relationship is complex (Malundo et al., 1995; Crisosto et al., 2007). Sugar composition is usually estimated by measuring the percentage of soluble solids (°Brix) using a refractometer (Esti et al., 2002). Acidity is determined by titration with a standard base (Abegaz et al., 2004). More detailed analysis and separation of individual sugars and acids can be determined using HPLC (Sturm et al., 2003).

Volatile compounds are responsible for the distinctive aromas associated with fruits and vegetables. These compounds, in combination with taste sensations (sweet, sour and bitter), form characteristic flavors. The volatile constituents of numerous fruits have been isolated and characterized using chromatographic techniques. More than 200 volatile compounds are found in orange juice (Selli et al., 2003), and more than 300 in apples (López et al., 1998). Many fruits contain one or two volatile compounds, known as character impact compounds, which convey the flavor message. Examples of character impact compounds are nootkatone in grapefruit oil and 1-p-methyl-8-thiol in grapefruit juice, raspberry ketone, 4-(4′-hydroxyphenyl)-butan-2-one, and 3-mercapto-1-ethanol in passion fruit (Rowe and Tangel, 1999). Full aroma of any fruit however, is a subtle combination of many compounds, which is why duplicating fruit flavors in artificial beverages is so difficult. Determining the volatile compounds responsible for aroma and flavor is a complex task. The complexity of flavor, and our inability to relate peaks of a few compounds to consumer perception of flavor adequately, greatly limits our ability to incorporate flavor into quality evaluation programs. Presence of bitter compounds, such as limonene and naringen in citrus fruits (Braddock, 1995), or absence of a critical flavor component such as cis-3-hexenal in chilled tomato fruits (Maul et al., 2000) are examples of flavor problems identified using gas chromatography.

E. Nutrients

Vitamins and minerals are hidden attributes that affect consumer perception. Nutrient composition varies widely in raw commodities because of genetics, preharvest factors (soil fertility, moisture content of the soil, growth temperature, growth regulators and cultural practices), maturity at harvest and postharvest handling conditions (mechanical damage, storage times, temperatures, relative humidity, gaseous atmosphere and the use of additives). Despite the importance of these compounds, little is known about the rates of degradation of nutrients during postharvest handling (Shewfelt, 1990) with most of the emphasis on loss of vitamin C (Kalt et al., 1999; Lee and Kader, 2000). Consumers buy certain items as good sources of specific nutrients, for example, leafy green vegetables for vitamin A, oranges for vitamin C and bananas for magnesium and potassium. Without sophisticated analytical equipment however, the consumer cannot detect differences in individual products at the point of purchase (Shewfelt, 1999). Thus there is little incentive to measure nutrient content in a quality control program, unless specific nutritional claims can be made. The two most commonly measured nutrients in fruits and vegetables are ascorbic acid (vitamin C) and β-carotene (pro-vitamin A). Ascorbic acid (Asami et al., 2003) and β-carotene (Hart and Scott, 1995) are measured by HPLC. Mineral analysis is usually performed by ashing and atomic absorption (Aleotor et al., 2002).

VI. Sensory evaluation techniques

Known widely as "taste" testing, sensory evaluation incorporates a much wider range of senses than merely taste. Taste is the sense that detects chemical properties of foods in the mouth in the absence of aroma. Usually considered to be limited to sweet, sour, salty and bitter sensations, taste is probably more complex (O'Mahony, 1991). The sense of smell (Lawless, 1991) to detect aroma, which combines with taste to form flavor; sight (Clydesdale, 1991), which detects color and other appearance characteristics; kinesthetics, which detect textural attributes by hands and mouth (mouth-feel) (Szczesniak, 1991); and even sound (Vickers, 1991), which is an indication of crispness and crunchiness; can all play a role in an understanding of sensory perception of food quality.

A. Types of sensory tests

Sensory tests are divided into affective and analytical tests (Meilgaard et al., 2006). Affective tests provide information on the preference (liking one sample better than other) or acceptance (how much is a sample liked or disliked) of products. Analytical tests seek to determine the level of specific attributes or the sensitivities of panelists. Most postharvest studies and quality control tests are designed to answer questions that require affective tests, whereas most tests conducted tend to be analytical. Examples of questions requiring affective tests include:

- Which treatment results in the preferred product?
- Is this product acceptable and will it remain acceptable long enough to satisfy consumer needs?

Unfortunately, analytical sensory tests are not designed to provide meaningful answers to such questions.

A minimum of 24 untrained panelists is essential to place any confidence in affective test results; usually 50–100 panelists are needed to provide adequate information. A demographic profile of the panelists is important to provide insight into wider applicability of the results (e.g. 24 white Anglo-Saxon men might not provide an accurate projection of consumers in New York City). Score sheets typically ask panelists to rank the samples in order of preference or rate each product from 9 (like extremely) to 1 (dislike extremely), this is known as hedonic scaling. Ranking tests give more direct information about which sample is preferred, but give no information about how much a sample is preferred and why. Hedonic scales are treated statistically as linear equal-interval scales, although panelists tend to ignore both extremes. These scales are more readily adaptable to obtaining information about some specific attributes. A willingness-to-purchase scale from 5 (definitely would purchase) to 1 (definitely would not purchase) (Malundo et al., 1997) or an acceptability scale from 3 (tastes great) to 2 (acceptable) to 1 (unacceptable) (Dubost et al., 2003) are more useful measures of fruit and vegetable acceptability. Rather than being reported as a mean on the scale, willingness-to-purchase is expressed as a percentage of purchase acceptability.

Analytical tests can be subdivided into descriptive and discriminative tests. Descriptive tests measure and quantify specific attributes of a product, for example, sweetness, juiciness, or flesh color, whereas discriminative tests determine differences in samples and products. In descriptive tests, the panelist is asked to rate the intensity of a particular attribute on a scale. Two such scaling techniques are quantitative descriptive analysis (QDA) (Stone and Sidell, 2004) and magnitude estimation (Lawless and Heymann, 1997). An example of a QDA score sheet for peaches is provided in Figure 17.4. Note that the panelist is not asked to indicate which sample is preferred. For example, some panelists may prefer sweet apples whereas others prefer tart ones, but such opinions are not relevant to these tests. Descriptive tests provide important information about specific attributes and should be incorporated into any study where appropriate chemical or physical tests cannot be developed for critical consumption attributes. Normally, descriptive panels consist of 5–15 trained panelists, usually permanent support staff personnel. Experienced panels contain panelists with a familiarity with the terminology and quality characteristics of the product. Panelists have normal sensory acuity, in contrast with members of highly trained panels, who can detect subtle changes in a product. It is critical that, within a given study, changes in the composition of a panel are minimized. A panelist whose scores differ from the norm can still be useful if judgments are consistent, but can skew results greatly if they are present for only part of the study. Managers, who can rarely be tied down to a specific location at a specific time on a predictable schedule, and students, who tend to graduate, make poor panelists.

Discriminative tests can be subdivided further into difference and sensitivity tests. Difference tests such as paired-comparison, duo-trio, or triangle tests can be used to determine if two products differ from each other. Postharvest scientists have largely ignored this useful technique. An example is provided for fruit juices by Valliant et al. (2001). A difference test can be used to determine if a new handling technique results in a detectable difference in overall quality or in a specific attribute. For example, if a new handling technique is introduced to improve the firmness of fresh avocados during shipment, demonstration of detectable differences in firmness would provide strong support to adopt the technique. However, finding no significant difference is not equivalent to finding no difference! Statistical tests are designed to minimize the risk of a Type I error (stating there is a difference when none exists) at the expense of making a Type II error (stating there is no difference when one exists) (Freund and Wilson, 2002). Unfortunately, there are no simple tests to determine if a modification of a system (for example, changing pre-cooling temperature requirements) will result in a product of comparable quality. Standard tests can detect only significant differences in quality, if they exist.

B. Sample preparation and presentation

Sensory evaluation tests are usually performed in special facilities housing a number of individual booths. These booths should provide an atmosphere conducive to making sound judgments, clean, adequately lighted and ventilated, free from audio and visual distractions, equipped with a sink for rinsing and expectoration, with ready access to the food preparation area. Samples should be presented to panelists in a

SENSORY EVALUATION OF PEACHES

Name________________________ Date _______________ A.M./P.M. Set _______

Please evaluate these samples of peaches using the rating scales below. Place vertical marks on each of the scales to indicate your rating of each sample. Label each mark with the code number of the sample it represents.

THE SAMPLE CODE NOS. ARE: ______ ______ ______ ______ ______

YOU SHOULD HAVE SIX MARKS ON EACH SCALE WHEN YOU COMPLETE THIS.

FLESH COLOR	green	yellow	red-orange
FLAVOR Sweetness	too bland	about right	too sweet
Sourness	too bland	about right	too sour
Peach flavor intensity	weak	moderate	strong
Overall flavor intensity	weak	moderate	strong
Off-flavor (IF ANY)	slight	moderate	strong

DESCRIBE OFF-FLAVOR ____________________________________

PLEASE TAKE YOUR SCORE CARD TO THE KITCHEN AREA TO EVALUATE SAMPLES FOR COLOR, FIRMNESS TO THE TOUCH, AND OVERALL PREFERENCE.

FLESH COLOR	green	yellow	red-orange
OVERALL EXTERNAL COLOR	fair	good	excellent
FIRMNESS TO THE TOUCH	not firm	moderately firm	very firm

Figure 17.4 Sensory panel sheet for evaluation of peaches.

form in which and at a temperature at which the item is consumed normally. Samples should be coded in a fashion that will not bias a panelist (three digit codes extracted from a random number table are sufficient) and should be presented in a random fashion to avoid first or last sample biases. Consider the number of samples provided at a sitting to avoid panelist fatigue. Consuming an unsalted cracker between strong samples, such as raw onions, helps prevent carryover. Otherwise, a water rinse is usually sufficient. Distilled water is preferable, particularly if a pronounced flavor is present in tap water. Tests should be conducted at the same time each day, preferably not to interfere with normal break times or close to a normal mealtime. More details on panel environment and sample preparation are provided by Lawless and Heymann (1997), Stone and Sidell (2004) and Meilgaard et al. (2006).

Design of a proper questionnaire for a sensory test is critical. Does the questionnaire adequately address the test objectives? Is the questionnaire readily understandable using unequivocal language? Is it too long, so it taxes the panelist? Does it present the samples to the panelist in the same order in which they are presented physically? As in any other analytical test, attention to detail is essential to generate valid, accurate data from sensory tests.

C. Evaluating purchase and consumption attributes

Most sensory tests are associated with consumption attributes, such as flavor and mouth-feel. As described earlier, sensory evaluation may be the only valid measure for consumption attributes for certain crops. Purchase attributes can also be evaluated by sensory techniques. Color, other appearance attributes, firmness to the touch and aroma are purchase attributes that can be assessed. Usually, purchase attributes are not evaluated in booths, but are measured on a well-lighted counter top. No communication is allowed between panelists. Unless individual items are small (peas or blueberries, for example), they should be evaluated individually and not in clusters of 2 or 3. More samples can be evaluated for purchase attributes by a panelist, since fatigue is usually not as much of a factor as it is for consumption attributes. When measuring consumption and purchase attributes as part of the same test, it is usually preferable to perform consumption tests first, followed by purchase tests, since the latter are more likely to bias the former than *vice versa*. When filtered light is being used to screen out color differences however, some time must be permitted between consumption and purchase evaluation to adapt to normal lighting, or the purchase attributes should be evaluated first. In any case, coding of samples for purchase and consumption samples should be different. It is always tempting to compare purchase and consumption attributes, although experience has suggested consistently that purchase attributes are not reliable predictors of consumption attributes. One goal of a systems approach is to improve consumption quality, while maintaining acceptable purchase quality (Malundo et al., 1997).

D. Correlating sensory and physico-chemical results

Quality tests are only meaningful if they relate to consumer acceptance. In the absence of consumer acceptance data for many commodities, most chemical and physical tests are evaluated for their ability to correlate with sensory results. In many cases, simple correlation coefficients are used; a coefficient of 0.9 ($R^2 = 0.81$) is preferable and 0.8 ($R^2 = 0.64$) is considered acceptable. More sophisticated techniques have been developed using cluster analysis and factorial analysis (Krumbein and Auerswald, 1997), which help reduce the data required to discriminate between samples from multiple attributes to a few critical ones. In any decision-making process, it is critical not to let the level of statistical significance obscure the practical implications of the results.

VII. Quality in a systems context

Quality is only one of the factors that influence consumer acceptability of a fruit or vegetable, but it is the only factor that is intrinsic to the item, and is the factor most directly affected by handling and storage conditions. Quality can be divided into purchase, consumption and hidden attributes. Each commodity has a unique set of quality attributes desired by the consumer. Maturity and quality indices have been developed for many commodities to permit quality evaluation of an item through the system and to separate "maturity effects" from "handling effects." Sensory evaluation represents an important means of assessing quality, but it is frequently misapplied in postharvest experiments. An understanding of the interaction of production systems and subsequent handling steps to affect quality represents the greatest potential application of a systems approach to postharvest handling.

Bibliography

Abbott, J.A. (2004). Textural quality assessment for fresh fruits and vegetables. In: Quality of Fresh and Processed Foods, F. Shahidi, A.M. Spanier, C.-T. Ho, T. Braggins (eds). Kluwer Academic/Plenum Press, New York, NY, USA, pp. 265–280.

Abegaz, E.G., Tandon, K.S., Scott, J.W., Baldwin, E.A., Shewfelt, R.L. (2004). Partitioning taste from aromatic flavor notes of fresh tomato (*Lycopersicon esculentum*, Mill) to develop predictive models as a function of volatile and nonvolatile components. Postharv. Biol. Technol., 34, 227–235.

Aletor, O., Oshodi, A.A., Ipinmoroti, K. (2002). Chemical composition of common leafy vegetables and functional properties of their leaf protein concentrates. Food Chem., 78, 63–68.

Almela, L., Fernández-López, J.A., Roca, M.J. (2000). High-performance liquid chromatographic screening of chlorophyll derivatives produced during fruit storage. J. Chromatog., A870, 483–489.

Asami, D.K., Hong, Y.-J., Barrett, D.M., Mitchell, A.E. (2003). Comparison of the total phenolic and ascorbic acid content of freeze-dried and air-dried marionberry, strawberry, and corn grown using conventional, organic, and sustainable agricultural practices. J. Agric. Food Chem., 51, 1237–1241.

Auerswald, H., Schwarz, D., Kornelson, C., Krumbein, A., Brückner, B. (1999). Sensory analysis, sugar and acid content of tomato at different EC values of the nutrient solution. Sci. Hort., 82, 227–242.

Ayala-Zavala, J.F., Wang, S.Y., Wang, C.Y., González-Aguilar, G.A. (2004). Effect of storage temperatures on antioxidant capacity and aroma compounds in strawberry fruit. Lebens-Wiss. und Technol., 37, 687–695.

Baker, G.A., Crosbie, P.J. (1994). Consumer preferences for food safety attributes: A market segment approach. Agribusiness, 10, 319–324.

Bergevin, M., N'soukpoé-Kossi, C.N., Charlebois, D., Leblanc, R.M., Willemot, C. (1995). Assessment of strawberry maturity by photoacoustic spectroscopy. Appl. Spectr., 49, 267–402.

Boulton, R. (2001). The copigmentation of anthocyanins and its role in the color of red wine: A critical review. Am. J. Enol. Vitic., 52(2), 67–87.

Bourne, M.C. (2002). Food Texture and Viscosity: Concept and Measurement. Academic Press, San Diego, CA, USA.

Braddock, R.J. (1995). Byproducts of citrus fruits. Food Technol., 49, 74–77.

Brecht, J.K. (1987). Locular gel formation in developing tomato fruit and the initiation of ethylene production. HortScience, 22, 476–479.

Brosnan, T., Sun, D.W. (2004). Improving quality inspection of food products by computer vision – a review. J. Food Eng., 61, 3–16.

Butz, P., Hofmann, C., Tauscher, B. (2005). Recent developments in noninvasive techniques for fresh fruit and vegetable internal quality analysis. J. Food Sci., 70, R131–R141.

Causse, M., Saliba-Colombani, V., Lecomte, L., Duffé, P., Rousselle, P., Buret, M. (2002). QTL analysis of fruit quality in fresh market tomato: a few chromosome regions control the variation of sensory and instrumental traits. J. Exp. Bot., 53, 2089–2098.

Chen, C.R., Ramaswamy, H.S. (2002). Color and texture change kinetics in ripening bananas. Lebens.-Wiss. Technol., 35, 415–419.

Cho, Y.-J., Han, Y.J. (1999). Nondestructive characterization of apple firmness by quantitation of laser scatter. J. Texture Stud., 30, 625–638.

Choi, K., Lee, G., Han, Y.J., Bunn, J.M. (1995). Tomato maturity evaluation using color image analysis. Trans. ASAE, 38, 171–176.

Clydesdale, F.M. (1991). Color perception and food quality. J. Food Qual., 14, 61–73.

Crisosto, C.H., Crisosto, G.M., Echeverria, G., Puy, J. (2007). Segregation of plum and pluot cultivars according to their organoleptic characteristics. Postharv. Biol. Technol., 44, 271–276.

Crisosto, G.U., Mitchell, F.G., Arpaia, M.L., Mayer, G. (1984). The effect of growing location and harvest maturity on the storage performance and quality of "Hayward" kiwifruit. J. Amer. Soc. Hort. Sci., 109, 584–587.

De Ketelaere, B., De Baerdemaeker, J. (2001). PH – Postharvest technology advances in spectral analysis of vibrations for non-destructive determination of tomato firmness. J. Agric. Eng. Res., 78, 177–185.

Dubost, N.J., Shewfelt, R.L., Eitenmiller, R.R. (2003). Consumer acceptability, sensory and instrumental analysis of peanut soy spreads. J. Food Qual., 26, 27–42.

Edan, Y., Pasternak, H., Shmulevich, I., Rachmani, D., Guedalla, D., Grinberg, S., Fallik, E. (1997). Color and firmness classification of fresh market tomatoes. J. Food Sci., 62, 793–796.

Esti, M., Cinquanta, L., Sinesio, F., Moneta, E., Di Matteo, M. (2002). Physicochemical and sensory fruit characteristics of two sweet cherry cultivars after cool storage. Food Chemistry, 76, 399–405.

Fernández-López, J.A., Almela, L. (2001). Application of high-performance liquid chromatography to the characterization of the betalain pigments in prickly pear fruits. J. Chromatog., A913, 415–420.

Ferrer, A., Remón, S., Negueruela, A.I., Oria, R. (2005). Changes during the ripening of the very late season Spanish peach cultivar Calanda, Feasibility of using CIELAB coordinates as maturity indices. Sci. Hort., 105, 435–446.

Freund, R., Wilson, W. (2002). Statistical Methods. Academic Press, San Diego, CA, USA.

Gilles, S.L., Toivonen, P.M.A. (1995). Cooling method influences the postharvest quality of broccoli. HortScience, 30, 313–315.

Gitelson, A.A., Merzlyak, M.N. (1997). Remote estimation of chlorophyll content in higher plant leaves. Int. J. Remote Sens., 18, 2691–2697.

Gómez, A.H., Wang, J., Pereira, A.G. (2005). Impulse response of pear fruit and its relation to Magness–Taylor firmness during storage. Postharv. Biol. Technol., 35, 209–215.

Hampson, C.R., Quamme, H.A. (2000). Use of preference testing to identify tolerance limits for fruit visual attributes in apple breeding. HortScience, 35, 827–832.

Harker, F.R., Maindonald, J., Murray, S.H., Gunson, F.A., Hallett, I.C., Walker, S.B. (2002). Sensory interpretation of instrumental measurements 1: Texture of apple fruit. Postharv. Biol. Technol., 24, 225–239.

Hart, D.J., Scott, K.J. (1995). Development and evaluation of an HPLC method for the analysis of carotenoids in foods, and the measurement of the carotenoid content of vegetables and fruits commonly consumed in the UK. Food Chem., 54, 101–111.

Hoehn, E., Gasser, F., Guggenbuhl, B., Kunsch, U. (2003). Efficacy of instrumental measurements for determination of minimum requirements of firmness, soluble solids, and acidity of several apple varieties in comparison to consumer expectations. Postharvest Biol. Technol., 27, 27–37.

Holcroft, D.M., Kader, A.A. (1999). Controlled-atmosphere-induce changes in pH and organic acid metabolism of color of stored strawberry fruit. Postharv. Biol. Technol., 17, 19–32.

Hung, Y.-C., Prussia, S.E., Ezeike, G.O.I. (1999). Nondestructive firmness sensing using a laser air-puff detector. Postharv. Biol. Technol., 16, 15–25.

Jaeger, S.R., Rossiter, K.L., Wismer, W.V., Harker, F.R. (2003). Consumer-driven product development in the kiwifruit industry. Food Qual. Pref., 14, 187–198.

Kalt, W., Forney, C.F., Martin, A., Prior, R.L. (1999). Antioxidant capacity, vitamin C, phenolics, and anthocyanins after fresh storage of small fruits. J. Agric. Food Chem., 47, 4638–4644.

Kramer, A., Twigg, B.A. (1970). Quality Control for the Food Industry, 3rd edn, Vol. 3. AVI/van Nostrand Reinhold, New York, NY, USA.

Krumbein, A., Auerswald, H. (1998). Characterization of aroma volatiles in tomatoes by sensory analyses. Nahrung, 42, 395–399.

Land, D.G. (1988). Negative influences on acceptability and their control. In: Food Acceptability, D.M.H. Thomson (ed.). Elsevier, New York, NY, USA, pp. 475–483.

Lawless, H. (1991). The sense of smell in food quality and sensory evaluation. J. Food Qual., 14, 3360.

Lawless, H.T., Heymann, H. (1997). Sensory Evaluation of Foods: Principles and Practices. Springer, New York, NY, USA.

Lee, S.K., Kader, A.A. (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharv. Biol. Technol., 20, 207–220.

López, M.L., Lavilla, M.T., Riba, M., Vendrell, M. (1998). Comparison of volatile compounds in two seasons in apples: Golden Delicious and Granny Smith. J. Food Qual., 21, 155–166.

Macnish, A.J., Joyce, D.C., Shorter, A.J. (1997). A simple non-destructive method for laboratory evaluation of fruit firmness. Aust. J. Exp. Agric., 37, 709–713.

Malundo, T.M.M., Shewfelt, R.L., McWatters, K.H., Hung, Y.-C. (1997). Quality enhancement. In: Quality in Frozen Food, M.C. Erickson, Y.-C. Hung (eds). Springer, New York, NY, USA, pp. 460–477.

Malundo, T.M.M., Shewfelt, R.L., Scott, J.W. (1995). Flavor quality of fresh tomato (*Lycopersicon esculentum* Mill) as affected by sugar and acid levels. Postharv. Biol. Technol., 6, 103–110.

Maul, F., Sargent, S.A., Sims, C.A., Baldwin, E.A., Balaban, M.O., Huber, D.J. (2000). Tomato flavor and aroma quality as affected by storage temperature. J. Food Sci., 65, 1228–1237.

Meilgaard, M., Civille, G.V., Carr, B.T. (2006). Sensory Evaluation Techniques, 4th edn. CRC Press, Boca Raton, FL, USA.

Meiselman, H.L. (2006). The role of context in food choice, food acceptance and food consumption. In: The Psychology of Food Choice, R. Shepard, M. Raats (eds). CABI Publishing, Oxfordshire, UK, pp. 179–200.

Mizrach, A., Flitsanov, U., Fuchs, Y. (1997). An ultrasonic nondestructive method for measuring maturity of mango fruit. Trans. ASAE, 40, 1107–1111.

Nelson, S.O. (2003). Frequency- and temperature-dependent permitivities of fresh fruits and vegetables from 0.01 to 1.8 GHz. Trans. ASAE, 46, 567–574.

O'Mahony, M. (1991). Taste perception, food quality, and consumer acceptance. J. Food Qual., 14, 9–31.

Olmo, M., Nadas, A., García, J.M. (2000). Nondestructive methods to evaluate maturity level of oranges. J. Food Sci., 65, 365–369.

Peng, Y., Lu, R. (2006). An LCTF-based multispectral imaging system for estimation of apple fruit firmness: Part II. Selection of optimal wavelengths and development of prediction models. Trans. ASABE, 49, 269–275.

Prior, R.L., Cao, G., Martin, A., Sofic, E., McEwan, J., O'Brien, C., Lischner, N., Ehlenfeldt, M., Kalt, W., Krewer, G., Mainland, C.M. (1998). Antioxidant capacity as influenced by total phenolic and anthocyanin content, maturity, and variety of *Vaccinum* species. J. Agric. Food Chem., 46, 2686–2693.

Rennie, T.J., Vigneault, C., Raghaven, G.S.V., DeEll, J.R. (2001). Effects of pressure reduction rate on vacuum cooled lettuce quality during storage. Canadian Biosyst. Eng., 43(3), 39–43.

Rowe, D., Tangel, B. (1999). Aroma chemicals for the sweet field. Perfumer Flavorist, 24(6), 36–41.

Selli, S., Cabaroglu, T., Canbas, A. (2004). Volatile flavour components of orange juice obtained from the cv. Kozan of Turkey. J. Food Comp. Anal., 17, 789–796.

Shewfelt, R.L. (1990). Sources of variation in the nutrient content of agricultural commodities from the farm to the consumer. J. Food Qual., 13, 37–54.

Shewfelt, R.L. (1999). What is quality? Postharvest Biol. Technol., 15, 197–200.

Shewfelt, R.L., Brückner, B. (2000). Fruit and Vegetable Quality: An Integrated View. Technomic Press, Lancaster, PA, USA.

Shewfelt, R.L. (2000). Consumer-friendly specifications to meet the demands of a global market. Food Australia, 2, 311–314.

Sinesio, F., Di Natale, C., Quaglia, G.B., Bucarelli, F.M., Moneta, E., Macagnano, A., Paolesse, R., D'Amico, A. (2000). Use of electronic nose and trained sensory panel in the evaluation of tomato quality. J. Sci. Food Agric., 80, 63–71.

Stern, D.J., Buttery, R.G., Teranihsi, R., Ling, L., Scott, K., Cantwell, M. (1994). Effect of storage and ripening on fresh tomato quality. Food Chem., 49, 225–231.

Stone, H., Sidell, J.L. (2004). Sensory Evaluation Practices. Academic Press, San Diego, CA, USA.

Sturm, K., Koron, D., Stampar, F. (2003). The composition of fruit of different strawberry varieties depending on maturity stage. Food Chemistry, 83, 417–422.

Sugiyama, J., Katsurai, T., Hong, J., Koyama, H., Mikuriya, K. (1998). Melon ripeness monitoring by a portable firmness tester. Trans. ASAE, 41, 121–127.

Szczesniak, A.S. (1991). Textural perception and food quality. J. Food Qual., 14, 75–85.

Terry, L.A., Joyce, D.C., Adikaram, N.K.B., Khambay, B.P.S. (2004). Preformed antifungal compounds in strawberry fruit and flower tissues. Postharvest Biol. Technol., 31, 201–212.

Thomson, D.M.H. (1988). Food Acceptability. Elsevier Applied Science, New York, NY, USA.

Toivonen, P.M.A., Sweeny, M. (1998). Differences in chlorophyll loss at 13°C for two broccoli (*Brassica oleracea* L.) cultivars associated with antioxidant enzyme activity. J. Agric. Food Chem., 46, 20–24.

Vaillant, F., Millan, A., Dornier, M., Decloux, M., Reynes, M. (2001). Strategy for economical optimisation of the clarification of pulpy fruit juices using crossflow microfiltration. J. Food Eng., 48, 83–90.

Vickers, Z. (1991). Sound perception and food quality. J. Food Qual., 14, 87–96.

Volz, R.K., Harker, F.R., Lang, S. (2003). Firmness decline in "Gala" apple during fruit development. J. Amer. Soc. Hort. Sci., 128, 797–802.

Voss, D.H. (1992). Relating colorimeter measurement of plant color to the Royal Horticultural Society Colour Chart. HortScience, 27, 1256–1260.

Watada, A.E., Herner, R.C., Kader, A.A., Romani, R.I., Staby, G.L. (1984). Terminology for the description of developmental stages of horticultural crops. HortScience, 19, 20–21.

White, A., de Silva, H.N., Requejo-Tapia, C., Harker, F.R. (2005). Evaluation of softening characteristics of fruit from 14 species of *Actinidia*. Postharv. Biol. Technol., 35, 143–151.

Wu, X., Prior, R.L. (2005). Systematic identification and characterization of anthocyanins by HPLC-ESI-MS/MS in common foods in the United States: Fruits and berries. J. Agric. Food Chem., 53, 2589–2599.

18

Modeling Quality Attributes and Quality Related Product Properties

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I. Introduction

Major changes in consumer behavior and in understanding the technical possibilities of production have occurred in the last couple of decades in agriculture and horticulture. Consumers have become increasingly aware of the importance of fruit and

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vegetable quality (Benner et al., 2003, Batt, 2006; Fearne et al., 2006; Hewett, 2006); and put more emphasis on the quality of their daily food. While retailers govern the fruit and vegetable supply chain in all developed countries, they have to comply with changing consumer demands and preferences to stay competitive. The increasing number of food quality issues covered in the media has added to the awareness and concern of the consumer, increasing the challenge to the grower and retailer.

Another change results from drastically increased technical and technological capabilities to measure food quality, together with the technology of modeling and data analysis. Combining this information at both the level of product usage and at the level of research and handling possibilities, it becomes increasingly clear that a systematic approach to fruit and vegetable quality, handling and modeling is vitally important. The traditional way of thinking about quality and of developing empirical models and data analysis, has to expand to include all available knowledge and information. Consequently, models must include not only information contained in experimental data but also, and especially, information contained in chemical, physical and physiological expertise accumulated over decades of scholarship.

The ultimate goal of modeling is to predict the future behavior of any product, in any circumstance, from any region and grown in any season. Modeling is the modern version of analyzing and understanding laboratory and practical experiments (Tijskens, 2004). It should allow the transfer of experimental results to practical applications. The world of food supply chains however, and especially globalized fruit and vegetable supply chains, has grown increasingly complicated. The quality of produce from different areas and growing conditions is sometimes different from that expected, making the usual rules for quality control no longer generally applicable. Traditional models, mainly statistical or empirical models, are no longer sufficiently reliable to predict quality. We have to include all (as much as possible) available knowledge, both in the preharvest realm (i.e. fruit and vegetable production) and in the postharvest phase (i.e. distribution, processing, sales and service). The barrier between both areas needs to be breached, so that ideas and information can be exchanged. However, communication between the two areas is often problematic (Tijskens and van Kooten, 2006) due to differing viewpoints on quality and importance. Process oriented modeling, based on knowledge of the processes occurring, is a system of modeling that provides a feasible approach to integrate the preharvest and postharvest areas (Tijskens, 2004; Tijskens et al., 2001).

This chapter attempts to achieve just that by presenting an expanded view on quality, modeling and modeling of quality. Since the variation in properties of individual items in a batch of commodities accounts for a large part of the problem in understanding and dealing with product behavior, special attention is devoted to the omnipresent biological variation and how to use it for competitive advantage.

II. What is quality?

When applying a systems approach to modeling, built on the processes active in commodities that change their behavior and quality over time, we also need a framework for quality within the same paradigm of system approach. As long as man is concerned with the quality of food, he will attempt to define that notion (see Chapters 3, 8, 9, 11, and 17). Sometimes, it is assumed that it is easier to define quality in terms of levels of attributes or properties for large groups of consumers. The problem with this approach is that each individual perceives quality differently. Consequently, every possible definition is of limited use. To deal with the variation between individuals in developing quality models, Sloof et al. (1996) developed working concepts on quality that proved to be successful outside the modeling framework as well.

The framework (Figure 18.1) was adapted evaluating the modeling requirements for globalization in the fruit and vegetable supply chain (Tijskens et al., 2006a) and for quality assurance (Tijskens et al., 2005a). The main assumption behind the framework is that the processes by which humans evaluate the quality of any commodity are likely to be highly similar in every human being, regardless of culture, upbringing and social circumstances. Differences among individuals, regions, states, societies and cultures come about because of the difference in applied limits and "initial conditions" (Brückner, 2006). Although obtaining suitable data on human behavior in assessing quality, and whether or not they purchase a particular commodity, is still far out of reach, psychologists are increasingly convinced these premises are applicable (personal communication R. de Wijk). Nevertheless, the fact that obtaining suitable data is virtually impossible should not prevent consideration of that framework.

Quality is assigned to a commodity by the buyer or consumer (Figure 18.1 shows the center of scheme), based on the perceived properties of a particular specimen. Consumers perceive those properties (e.g. sugar content) and convert them into attributes (e.g. sweetness). The value of a particular product is also assigned, by the user, based on the market situation (assigned value). Based on the social circumstances of the evaluator (user, buyer), and the intended use for the commodity, a usability is assigned (assigned usability). Consumers ultimately use all three assigned notions to decide whether to accept a product.

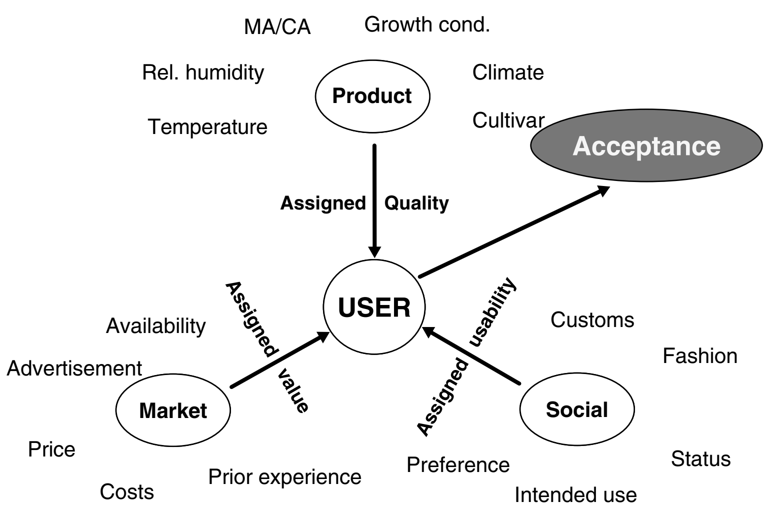

Figure 18.1 Schematic representation of quality and acceptance.

Figure 18.1 shows that on the first assigned item, quality, some information is available. With respect to modeling quality, that intrinsic or assigned quality depends almost exclusively on the quality attributes of the product, and hence on properties of that product that are related to the attributes under consideration. On the last two assigned items (value and usability) however, not much is known (Botonaki et al., 2006). Modeling acceptance is, therefore, much more difficult and cumbersome if the market situation and the social circumstances vary, because economical and psychological issues also come into play. Although there is increased interest in this area (Moskowitz, 2005; Morris and Young, 2000), as already mentioned, not much is known about the economical and psychological items in a systems approach framework.

Kramer and Twigg (1983) defined quality as:

> "The composite of those characteristics that differentiate individual units of a product, and have significance in determining the degree of acceptability of that unit by the buyer."

Their definition clearly connects acceptability to product properties and attributes (here called characteristics). The keeping quality of products, that is the time a product remains acceptable during handling and storage, is closely related to acceptability (Rico et al., 2007; Tijskens et al., 1996a,b). At the same time, the definition of Kramer and Twigg stresses the importance of the difference between units of product, which is actually the biological variance present in a batch of individual items.

Consumer acceptance based on product attributes has been the subject of studies and reports on its own (Crisosto et al., 2003, 2006; Berna et al., 2005; Tomlins et al., 2007). However, research on consumer acceptance and its effects on post-harvest technology applications will remain very cumbersome without an attempt to base this on fundamental models (Schouten et al., 2007a,b).

A. Attributes versus properties

A consumer assigns attributes to a product based on its relevant properties (Figure 18.1). For practical application, the differences between product properties (physical, chemical) and quality attributes (psychological) are not that important. In fact, sometimes the differences between properties and attributes are not very clear.

However, for the sake of developing theories and viewpoints and for research in the area of quality and human behavior, it is of utmost importance to understand the difference. This is particularly true when a variable is measured using objective measuring techniques, when the variable is often assumed to be a property. A good example is color. Does a tomato in pitch darkness have a color? We cannot judge that, since we need light to observe it. What a tomato always has however, whether or not we observe them, are color compounds such as chlorophyll or lycopene. Therefore, the properties related to the attribute color are light absorbing compounds.

It is important to note that, frequently, so-called objective measuring techniques are designed in such a way that the impact of human sensitivity on the factor is already incorporated in the measuring technique. Again, color is a good example: the well-known L*a*b* color space does reflect the sensitivity of the human eye by the choice of wavelengths used.

Firmness can also be regarded as an attribute based on the properties of strength generating compounds. Many of the objective firmness-measuring techniques do reflect the way humans observe product strength while chewing, bending, breaking or touching the product. When dealing with this type of data, it is important to realize the nature of the variable measured, in order to deduce the proper framework of reasoning.

Most of the time attributes are based on more than a single property, while properties may affect several attributes. The relationships between properties and attributes are very complex and still not well understood. Table 18.1 shows some examples. A more elaborate example from texture research can be found in Table 18.2, as reported by Tijskens and Luyten (2004) based on the work of de Wijk et al. (2003).

B. Assigned quality versus acceptance

From the definition by Kramer and Twigg (1983, see previous section) and the representation of quality relations (Figure 18.1), it is clear that assigned (or intrinsic) quality differs from product acceptance. The concepts are highly related to one another in a more or less unidirectional way: assigned quality can exist without acceptance however, acceptance never occurs without quality. In the latter case, other issues such as availability or cost (Figure 18.1, market), or personal preference (Figure 18.1, social), come into play in the context of acceptance. The principles of acceptance of potted plants based on assigned quality are described in Tijskens (2000) and Tijskens et al. (1996a). Recently, a similar approach has been applied to obtain information of consumer buying behavior for tomatoes (Schouten et al., 2007a,b), based on color and firmness as limiting attributes.

Table 18.1 Relations between most common sensorial attributes and physical or chemical properties of fruits and vegetables

Attribute	Property
Color	Amount/concentration coloring compounds Wavelength light
Texture	Amount/concentration strength generating compounds Tissue structure Cell size
Sweetness	Amount/concentration sugars Amount/concentration acids
Flavor	Amount/concentration aroma compounds Texture (ripeness) Adsorbent properties tissue

Table 18.2 An illustration of the complexity in the attribute-property relations using the example of mayonnaise and custards

Physical property	affects	Sensorial property
Viscosity		Thickness, stickiness, compactness, melting, creaminess
Density		Compactness
Particle size		Compactness, creaminess
Adhesion		Thickness, stickiness
Concentration of flavoring compounds		Creaminess
Sensorial property	**relates to**	**Physical property**
Thickness		Viscosity, adhesion
Stickiness		Viscosity, adhesion
Compactness		Viscosity, density, particle size
Melting		Viscosity
Creaminess		Viscosity, particle size, concentration of flavoring compounds

Source: de Wijk et al. (2003)

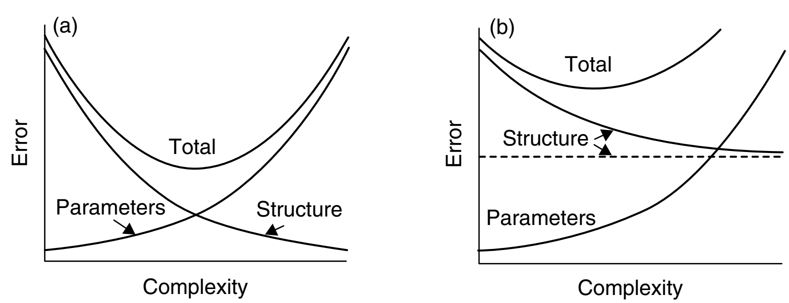

Figure 18.2 Notional components of prediction error in models of increasing complexity: (a) when the structure of the system is well understood; (b) when the model structure or the mechanism applied is wrong, with the irreducible structural error represented by the dotted asymptote. Complexity and error increase away from the intercept. Source: Passioura (1996). Courtesy of Agronomy Journal.

In most cases laymen mean acceptance when referring to quality. Even in scientific publications, more often than not, quality is used in the meaning of acceptance. However, the concepts are not the same. For economic purposes, commercial companies are much more interested in product acceptance than in product quality. In that sense, acceptance is more important than assigned quality. On the other hand, without quality the acceptance of the commodity is at risk.

In summary, both product acceptance and product quality are extremely important, sometimes hard to discern, and pose a challenge to model. A direct consequence of the applied quality philosophy, however, is that as long as one is primarily concerned with assigned or intrinsic quality, and does not include economic or socio-psychological aspects, the modeling approach can be based entirely on the behavior of relevant product properties. If economic and social issues are also to be considered, modeling becomes very difficult, not because of practical or mathematical reasons, but because of the sheer differences in expertise and level of understanding in the three areas of product, market and consumer research.

III. Systems approach in modeling

Many scientists consider modeling to be very difficult, highly mathematical and far out of reach. However, modeling is as old as science. Every conclusion based on scientific research is, in fact, a model. Not a mathematical model but a conceptual one, often applied inconsistently and variably, but nevertheless a model.

Modeling in agriculture started in the late sixties with, among others, the work of Thornley (1976) and the school of C.T. De Wit at what is now Wageningen University and Research Centre (de Wit, 1968; Wierenga and de Wit, 1972; de Wit and van Keulen, 1972; van Keulen et al., 1976). For several decades, these traditional empirical/statistical models induced a tremendous impetus in agricultural research and optimization, especially in the area of production, both in open fields and in greenhouses.

However, the technology of modeling has improved considerably over the last decades. Parameter estimation on measured data can now be based easily on non-linear regression analysis (statistical packages like SAS, Statistica, Genstat, R-Project); mechanisms can be automatically converted into differential equations and (possibly) solved for analytical solutions (e.g. Maple 10, MapleSoft, Waterloo Maple Inc., Waterloo, Canada or Mathematica, Wolfram Research, Inc., Champaign, IL, USA). These technical developments enable the use of conceptual models, directly derived from available expertise, and the use of all laws of nature and scientific rules of disciplines in developing improved, more reliable and more understandable models.

A. Process oriented modeling versus statistical models

The main and mostly only source of information for traditional mathematical models is data gathered during experiments. The expertise and rules of statistics and data analysis are applied. Very often these types of models are developed, extended and refined over several years or even decades, often with amazing applicability.

However, those models generally ignore existing expertise and scientific knowledge. Concepts of processes occurring in nature, which are part of expert knowledge of a particular area of research, are much more valuable in general application, as well as in understanding power, than mere mathematical or statistical models. For example, William of Ockham (a fourteenth-century logician) was right with Ockham's razor (make models as simple as possible), but statisticians have wrongly translated his wisdom into tests on the number of parameters in the model (e.g. goodness of fit).

As Passioura reported (1996), a clear relationship exists between the estimation error (or goodness of fit measures), the structure of a model, the number of parameters in the model, and the complexity of the model. A minimum number of parameters only provide an (statistically) improved, more useful model for very simple models (Figure 18.3). In more complex models, decreasing the number of parameters as much as possible seems futile. The structure of the model (which processes need to be included) becomes much more important. Ockham's razor can be applied to deciding which processes that occur in the product are important, and which must be disregarded, to arrive at models applicable in practice. In other words, the problem has to be decomposed into the constituting processes (Sloof, 2001). Simplification needs to be done on the level of processes to be included or excluded, and not on the level of mathematics and statistics.

Fundamental rules of disciplines (e.g. chemical kinetics), and the laws of nature (e.g. basic physics), are well established. Besides the use of statistical and mathematical skills, these rules and all the available expertise should be used fully in building models for complex and variable fields, such as agriculture and food. Data gathered can and must be used only for setting up the problem framework, and finally for calibration and validation of the developed models.

By including all available fundamental knowledge at our disposal, we achieve the ultimate goal of modeling: the prediction of future behavior in any circumstance, from any region, grown in any season, while generating more knowledge about the process under study. This approach yields the so-called fundamental process oriented model. Research on modeling the effects of globalization of the fruit and vegetable trade is, as far we are aware, non-existent. Effects of different batches, seasons (both within one year and from year to year), harvest maturity, and field management conditions are abundant. Proper interpretation with a global view, however, is mostly absent. By considering these differences, we basically deal with biological variation. Lately reports have covered this subject (Hertog, 2002; Hertog et al., 2004; Schouten et al., 2004a; Tijskens et al., 2003, 2005c). These reports indicate that it should be possible to interpret experimental data in a global context applying process oriented modeling.

The most basic rule of modern science is that of the repeatability of experiments. Under the same conditions, the same set-up and ingredients should provide identical results. This means, for example, that the rate constant of chemical reactions should be the same, regardless of the level of reactants present. Considering that many, presumably most, processes occurring in food products are of a chemical nature, the rate constant of a process has only to be determined once in the controlled circumstances of a laboratory, and henceforward, can be reused in different situations outside the laboratory. Moreover, a rate constant has to obey the fundamental rule of temperature dependence, according to Arrhenius' or Eyring's law (van Boekel and Tijskens, 2001). If, during model development and calibration, the rate constant of a process does not meet these requirements, either a wrong mechanism was selected or more processes are active than were considered in the model. The decomposition of the problem was improper (Sloof, 2001).

Applying the fundamental rules and problem decomposition in a systems approach to build process oriented models are a few of the powerful tools capable of describing phenomena under any circumstances in the fruit and vegetable supply chain. The next sections discuss examples of this approach applied to quality behavior in any link of the supply chain.

B. Area of dedication

Traditional empirical and/or statistical models are frequently specified for a dedicated application or for one factor in the supply chain (growing, storage, transportation, etc.). When building models based on occurring processes, however, it does not matter where the product is in the chain or what conditions are imposed on the product. For the occurring processes, for example degreening, it is not important whether they occur in storage or during transport. The mechanism will be the same, as will be the derived model. Therefore, models developed based on the mechanism of occurring processes have a much wider application throughout the entire supply chain. Moreover, data gathered in different parts of the chain can be pooled and analyzed, increasing their applicability and reliability.

IV. Examples of modeling

Firmness and color are the main attributes of the majority of agricultural commodities, because they are important to consumers and the trade. Moreover, firmness and color can both be measured quite easily. Because both of these attributes have been measured for some time, a lot of knowledge has been accumulated. That does not mean that other quality attributes (e.g. sugar content, acid content, taste, flavor, juiciness) are less important for fruit and vegetables, but merely that there is less opportunity to analyze them because of the relatively more difficult measurement procedures. The majority of examples in the next sections are predominantly concerned with color and firmness of fruit and vegetables. In all examples, color and firmness must be defined, to deal properly with changes in these attributes.

Color is generated by coloring compounds, such as chlorophyll, pheophytine, lycopene and anthocyanins, by reflection or absorption of incident light as observed by human senses. Changes in observed color can be caused by any of the three major constituents: the senses, the light and the content of coloring compounds. For practical product research, incident light and senses are kept or considered constant, while the coloring compounds are items to be described and modeled. When the target area is changed, for example, to consumer research (what are possible differences between population segments?), the models developed for product research should not be translated or reused without considering the possible effect of changes in perception. However, in product research, the main focus is on the chemistry of the coloring compounds involved in the product under study.

Most horticultural products are green (chlorophyll) at some stage of development, but towards maturity a whole range of colors and coloring compounds develop. Chlorophyll content is, or should be, a good reference when considering maturity and ripening in any stage of development. The specific coloring compounds that develop on ripening (red tomatoes, yellow bananas, brown nuts) can also be used for this purpose, but only in the later (more critical) stages of maturity. The typical red coloration (for example, the blush in nectarines, apples) caused by anthocyanins is, most of the time, primarily related to the amount of sunlight received during growth and is hardly related to that part of quality that is affected in postharvest handling.

Firmness can originate from different sources. Most common sources are pectines, cellulosic structuring material, cell turgor, granules inside cells, shape and size of cells (van Dijk and Tijskens, 2000; Tijskens and Luyten, 2004). Firmness is measured by applying a force to a structure. Again, the observer and the type and circumstances of the force applied may affect firmness. Objective firmness is measured by a standardized procedure using a machine. Non-standardized human forces and senses are used in subjective assessment. Again this is the major difference between product research and consumer/sensory research.

The different sources of firmness directly affect the development of models. Sometimes, but rarely, only one source of firmness is present in a commodity. In that case, modeling of firmness is rather straightforward by focusing on that one process. More frequently multiple sources of firmness are present. In those cases, each source of firmness can change at its own rate in actual conditions under study, including a no change (zero rate). The latter case is the most common effect of multiple sources of firmness: firmness does not decay towards zero, but to a fixed end-value. However, one has always to be aware of multiple processes acting concurrently on multiple sources of firmness, and take these into consideration when building a model on firmness.

A. Models for storage

Color

Changes related to chlorophyll breakdown and pheophytine production are the most common color changes in fruits and vegetables during storage. The most frequent behavior of color, especially expressed in the $L^*a^*b^*$ system, shows a sigmoidal pattern that is modeled using a logistic function (see Table 18.5 for notation):

$$col = \frac{col_{\max} - col_{\min}}{1 + \left(\dfrac{col_{\max} - col_0}{col_0 - col_{\min}}\right) \cdot e^{k_{col} \cdot (col_{\max} - col_{\min}) \cdot t}} + col_{\min} \tag{18.1}$$

The logistic equation, of which Equation 18.1 is just a specific case, has been used empirically to describe various kinds of sigmoidal behavior. The equation, however, can be deduced assuming an autocatalytic reaction:

$$\begin{aligned} col_{pre} + Enz &\xrightarrow{k_{col}} col + Enz \\ Enz_{pre} + Enz &\xrightarrow{k_{Enz}} 2 \cdot Enz \end{aligned} \tag{18.2}$$

This reaction can progress under the influence of an enzyme (*Enz*) or ethylene. Using the application of the fundamental rules of chemical kinetics, including mass conservation laws, and the assumption that the two rate constants are the same, the analytical solution results in Equation 18.1. When the two rate constants are different, a more elaborated model describes an asymmetrical sigmoidal behavior often found in preharvest growth phenomena (Tijskens and van Kooten, 2006):

$$Col = \frac{Col_0}{(Enz_0 + Enz_{pre,0})^{-\frac{k_{col}}{k_{Enz}}}} \cdot \left(Enz_{pre,0} + e^{(k_{Enz} \cdot (Enz_0 + Enz_{pre,0}) \cdot t)} \cdot Enz_0\right)^{-\frac{k_{col}}{k_{Enz}}} \tag{18.3}$$

In Figure 18.2, an example is shown for both types of behavior. Although the models cannot be considered fully kinetic models (the mechanisms are not proven, only assumed), the meaning of their parameters can be clearly described. Some model parameters are concentrations or related to concentrations (*Enz*, *Col*), while others are reaction rate constants (*k*). From the rules of chemical kinetics, one can deduce that reaction rate constants inherently depend on temperature, according to the fundamental rules such as Arrhenius (Equation 18.4) or Eyring, found in textbooks on chemical or enzymatic kinetics:

$$k = k_{ref} \cdot e^{\frac{Ea}{R} \cdot \left(\frac{1}{T_{ref}} - \frac{1}{T}\right)} \tag{18.4}$$

Heaton and Maragnoni (1996) and van Boekel (1999, 2000) provided extended descriptions of the mechanism involved in change of color in horticultural products, in terms of the concentration of different coloring compounds. Schouten et al. (2002) applied part of that mechanism to describe the color changes in cucumbers

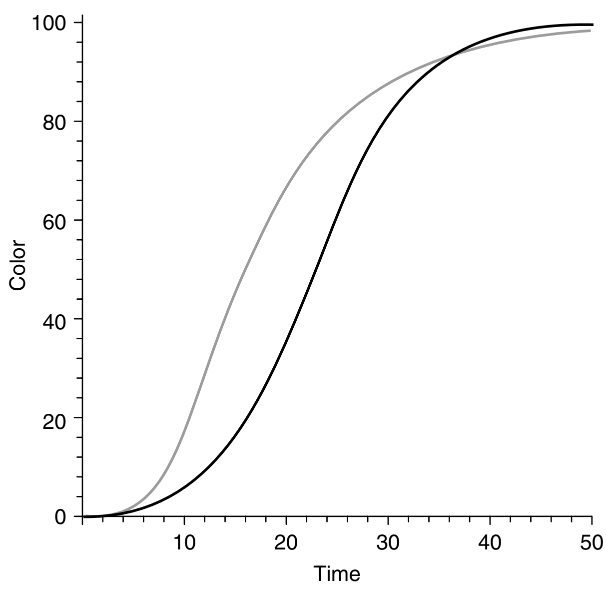

Figure 18.3 Behavior of the symmetrical (black line) and asymmetrical (grey line) sigmoidal function according to Equations 18.1 and 18.3, using $Col_{max} = 100$ and $Col_{min} = 0$. All parameter values and time units are arbitrarily selected.

(expressed in RGB value from computer imaging), including the sometimes observed deepening of the green color in the early part of storage in the dark.

Firmness

Changes in firmness of horticultural products can be caused by a plethora of reactions. For fruit of deciduous trees, the major cause of softening is pectin degradation. For fruit from shrubs and herbs and for vegetables (like currants, strawberries, grapes) the major cause is moisture loss. However, firmness and changes in firmness of horticultural products cannot be attributed to a single cause. A possible mechanism is depicted in the following simple reaction:

$$\begin{aligned} F_1 &\xrightarrow{k_{f,1}} decay \\ F_2 &\xrightarrow{k_{f,2}} decay \\ F_3 &\xrightarrow{k_{f,3}} decay \end{aligned} \tag{18.5}$$

where F_1, F_2 and F_3 are possible sources of firmness. The observed firmness is, then, related to the total of all items involved. Not all of the sources of firmness have to change under the same conditions. For some of them the rate of change is so low that no change can be observed in the period of study. The application of the fundamental rules of chemical kinetics and the solution of the derived differential equations for constant external conditions (such as temperature) yields:

$$F = F_{1,0} \cdot e^{-k_{f,1} \cdot t} + F_{2,0} \cdot e^{-k_{f,2} \cdot t} + F_{3,0} \cdot e^{-k_{f,3} \cdot t} \tag{18.6}$$

The three reactions in Equation 18.5 can all obey different relations with temperature. Equation 18.6 indicates that at different storage temperatures an apparently completely different behavior is observed. Figure 18.4a shows an example for some imaginary fruit stored at seven temperature levels (0°C to 30°C in 5°C increments) using parameter values from Table 18.3. At low temperatures, only the first reaction actually takes place, while at higher temperatures the second reaction also starts to develop, due to the higher activation energy (*Ea*). The third reaction is kept constant ($k_{f,3}$ is zero). Figure 18.4a, while maintaining an apparent exponential behavior for each series separately, indicates a change in asymptotic end-value with increasing temperatures. This behavior is frequently found in measured data, but is rarely taken into account.

All kinds of variations on this central mechanism (Equation 18.5) can occur. In horticultural products, almost all reactions are catalyzed by some enzyme (*Enz*). When the enzyme activity is (virtually) constant during storage, the results are similar to those depicted above. However, batches of different origin may have different levels of enzyme activity. Consequently, the apparent rate of change may vary from batch to batch, depending on, for example, growing conditions and maturity at harvest. This complex mechanism can simply be represented as:

$$\begin{aligned} F_1 + Enz &\xrightarrow{k_{f,1}} decay + Enz \\ F_2 + Enz &\xrightarrow{k_{f,2}} decay + Enz \\ F_3 + Enz &\xrightarrow{k_{f,3}} decay + Enz \end{aligned} \tag{18.7}$$

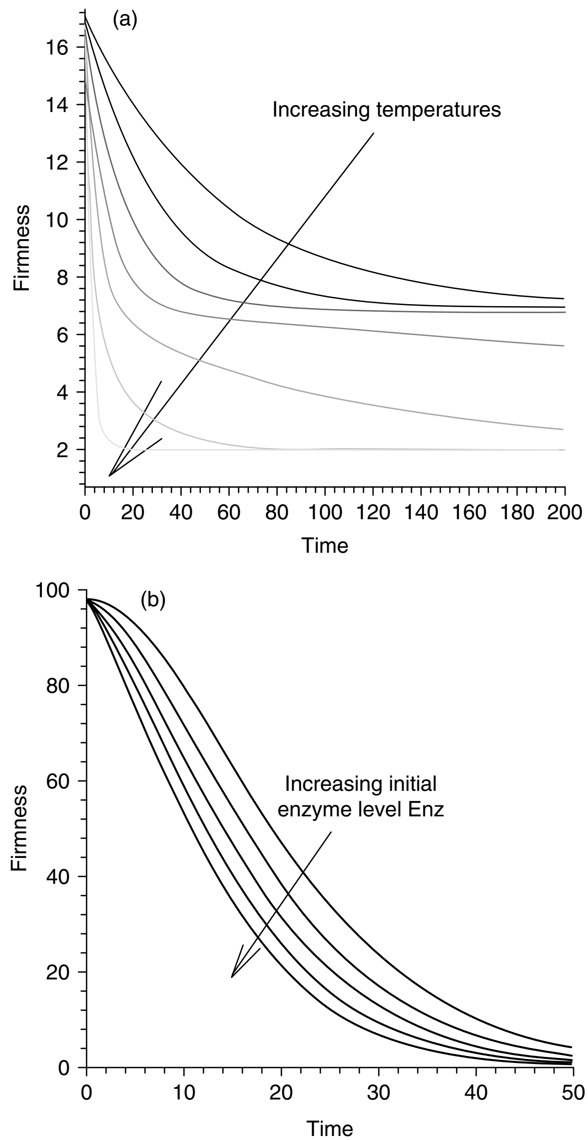

Figure 18.4 Firmness behavior according to Equation 18.6 based on parameter values as shown in Table 18.3. (a) at different levels of temperature. The model includes different sources of firmness, that start changing only at higher temperatures, reflected in the different level of the asymptots as the time increases. (b) at different levels of initial enzyme activity, indicating the increasing rate of decay with increasing enzyme activity, thereby changing the apparent behaviour of softening (from sigmoidal to exponential).

The result is an equation similar to Equation 18.6, but includes the rate constants multiplied by the actual enzyme activity. However, different enzymes could catalyze each reaction. In that case, the situation rapidly becomes very complex. The approach to achieve a feasible model however, is highly similar to the mechanism shown in Equation 18.7.

Table 18.3 Parameter values for Equation 18.6 used for simulation in Figure 18.3a

Reaction	$F_{x,o}$	$k_{f,x}$	Ea_x
1	10	0.2	80
2	5	0.01	250
3	2	0	0

Note: Dimensions and values selected completely arbitrary.

Table 18.4 Simulation parameters (Equation 18.8 and Figure 18.3b)

Parameter name	Value
F_0	100
$Enz_{pre,0}$	1
Enz_0	0–0.41
k_f	0.1
k_e	0.05

Note: Dimensions and values selected completely arbitrary.

When the enzyme activity is not constant during storage but, for example, increases, a completely new situation arises. The mechanism of enzyme change will have a profound effect on the observed behavior. A possible mechanism is shown in Equation 18.8:

$$\begin{aligned} F + Enz &\xrightarrow{k_f} decay + Enz \\ Enz_{pre} &\xrightarrow{k_e} Enz \end{aligned} \tag{18.8}$$

where F is again the firmness (only a single source), k the rate constant, and Enz the available enzyme activity. Subscript *pre* indicates a precursor, f for firmness and e for enzyme. Figure 18.4b shows an example for increasing initial levels of Enz activity using parameters values shown in Table 18.4. With higher levels of Enz_0, the enzyme activity at the moment of harvest, the firmness breakdown does resemble the normally found exponential behavior. On the other hand, when the level of initial enzyme activity is very low, the behavior resembles the sigmoidal behavior, frequently modeled using the logistic curve (Equation 18.1). For example, such behavior was found in ripening nectarines (Tijskens et al., 2007).

Another possible situation is when one of the reactions in Equation 18.5 or 18.7 is inhibited by controlled atmosphere (CA), and the other is not. CA slows physiological

Table 18.5 Description of notation and subscripts used in equations legend of symbols

Name	Description
Col	Color (any type)
decay	Unnamed decay product
Ea	Activation energy
Enz	Enzyme activity
F	Firmness
k	Reaction rate constant
P	Density function
Pr	Probability function
Q	Quality
q_a, q_b	Lower and upper limit quality class
t	Time
T	Temperature
Δt	Time shift/biological shift factor
μ	Mean value
σ	Standard deviation or biological variation
Φ	Cumulative normal probability function
All dimensions are arbitrary unless indicated	
Subscripts	**Description**
col	Color
Enz, e	Enzyme
f	Firmness
fix	Invariable part/asymptotic end-value
post	Postharvest conditions
max	Maximum value
min	Minimum value
pre	Precursor or preharvest conditions
ref	At some reference
0	Initial/at harvest
1	Source 1
2	Source 2
3	Source 3

aging reactions in many fruits and vegetables by decreasing the product's respiration. Application of CA conditions would then lead to a behavior as depicted in Figure 18.4, now not as a function of temperature, but of the intensity of the CA condition. Tijskens modeled the change in firmness behavior of Golden Delicious apples in different CA regimes in 1979. The findings were used in a simulation application for Elstar apples (Tijskens et al., 1999). Additional details regarding the modeling of respiration and its effects on the quality of horticultural products can be found in Hertog et al. (1999), Hertog (2001), Schouten et al. (2004b) and the references cited therein.

B. Models for batches

Dealing with general patterns and variation in measured properties or attributes is, in its basic premises, the technical goal of modeling. The previous few years have seen the emergence of a new type of model: batch models. This type of model describes the variation resulting from slightly different conditions during growth for all individuals with a common growth history ("batch"). This variation, known as biological variation, may be described as the composite of biological properties that differentiate individuals in a batch (adapted from Tijskens et al., 2003).

In fruit and vegetables, biological variation is often larger in magnitude than that of other sources of variation, such as random and systematic errors related to data gathering (e.g. observational errors, technical variation). Until recently however, biological variation has been neglected for various reasons. Tijskens et al. (2003) describe how, in practice, variation in properties has been addressed by sorting and grading with emphasis on uniform production. However, uniform production methods do not produce batches with zero biological variation, because small spatial or temporal variation in growth conditions cannot be avoided. Hertog et al. (2004) mentioned that if all fruit was harvested at the same stage of ripeness, the variation at harvest would be negligible and would remain negligible throughout the postharvest period. However, this is never the case. The problem with sorting and grading is two-fold. First, sorting and grading on (external) quality attributes will only sort on the current quality attributes. Limiting variation in the quality attribute by mixing batches will mask information how the variation will develop later in the supply chain. Secondly, given the available commercial technology, sorting and grading is primarily conducted using external attributes. Sorting and grading might reduce the variation in other (internal) attributes (see Chapter 14), but much less than for the external properties (Tijskens et al., 2003).

This section illustrates different aspects of biological variation and its propagation in time, with examples of how these batch models advance the understanding of physiology. Progress is swift and it is likely that this overview will be outdated in a few years time, but the practical benefits will become clear in the section on globalization.

Batch models combine quality models that describe the change of properties or attributes of individual products over time (see examples in previous sections) with the probability theory, which describes the variation of measured properties or attributes as a function of time. Biological variation is a mathematical concept that can be incorporated into quality models, by assuming that the change in quality behavior is deterministic, and any biological variation is included as a stochastic deviation of a single individual around the deterministic part (De Ketelaere et al., 2006). For the deterministic part, a whole range of (individual) quality models is available in literature.

Incorporating biological age

One approach to obtain information about biological variation is to adapt an individual model to allow for the estimation of the biological age for each individual fruit or vegetable in a batch. This procedure requires that individuals are measured repeatedly over time, using non-destructive measuring techniques. Biological age can be defined as the age of the individual relative to an arbitrary reference point (see Example 18.1). The individual model is adapted to allow the estimation of the biological age for each individual fruit as the time necessary for the change in the initial firmness to an arbitrarily chosen reference firmness (Δt_F), and the estimation of all other model parameters in common for the whole batch.

Example 18.1 Firmness of tomatoes (adapted from Schouten et al., 2007a)

Tomatoes tend to lose firmness according to an exponential function when they have reached commercial size, either on the plant or off the plant. Apparently, two sources of variation suffice for tomato firmness: a changing property and an invariable one (see Equation 18.6). Firmness breakdown occurring over time during postharvest can be described according to Equation 18.9:

$$F(t) = (F_0 - F_{fix}) \cdot \mathrm{e}^{-k_{f,post} \cdot t} + F_{fix} \tag{18.9}$$

with F_0 the firmness at harvest (in N), with $k_{f,post}$ (in day^{-1}) the reaction rate constant for the firmness breakdown after harvest and F_{fix} the invariable part (in N). The firmness at harvest, F_0, was assumed to be the result of firmness changes during preharvest. Subsequently the postharvest firmness change model can then be expressed as a function of the storage time after harvest, and the biological age firmness at harvest for constant temperature conditions (Equation 18.10).

$$F(t) = (F_{ref} - F_{fix}) \cdot \mathrm{e}^{-k_{f,post} \cdot t - k_{f,pre} \cdot \Delta t_F} + \mathrm{F}_{\mathrm{fix}} \tag{18.10}$$

with $k_{f,pre}$ (in day^{-1}) the reaction rate constant for the firmness change before harvest, F_{ref} an arbitrary reference firmness and Δt_F the biological age expressed as the time (in days) necessary for the firmness to change from F_{ref} to F_0. Equation 18.10 expresses the postharvest firmness behavior as a function of the preharvest growing conditions with regard to firmness breakdown, the firmness at harvest, the storage time after harvest and the biological age firmness at harvest (Figure 18.5a,b).

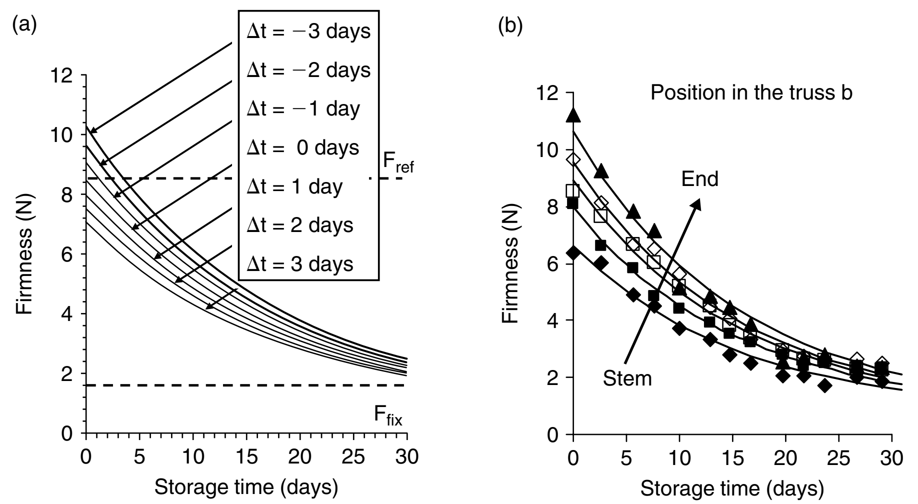

Figure 18.5 (a) simulated firmness behavior over time of tomatoes stored at 16°C as a function of the maturity at harvest. Harvest maturity varies from −3 to +3 days, which reflects the normally encountered variation in harvested fruit. (b) the observed (measured) and expected (simulated) values for five tomatoes as a function of their location in the truss at the plant: the closer the tomatoes grow to the plant, the more mature they are compared to the tomatoes further away. Adapted from Schouten et al. (2007a).

There seems to be two (almost identical) methods to incorporate biological age. The first method is used by Hertog et al. (2004, 2007b) and Schouten et al. (2007a) who showed, by comparing root mean square error plots, that most of the variation between tomatoes of the same batch originated from picking at a different initial color. The concept that biological age can be applied to the initial values of a quality attribute or property to develop individual models is shown later in this chapter. The second method is to add the biological age (which is actually the transformed initial condition F_0 to the timeframe, using the model under study), to the time variable as a stochastic variable called biological time. This biological time will have a different value for each individual in a batch. This second method has been presented by Tijskens et al. (2003, 2007) and De Ketelaere et al. (2006).

Both methods of incorporating biological variance mentioned above can be used to obtain information about the biological variation present in a batch. Using non-linear mixed effects regression analysis it is possible to estimate the joint model parameters, such as $k_{f,post}$, $k_{f,pre}$ and F_{fix} in Example 18.1, and all the values for the biological age of the individuals in the batch. The values appear to be distributed according to a normal or Gaussian distribution, for example, the color biological age in tomatoes (Hertog et al., 2004) and the firmness biological age measured by the chlorophyll-related absorption coefficient μ_a of nectarines (Tijskens et al., 2006b; Tijskens

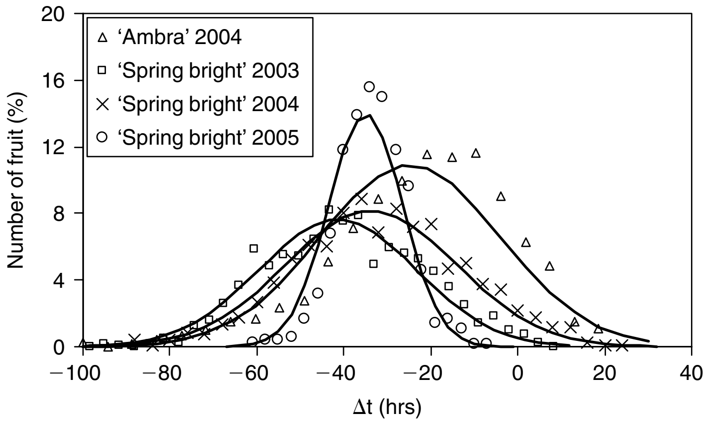

Figure 18.6 Distribution of the firmness biological age of nectarines by the absorption coefficient μ_a measured at 670 nm for four batches, differing in season (2003–2005) and cultivars (Ambra and Spring Bright) at commercial harvest. Source: Tijskens et al. (2007).

et al., 2007). The distribution of biological age can be characterized by the mean and the standard deviation. It is clear from Figure 18.6 that this approach is successfully describing the large differences present between batches, both in the value of the mean and the standard deviation of the biological age distribution.

Biological variation

Another approach to obtaining information about biological variation is to incorporate the finding that the biological age is apparently normally distributed. This information can be obtained in two ways. The first method is preferable when dealing with experimental data that have been classified into (quality) categories (relative frequency data), while the second approach is useful when no classification is used. The first method expresses the batch model as the probability that measurements belong to a certain class (q_a, q_b) of the quality function Q. Assuming that the biological age (Δt) is normally distributed will result in the following batch model formulation (Equation 18.11) (Schouten et al., 2004b):

$$\begin{aligned}\Pr(Q(t) \in (q_a, q_b)) &= \Pr\left(\mathrm{Q}(\Delta \mathrm{t}) \leq \mathrm{q_b}\right) - \Pr\left(\mathrm{Q}(\Delta \mathrm{t}) \leq \mathrm{q_a}\right) \\ &= \Phi\left(\frac{Q^{-1}(q_a) - \mu}{\sigma}\right) - \Phi\left(\frac{Q^{-1}(q_b) - \mu}{\sigma}\right)\end{aligned} \tag{18.11}$$

with Φ the cumulative standard normal distribution function, μ the mean and σ the standard deviation of the (biological age) distribution. The derivation of the applicable dedicated equation is shown in Example 18.2.

Example 18.2 Method 1. Firmness batch model for tomatoes (from Schouten et al., 2007b)

To create a batch model according to the first method of the firmness behavior the inverse of the quality function (Equation 18.10) is needed, and applying Equation 18.11 leads to Equation 18.12:

$$\Pr(F) = \Phi\left(\frac{\dfrac{-\ln\left(\dfrac{F_a - F_{fix}}{F_{ref} - F_{fix}}\right) - k_{f,post}\cdot t}{k_{f,pre}} - \mu}{\sigma}\right) - \Phi\left(\frac{\dfrac{-\ln\left(\dfrac{F_b - F_{fix}}{F_{ref} - F_{fix}}\right) - k_{f,post}\cdot t}{k_{f,pre}} - \mu}{\sigma}\right) \tag{18.12}$$

with μ the mean value and σ the standard deviation of the development time of the mother population.

Figure 18.7 shows, from left to right, the propagation of measured firmness distributions (bars) and simulated probabilities (lines) over time and temperature for one batch of breaker tomatoes. It is clear that the frequency distributions and simulated probabilities move, starting from the initial distribution at harvest ($t = 0$), towards an asymptote (F_{fix}) at a speed that increases with storage temperature. The closer the mean value of the distributions is to F_{fix}, the more skewed it becomes, finally reducing to a single column/spike.

The second method is based on understanding how one variable is affected by the variation in another variable, on which it depends. Let's assume that a quality function Q, as a function of biological age, is prone to biological variation. In that case, the probability density P(Q(t)) can be expressed according to Equation 18.12, assuming that the biological age is normally distributed with mean μ and σ the standard deviation (Hertog et al., 2004):

$$P(Q(t)) = P(Q^{-1}(q))\cdot\frac{dQ^{-1}(q)}{dq} = \frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{1}{2}\left(\frac{Q^{-1}-\mu}{\sigma}\right)^2}\cdot\frac{dQ^{-1}(q)}{dq} \tag{18.13}$$

The inference of the applicable dedicated equation is shown in Example 18.3. In the case of large amounts of individual fruits or vegetables in a batch, no differences between the two methods are expected in terms of batch or model parameters. However, when only a limited number of individuals in a batch is available, estimations will depend on the chosen class widths (q_a, q_b). In that latter case, the second method will likely result in improved descriptions of the batch variation.

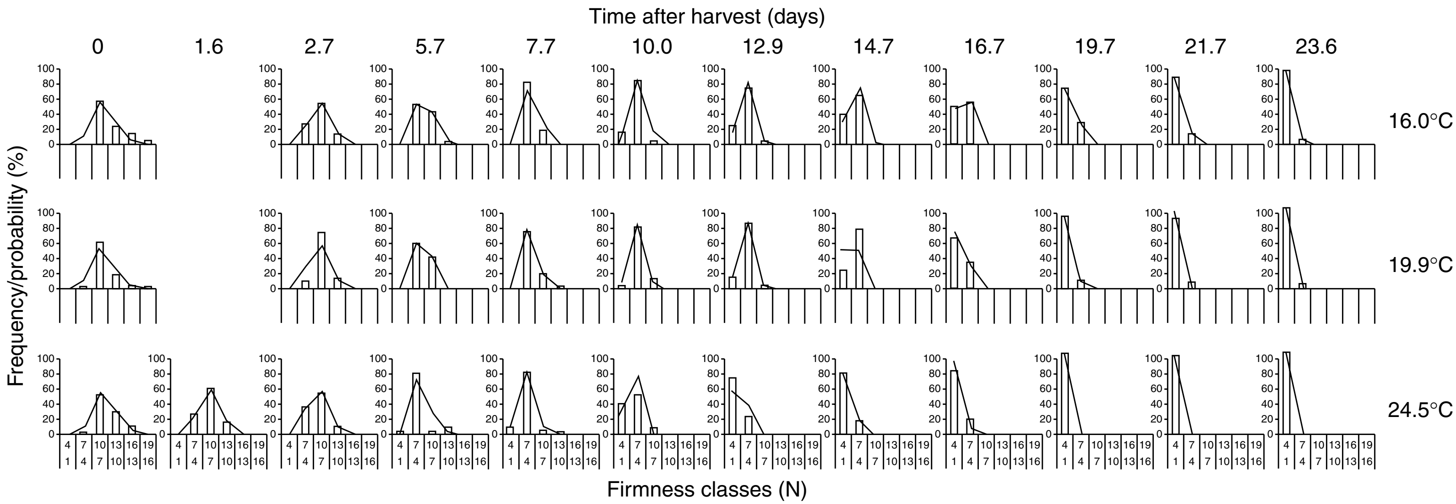

Figure 18.7 The propagation of biological variation over time. Measured firmness distributions (bars) and simulated firmness probability distributions (lines) from tomatoes from one batch stored at three different temperatures and a class width of 4 (N). Source: Schouten et al. (2007b).

However, the first method provides results that are easier to interpret, because they are expressed as probability values between 0 and 1, instead of probability density functions that have no upper limit and can easily exceed 1. Both methods are generic in nature, but limited to those quality functions with an inverse (Q^{-1}).

Example 18.3 Method 2. Firmness batch model for tomatoes

To create a batch model using the second method of firmness behavior, the inverse of the quality function (Equation 18.10) has to be differentiated with regard to q. The derivative with regard to q is applied in Equation 18.13 and leads to Equation 18.14:

$$\mathrm{P}(F) = \frac{e^{-\frac{1}{2}\left(\frac{\frac{-\ln\left(\frac{F-F_{fix}}{F_{ref}-F_{fix}}\right)-k_{f,post}\cdot t}{k_{f,pre}}-\mu}{\sigma}\right)^2}}{\sigma\sqrt{2\pi}\cdot(F_{fix}-F)\cdot k_{f,pre}} \qquad (18.14)$$

Figure 18.8 shows an example of the propagation of the probability density function assuming the logistic quality function rather than exponential. The distribution changes from the start ($t = 0$) as a symmetrical distribution that becomes skewed over time until all tomatoes show only little variation in color ($t = 20$).

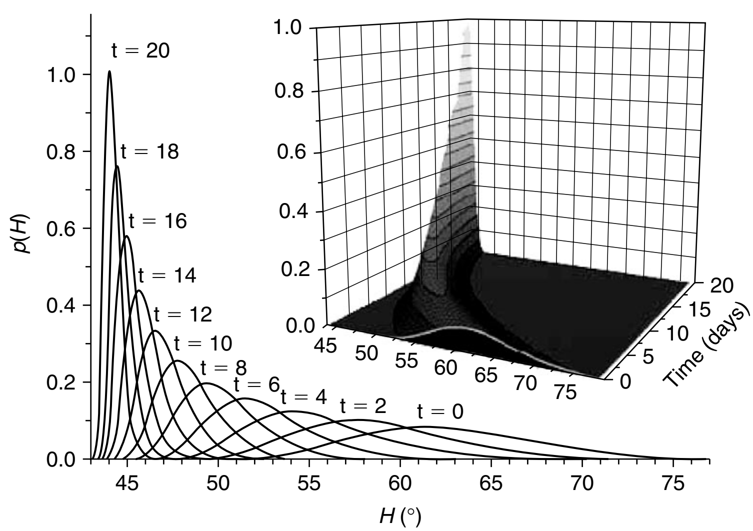

Figure 18.8 Propagation of the probability density function for the color p(H), expressed as hue (H) for tomatoes stored at 15°C every other day (main plot), or as a gradually changing density over time (insert). Source: Hertog et al. (2004).

Multiple sources of variation

Schouten et al. (2007a) investigated whether the biological ages based on (individual) color measurements and (individual) firmness measurements in tomato were linked. They found that the mean biological ages between batches from the same greenhouse were strongly linked. Apparently, the biological age based on mean color and biological age based on mean firmness of tomatoes are synchronized per grower, which points at links between the different metabolic pathways that result in synchronized quality attributes. This link between the biological age based on color and on firmness is also apparent when the chlorophyll related absorption coefficient μ_a was linked to the biological age based on firmness of nectarines (Tijskens et al., 2006b; Tijskens et al., 2007). The viewpoint that multiple sources of variation may exist was investigated by De Ketelaere (2006) who showed that, within a batch of mangoes, next to the biological age based on firmness variation is also present in the rate of the logistic firmness breakdown process. This is remarkable, because in many deterministic quality models the rate constant of firmness breakdown is considered to be a reaction rate constant that only varies between cultivars, not within batches.

Hertog et al. (2007a) recently proposed an approach to generate batch models with two stochastic variables, for two different sources of biological variation. This was accomplished by extending the second method discussed above to the situation, where the quality function Q depends on two covarying sources of biological variation. The approach was demonstrated on postharvest stem growth data affected by biological variation in the mass of the head and initial length of the central stem of Belgian endive applying a bivariate normal distribution.

Application of batch models

Practical applications based on batch models are quickly becoming a reality. For instance, the (logistic) batch model describing the variation in the chlorophyll precursor in cucumbers has been shown to have an upper limit in the cultivar specific amount of this precursor (Schouten et al., 2004a). This information could be used by cucumber breeders to create genotypes with a specific keeping quality. Another application for breeders and participants in the tomato supply chain might be to combine batch models for color and firmness with consumer limits, to provide the purchase period for consumers that starts when a tomato batch becomes acceptable (from unripe to ripe) and ends when the batch becomes unacceptable (from ripe to over-ripe) (Schouten et al., 2007b).

C. Models for growth

The modeling of quality attributes and quality related product properties during growth are not well developed. In general, quality attributes important for postharvest handling of fruit and vegetables play a minor role in the production phase, except in floriculture. Attention is devoted to mass gain, absence of defects and management of the plantation. In fact, quality is mainly reduced to selecting an appropriate cultivar. Little is known about how postharvest quality actually changes during growth.

However, the growing conditions in open field are highly variable, due to weather and the inability to control rainfall, sunlight or day length. Open field conditions make it very hard to pinpoint the active processes, study them in isolation and construct mechanistic models from that knowledge. Preliminary trials (Tijskens and van Kooten, 2006) have revealed that progress can be expected from a thorough problem decomposition and modeling in a mechanistic way. The empirical temperature sum has been used very successfully, and can be connected to summed rate constants of occurring reactions (Tijskens and Verdenius, 2000).

D. Models for globalization

The globalization of the fruit and vegetable supply chain has been occurring for quite some time. Globalization offers major advantages, but also considerable disadvantages (Phillips, 2006). However, the need to understand how different regions and different seasons across the world affect quality and quality behavior (Tijskens et al., 2006a; Banks, 2006) has been neglected. Understanding and integration requires a fundamental approach that incorporates the relevant behavior of the product, both in the preharvest and in the postharvest realm. Quality differences induced by different cultivars, growing sites, soil types, climate and weather have to be merged and combined into a single description. Because traditional modeling approaches are unsuitable to accommodate this integration of knowledge, we have to turn to modeling based on available knowledge of the processes that occur in the produce and initiate or cause the phenomena observed: a systems approach.

The concept of biological variation may be linked directly to certification issues. Food safety and product quality is increasingly controlled during the production process, and in the supply chain, through the development and implementation of food safety and quality standards such as EUREPGAP, HACCP, IFS, BRC, or GHP. Traceability (see Chapter 12) of batches is a prerequisite for these standards. Knowledge of how quality attributes or properties of batches change helps supply chain partners understand why sometimes batch behavior differs from expectations based only on mean values.

The models elaborated above may seem over-expanded and too complex for the intended simple target. An application targeting a global supply chain, however, has to account for effects of growing region, management, cultivar and the influence of other conditions affecting the behavior of batches from all over the world. In addition, models for practical applications should include the various preferences and likings of different consumers across the world. The latter part is still largely out of reach, although some interesting developments are taking place in combining process oriented quality change models and models on consumer acceptance with economic aspects for the entire supply chain (Schepers et al., 2004, 2005).

A simple example of a model of the effects associated with different growing regions and management procedures on the quality and quality behavior in the globalized fruit and vegetable supply chain can be found in maturity at harvest. The effects of harvest maturity on product behavior can be manifold. In its simplest form harvest maturity induces a mere shift in the biological time, without fundamentally altering the behavior of the aspect studied (Tijskens et al., 2005b). Based on a simple exponential breakdown (Equation 18.10), the system of biological shift factors allows the standardization of graphical representations (see, for example, Figures 2 and 3 in Tijskens et al., 2005b).

The principle of biological shift factor (Δt in Equation 18.10) has been applied to firmness (Lana et al., 2005) and color (Lana et al., 2006) of fresh whole and cut tomatoes, the color of bell peppers (Tijskens et al., 2005b) and Granny Smith apples (Tijskens and Verdenius, 2000; Tijskens et al., 2005b). The system of biological shift factor has the additional advantage that the values of the biological shift factor (encountered until now) are normally distributed. A new and exciting development is described in Tijskens et al. (2006b, 2007) indicating that the actual biological shift factor of nectarines could be measured directly by time-resolved spectroscopy. In the long run the addition of biological variation resulting from products that originate in different regions of the world will provide the means to develop models applicable to the globalized fruit and vegetable supply chain.

A generic approach to generate a batch model that accounts for dynamic temperature scenarios, proposed by Hertog et al. (2007b), provides an example of how to link biological variation methodology and globalization/certification into practical applications. The concept is based on the transformation of the actual time to "physiological time" or "biological time" that converts the batch model into a version based on differential equations. The conversion includes dynamic changes in temperature. The dynamic approach is important, because temperature fluctuations in the supply chain are the norm. One application area can be telemetric monitoring (using RFID technology and temperature loggers) in truck/reefer transport to inform chain managers about the quality status, based on the current temperature and the effect it is has on the propagation of the biological age distribution of each batch.

V. Conclusions and future developments

A decomposition of a problem into the constituent processes leads to the identification of plausible mechanisms occurring in the product. In using these mechanisms to build models, all available theoretical knowledge can be used. The application of fundamental rules, for example chemical kinetics, allows these mechanisms to be expressed in the form of differential equations. These differential equations can (sometimes) be solved analytically under constant external conditions. When the conditions are not constant, or when the differential equations are too complex to be solved, the differential equations can be used to solve the problem in a numeric fashion. The practical and empirical knowledge and product expertise and available data are merely used to calibrate the developed models.

This chapter shows not only that problems in horticulture can and may be tackled by this system, but it also shows that the method of process oriented modeling opens new alleys to include the omnipresent biological variation into the system. To model the supply chain and, especially, the global supply chain the addition of the biological variation of product batches originating from a large number of growing conditions is of the utmost importance.

The technical equipment to make this approach more feasible than it is currently will be developed further: more powerful computers, more powerful simulation packages, but especially important more suitable non-destructive measuring techniques to measure the same samples repeatedly for a more extended set of attributes.

Moreover, statistical procedures will be developed in the near future to account for the biological variation in the analysis of data gathered by destructive methods, which are currently by far the most abundant methods.

By applying process oriented models in the statistical analysis of experimental data, an increase in estimation reliability from e.g. 70% to 90% and higher, can frequently be obtained. The use of the technique of multi-response-multi-variate statistical analysis will increase and further improve the understanding of the problem, and enhance the physiological basis of the systems approach in modeling.

Key words

Process oriented modeling, quality, product properties, product acceptance, consumer behavior, color, firmness, globalization.

Bibliography

Banks, N. (2006). Picking winners. Acta Hort., 712(I), 113–120.

Batt, P.J. (2006). Fulfilling customer needs in agribusiness supply chains. Acta Hort., 699, 83–89.

Benner, M., Geerts, R.F.R., Linnemann, A.R., Jongen, W.M.F., Folstar, P., Cnossen, H.J. (2003). A chain information model for structured knowledge management: Towards effective and efficient food product improvement. Trends in Food Sci. Technol., 14(11), 469–477.

Berna, A.Z., Lammertyn, J., Buysens, S., Di Natale, C., Nicolaï, B.M. (2005). Mapping consumer liking of tomatoes with fast aroma profiling techniques. Postharvest Biol. and Technol., 38, 115–127.

Botonaki, A., Polymeros, K., Tsakiridou, E., Mattas, K. (2006). The role of food quality certification on consumers' food choices. British Food J., 108(2), 77–90.

Brückner, B. (2006). Addressing consumer notions and individuality. Acta Hort., 712, 121–130.

Crisosto, C.H., Crisosto, G.M., Metheney, P. (2003). Consumer acceptance of "Brooks" and "Bing" cherries is mainly dependent on fruit SSC and visual skin color. Postharvest Biol. and Technol., 28, 159–167.

Crisosto, C.H., Crisosto, G., Neri, F. (2006). Understanding tree fruit quality based on consumer acceptance. Acta Hort., 712, 183–190.

De Ketelaere, B., Stulens, J., Lammertyn, J., Cuong, N.V., De Baerdemaeker, J. (2006). A methodological approach for the identification and quantification of sources of biological variance in postharvest research. Postharvest Biol. Technol., 39, 1–9.

de Wijk, R., Rasing, F., Wilkinson, C. (2003). Texture of semi-solids 2: Sensory flavor-texture interactions for custard desserts. J. of Texture Studies, 34(2), 131–146.

de Wit, C.T. (1968). Theorie en model (in Dutch). Inaugural speech. Veenman, Wageningen, The Netherlands.

de Wit, C.T., van Keulen, H. (1972). Simulation of transport processes in soils. Pudoc, Wageningen, The Netherlands.

Fearne, A., Barrow, S., Schulenberg, D. (2006). Implanting the benefits of buyer-supplier collaboration in the soft fruit sector. Supply Chain Manage., 11(1), 3–5.

Heaton, J.W., Marangoni, A.G. (1996). Chlorophyll degradation in processed foods and senescent plant tissues. Trends in Food Sci. Technol., 7, 8–15.

Hertog, M.L.A.T.M., Peppelenbos, H.W., Evelo, R.G., Tijskens, L.M.M. (1999). A dynamic and generic model of gas exchange of respiring produce: The effects of oxygen, carbon dioxide and temperature. Postharvest Biol. and Technol., 14, 335–349.

Hertog, M.L.A.T.M. (2001). Improving modified atmosphere packaging through conceptual models. In: Food Process Modeling, L.M.M. Tijskens, M.L.A.T.M. Hertog, B.M. Nicolaï (eds). Woodhead Publishing, Cambridge, UK.

Hertog, M.L.A.T.M. (2002). The impact of biological variation on postharvest population dynamics. Postharvest Biol. and Technol., 26, 253–263.

Hertog, M.L.A.T.M., Lammertyn, J., Desmet, M., Scheerlinck, N., Nicolaï, B.M. (2004). The impact of biological variation on postharvest behavior of tomato fruit. Postharvest Biol. and Technol., 34, 271–284.

Hertog, M.L.A.T.M., Scheerlinck, N., Lammertyn, J., Nicolaï, B.M. (2007a). The impact of biological variation on postharvest behavior of Belgian endive: The case of multiple stochastic variables. Postharvest Biol. Technol., 43, 78–88.

Hertog, M.L.A.T.M., Lammertyn, J., Scheerlinck, N., Nicolaï, B.M. (2007b). The impact of biological variation on postharvest behavior: The case of dynamic temperature conditions. Postharvest Biol. Technol., 43, 183–192.

Hewett, E.W. (2006). Progressive challenges in horticultural supply chains: Some future challenges. Acta Hort., 712(I), 39–49.

Kramer, A., Twigg, B.A. (1983). Quality Control in the Food Industry, 3rd edn. AVI Publishing Co., Westport, CT, USA.

Lana, M.M., Tijskens, L.M.M., van Kooten, O. (2005). Effects of storage temperature and fruit ripening on firmness of fresh cut tomatoes. Postharvest Biol. Technol., 35, 87–95.

Lana, M.M., Tijskens, L.M.M., van Kooten, O. (2006). Effects of storage temperature and stage of ripening on RGB color aspects of fresh-cut tomato using video image analysis. J. of Food Engin., 77, 871–879.

Morris, C., Young, C. (2000). "Seed to shelf", "teat to table," "barley to beer" and "womb to tomb": Discourses of food quality and quality assurance schemes in the UK. J. Rural Studies, 16, 103–115.

Moskowitz, H.R. (2005). Psychophysical thinking in business: Products and concepts. J. of Sensory Studies, 20, 389–396.

Passioura, J.B. (1996). Simulation models: Science; snake oil, education, or engineering? Agronomy J., 88, 690–694.

Phillips, L. (2006). Food and globalization. Annual Rev. Anthropology, 35, 37–57.

Rico, D., Martín-Diana, A.B., Barat, J.M., Barry-Ryan, C. (2007). Extending and measuring the quality of fresh-cut fruit and vegetables: A review. Trends in Food Sci. Technol., 18, 373–386.

Schepers, H.E., van Henten, E.J., Bontsema, J., Dijksterhuis, G.B. (2004). Tactics of quality management and promotions: Winning consumers for fresh exotic produce. In: Dynamics In Chains and Networks, H.J. Bremmers, S.W.F. Omta, J.H. Trienekens, E.F.M. Wubben (eds). Wageningen Academic Publishers, The Netherlands, pp. 568–582.

Schepers, H., van Kooten, O. (2005): Profitability of ready to eat strategies: Towards model-assisted negotiation in a fresh produce chain. Quantifying the Agri-Food Supply Chain. Proceedings of the Frontis Workshop on Quantifying the Agri-Food Supply Chain, Frontis series, C.J.M. Ondersteijn, J.H.M. Wijnands, R.B.M. Huirne, O. van Kooten (eds). Wageningen, The Netherlands, 22–24 October 2004. http://library.wur.nl/frontis/quantifying_supply_chain/09_schepers.pdf

Schouten, R.E., Tijskens, L.M.M., van Kooten, O. (2002). Predicting keeping quality of batches of cucumber fruits based on a physiological mechanism. Postharvest Biol. Technol., 26, 209–220.

Schouten, R.E., Jongbloed, G., Tijskens, L.M.M., van Kooten, O. (2004a). Batch variability and cultivar keeping quality of cucumber. Postharvest Biol. Technol., 32, 299–310.

Schouten, R.E., Veltman, R.H., De Wild, H.P.J., Koopen, T.J., Staal, M.G., Tijskens, L.M.M. (2004b). Determination of O_2 and CO_2 permeance, internal respiration and fermentation for a batch of pears (cv Conference). Postharvest Biol. and Technol., 32, 289–298.

Schouten, R.E., Huijben, T.P.M., Tijskens, L.M.M., van Kooten, O. (2007a). Modeling quality attributes of truss tomatoes: Linking color and firmness maturity. Postharvest Biol. Technol., 45(3), 298–306.

Schouten, R.E., Huijben, T.P.M., Tijskens, L.M.M., van Kooten, O. (2007b). Modeling the acceptance period of truss tomato batches. Postharvest Biol. Technol., 45(3), 307–316.

Sloof, M., Tijskens, L.M.M., Wilkinson, E.C. (1996). Concepts for modeling quality of perishable products. Trends in Food Sci. Technol., 7, 165–171.

Sloof, M. (2001). Problem decomposition. In: Food Process Modeling, L.M.M. Tijskens, M.L.A.T.M. Hertog, B.M. Nicolaï (eds). Woodhead Publishing, Cambridge, UK, pp. 19–34.

Thornley, J.H.M. (1976). Mathematical models in plant physiology. A quantitative approach to problems in plant and crop physiology. Academic Press, London, UK.

Tijskens, L.M.M. (1979). Texture of Golden Delicious apples during storage. Lebensmittel-Wissenschaft-und-Technologie, 12(3), 138–142.

Tijskens, L.M.M., Sloof, M., Wilkinson, E.C., van Doorn, W.G. (1996a). A model of the effects of temperature and time on the acceptability of potted plants stored in darkness. Postharvest Biol. and Technol., 8, 293–305.

Tijskens, L.M.M., Polderdijk, J.J. (1996b). A generic model for keeping quality of vegetable produce during storage and distribution. Agricul. Systems, 51, 431–452.

Tijskens, L.M.M., Hertog, M.L.A.T.M., Van Schaik, A.C.R., De Jager, A. (1999). Modeling the firmness of Elstar apples during storage and transport. International Symposium on Effect of Preharvest and Postharvest factors on Storage of Fruits and Vegetables, August 1997, Warsaw, Poland, Acta Hort., 485, 363–372.

Tijskens, L.M.M. (2000). Acceptability. In: Fruit and vegetable quality: an integrated view, R.L. Shewfelt, B. Brückner (eds). Technomic Press, Lancaster, PA, USA, pp. 125–143.

Tijskens, L.M.M., Verdenius, F. (2000). Summing up dynamics: modeling biological processes in variable temperature scenarios. Agricul. Systems, 66(1), 1–15.

Tijskens, L.M.M., Hertog, M.L.A.T.M., Nicolaï, B.M. (eds) (2001). Food Process Modeling. Woodhead Publishing, Cambridge, UK.

Tijskens, L.M.M., Konopacki, P., Simčič, M. (2003). Biological variance, burden or benefit? Postharvest Biol. Technol., 27, 15–25.

Tijskens, L.M.M., Luyten, H. (2004). Modeling food texture. In: Texture in Food. Vol. 1: Solid Foods, D. Kilcast, (ed). Woodhead Publishing, Cambridge, UK.

Tijskens, L.M.M. (2004). Discovering the Future: Modeling Quality Matters. Ph.D. thesis Wageningen University, The Netherlands. ISBN 90-8504-017-5.

Tijskens, L.M.M., Schepers, H., van Kooten, O. (2005a). Modelling for Quality Assurance. Proceedings of the APEC symposium on assuring quality and safety of fresh produce. S. Kanlayanarat, W.B. McGlasson (eds). Bangkok, Thailand, August 1–3, pp. 23–33.

Tijskens, L.M.M., Heuvelink, E., Schouten, R.E., Lana, M.M., van Kooten, O. (2005b). The biological shift factor. Biological age as a tool for modeling in pre- and post-harvest horticulture. Acta Hort., 687, 39–46.

Tijskens, L.M.M., Lin, W.C., Schouten, R.E. (2005c). Predicting harvest labour allocation in bell pepper production. Acta Hort., 682, 1435–1442.

Tijskens, L.M.M., van Kooten, O. (2006). Theoretical considerations on generic modeling of harvest maturity, enzymes status and quality behavior. Intern. J. of Postharvest Technol. Innov., 1, 106–120.

Tijskens, L.M.M., van Kooten, O., Schouten, R.E. (2006a). Modeling for globalization. Conference MQUIC, 7 August 2006, Bangkok. Acta Hort., 712, 51–58.

Tijskens, L.M.M., Eccher Zerbini, P., Vanoli, M., Jacob, S., Grassi, M., Cubeddu, R., Spinelli, L., Torricelli, A. (2006b). Effects of maturity on chlorophyll related absorption in nectarines, measured by non-destructive time-resolved reflectance spectroscopy. Intern. J. Postharvest Technol. Innov., 1, 178–188.

Tijskens, L.M.M., Eccher Zerbini, P., Schouten, R.E., Vanoli, M., Jacob, S., Grassi, M., Cubeddu, R., Spinelli, L., Torricelli, A. (2007). Assessing harvest maturity in nectarines. Postharvest Biol. Technol., 45(2), 204–213.

Tomlins, K., Manful, J., Gayin, J., Kudjawu, B., Tamakloe, I. (2007). Study of sensory evaluation, consumer acceptability, affordability and market price of rice. J. the Sci. of Food and Agric., 87, 1564–1575.

van Boekel, M.A.J.S. (1999). Testing of kinetic models: Usefulness of the multiresponse approach as applied to chlorophyll degradation in foods. Food Res. Intern., 32, 261–269.

van Boekel, M.A.J.S. (2000). Kinetic modeling in food science: A case study on chlorophyll degradation in olives. J. Sci. Food Agric., 80, 3–9.

van Boekel, M.A.J.S., Tijskens, L.M.M. (2001). Kinetic modeling. In: Food Process Modeling, L.M.M. Tijskens, M.L.A.T.M. Hertog, B.M. Nicolaï (eds). Woodhead Publishing, Cambridge, UK.

Van Dijk, C., Tijskens, L.M.M. (2000). Mathematical modeling of enzymatic reactions as related to the texture of fruits and vegetables after storage and mild preheat treatments.. In: Design of minimal processing technologies for fruit and vegetables, Chapter 8, S.M. Alzamora, S.M. Tapia, A. López-Malo (eds). Aspen Publishers Inc., USA, pp. 127–152.

van Keulen, H., de Wit, C.T., Lof, H. (1976). The use of simulation models for productivity studies in arid regions. In: Ecological studies analysis and synthesis, O.L. Lange, L. Koppen & E.D. Schulze (eds), Vol. 19. Springer Verlag, Heidelberg, pp. 408–420.

Wierenga, P.J., De Wit, C.T. (1972). Simulation of heat transfer in soils. Soil Sci. Soci. of Ameri. Proceedings, 34, 845–848.

19

Refrigeration of Fresh Produce from Field to Home: Refrigeration Systems and Logistics

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I. Introduction

While consumption of fresh produce has been historically highly seasonal, international trade, with improvements in refrigeration, transport and storage facilities allowing even highly perishable products such as raspberries, to be shipped from distant countries, has led consumers to expect a near complete range of produce to be available year-round. In the food industry, the system that moves a steady supply of fresh produce is simply called the "cold chain." The cold chain encompasses all the critical steps and processes that foods and other perishable products must undergo in

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order to maintain their quality. Therefore, logistics plays a central role in ensuring an efficient cold chain from the field, through distribution channels, to the home refrigerator. In addition to examining these requirements at local levels, the intricacies of transcontinental shipment, customs requirements, air and sea freighting and special packaging, add complexity to the logistics. Besides, in recent years, precautions to combat terrorism have tended to put additional constraints on an already complicated system.

A. The supply chain system

Supply chains are all about linkages. A supply chain is only as strong as its weakest link. Whenever a chain breaks, it usually does so at the weakest link. In a supply chain there are many interfaces (links), such as the ones between customer and store, producer and packing house. Problems develop at these interfaces (Katzorke and Lee, 1998), and the best way to overcome these problems is to manage the supply chain efficiently. Major limitations experienced by the cold chain include poor temperature management, due to either the lack of, or limitations in, refrigeration, handling, storage and relative humidity (RH) control. Temperature management during transportation of fresh fruits and vegetables over long distances is critical. Loads must be stacked so as to enable proper air circulation, in order to facilitate removal of heat from the produce, as well as to dissipate incoming heat from the atmosphere and off the road. Stacking of loads must also consider minimizing mechanical damage. Transit vehicles must be cooled prior to loading the fresh produce. Delays between cooling after harvest and loading into transit vehicles should also be avoided. Proper temperature maintenance should be ensured throughout the handling system.

Logistics is the process of planning, implementing and controlling the efficient flow and storage of goods, services and related information, from the point of origin to the point of consumption, to meet customers' requirements (Luo and Findlay, 2002). According to Tarnowski (2006), the biggest problem is that some players cannot see past their own concerns. For example, retailers blame transportation companies for not delivering within a specified window of time, the transportation companies blame the suppliers for not having enough product, suppliers blame the retailers for not properly inspecting deliveries and so on. Apparently, no one wants to be accountable. Improved communication and information exchange seems to be the way to achieve better cohesion (see Chapters 1, 2, 3, 6 and 7).

Christopher and Lee (2001) acknowledge the inherent complexity of inter-organizational supply chain networks, promoting the virtues of visibility and velocity as key elements to improve the supply chain. Supply chain visibility is the ability to see from one end of the pipeline to the other. Visibility implies a clear view of upstream and downstream inventories, demand and supply conditions, and production and purchasing schedules. The achievement of supply chain visibility is based upon close collaboration with customers and suppliers, as well as internal integration within the business. The second ingredient of supply chain agility is velocity. Velocity is defined as distance over time. Hence to increase velocity, time must be reduced. Here we are referring to "end-to-end" pipeline time, i.e. the total time it takes to move products and materials from one end of the supply chain to the other.

In addition, how rapidly the supply chain reacts to changes in demand, upwards or downwards, which could be described as acceleration, is important. The three basic foundations for improved supply chain velocity and acceleration are: streamlined processes reduced inbound lead-times and non-value added time reduction (Christopher and Lee, 2001).

B. Important factors to consider

According to Fearne and Hughes (1999) a number of driving forces were evident, to varying degrees, for success of the supply chain system in the United Kingdom (UK). These included: continuous investment (despite increasingly tight margins), good staff (to drive the process of innovation and develop good trading relationships with key customers), volume growth (to fund the necessary investment and provide a degree of confidence in the future), improvement of measurement and control of costs (in the pursuit of further gains in efficiency) and innovation (not just in the product offer, but also in the level of service and the way of doing business with key customers).

Recently, there is increasing attention on product traceability (see Chapter 12), particularly for produce, to assist with product recalls and bioterrorism. However, conventional barcodes for labeling shipped produce are still used extensively. It is now globally important that the ability to trace backward and forward information about production and postharvest handling operations should be part of good agricultural practices (GAPs). In the process, we achieve greater certainty regarding quality, delivery options and intervention measures along the entire food chain. In addition, there is an opportunity to add value to the food system. Bollen et al. (2006) discussed the need for traceability in the fresh produce chain. They contend that a good traceability management system will allow product to be traced to any point in the supply chain, in the event that a recall is required or there is an issue on quality. Since then, new concepts have been developed to enhance the quality of the information captured to be even more efficient and relevant to current operations.

The development of market-oriented produce supply chains is a major challenge for developing countries, and some of the constraints faced by the industry stakeholders are directly linked to the specific characteristics of fresh produce. These products have a high market value compared with grains, and their labor-intensiveness makes them suitable for smallholder production. Producing fruits and vegetables is also considered risky because of the relatively high investment costs, wide market price fluctuations and high perishability of the crops, among other factors. For example, farmers and traders dealing in organic or superior-quality vegetables complain that they cannot obtain an adequate price premium for the extra quality produce they supply. At the same time, agro-processing and supermarket buyers find it difficult to identify and retain producers willing to adhere to their stringent quality assurance schemes. This paradox suggests that it is a problem for supply chain stakeholders to work together on quality management and value creation.

Another major barrier to implementing cold chain logistics, especially in a rural setting, is the integration of all requirements (Thomson et al., 2001). For example, in Asia, the fragmented nature of the "fledgling" Asian vegetable industry is due to primary growing areas being diversely located through the eastern seaboard. Asian vegetable growers often have a non-English speaking background and, consequently, transfer of technology needs special attention. The infrastructure for optimum postharvest handling of crops is not often currently available for use in communities growing Asian vegetables. The future should see improved vegetable quality as a consequence of increased handling awareness, and investment in equipment (e.g. cooling).

Minimal processing is one way to add value to fruit and vegetables, and address the perishable nature of fresh produce. The perception by consumers of fresh, nutritious, convenient, ready to use products is making these commodities increasingly popular. Improvement of postharvest practices to deliver fresh vegetables in optimum condition to consumers complements cold chain logistics. The value of whole, fresh vegetables often does not justify the use of quicker, but far more expensive, transportation and distribution systems. The use of "value-adding" activities to create products such as ready-to-use fresh-cut produce or processed produce may circumvent the cost issue.

Another example of how to address the lack of a cold chain network is a program at the USDA Agricultural Trade Office (ATO) which worked with USDA-FAS' Emerging Markets Office to help developing countries to build and improve their cold chain. One activity was to build a cold chain program in China that helps local logistics providers improve their capability to handle temperature-sensitive imports. The ATO also uses this network of contacts to identify distributors with the capability to handle US produce, and link them with Chinese buyers and US exporters. The ATO has also taken these efforts inland. For example, ATO has been working with local distributors in Chengdu to buy directly from importers in Shanghai, rather than through a long chain of sub-distributors. Direct exports of fresh produce to mainland China from the US jumped from $5.5 million in 1999 to $80 million by 2005 (Marks and Bean, 2006).

II. Logistics supply

In many countries competition in the produce industry is fierce. In order to be successful, one strategy is to compete on quality, not on price. One key factor is to maintain cold chain integrity, as many perishable commodities are damaged by even slight fluctuations in temperature. Ideally, a warehouse should be fitted with one or multiple drive-in chill rooms, equipped with a container hoist, digital scales and packaging areas, each chill room able to operate at different temperatures to cater to different product requirements.

A. Protocols for domestic, sea and air freight

Air freight transportation plays an increasingly important role in the global economy. Although it accounts for around 2% of all cargo moved worldwide in terms of tonnage, it represents over one third of the value of world trade in merchandise (Hubner and

Sauvé, 2001). Air cargo transport is a key determinant in meeting the demand for perishable goods which are highly dependent on accurately timed imports of inputs and exports of semi-finished or finished products as part of global sourcing and manufacturing networks. It also often offers the only viable means of freight transport to remote, peripheral regions and landlocked countries, particularly in the developing world in light of more limited land transport infrastructure.

Air freight transport is broadly divided into air carriers (which carry freight between airport points), freight forwarders (which design and market cargo services, collect freight and consolidate shipments for carriers, and deliver the goods to consignees), and integrated express carriers (which, as one entity, provide the different components of door-to-door services). Air carriers can be dedicated freighters or combine passenger and cargo operators (by using dedicated cargo aircraft and the holds in passenger aircraft to move cargo, or only the latter). All cargo and combined cargo each account for around 50% of the total freight market (Hubner and Sauvé, 2001). Airport facilities and services, from runway operating services to cargo handling, storage and warehousing, are also essential for the quality, cost and efficiency of services.

According to a classification by the Bureau of Labor Statistics (2006), freight trucking can be grouped as motor vehicles, such as trucks and tractor-trailers, to provide over-the-road transportation of general commodities. This industry segment is further subdivided based on distance traveled. Local trucking establishments carry goods primarily within a single metropolitan area and its adjacent non-urban areas. Long-distance trucking establishments carry goods between distant areas. The work of local trucking firms varies with the products transported. Produce truckers usually pick up loaded trucks early in the morning and spend the rest of the day delivering produce to many different grocery stores. Long-distance trucking comprises establishments engaged primarily in providing long-distance trucking between distant areas, such as between the US and Canada or Mexico.

Some goods are carried cross-country using intermodal transportation to save time and money. Intermodal transportation encompasses any combination of transportation by truck, train, plane, or ship. Typically, trucks perform at least one leg of the journey. Each of these steps is carefully orchestrated and timed so that produce arrives on time, in the best possible quality and condition. Goods can be transported at lower cost this way, but they cannot be highly perishable (for example, cherries and blueberries) nor have strict delivery schedules. Trucking still dominates the transportation of perishable and time-sensitive goods.

B. Traceability, barcode and labeling

Barcodes are currently used for identification and tracing of packaged produce (see also Chapter 12). Producers, carriers and retailers are discovering radio frequency identification (RFID), which provides additional benefits to ensure the quality and safety of products. It stores and remotely retrieves data using an RFID device or tag. This device sends a radio frequency signal that can be recognized by RFID readers. A "passive" RFID device can only absorb and use the energy from the reader signal to transmit their response. An "active" RFID device has its own power supply to transmit a signal. Although an RFID reader costs 10 times more than a barcode reader, an RFID can store much more information than a traditional barcode. This allows each tag or device to have a unique code, while current barcodes are limited to a single type of code for all instances of a particular product. A complete history of each product is available in case of recalls or cold chain management.

A unit-level identification system, HarvestMark, developed by Yottaamark technologies, has been used for fresh product tracing (Engedi, 2007). It is an advanced tagging system that allows fresh produce, such as vegetables and fruits, to be traced back to the location where they were picked. With shipping information open to the general public, anyone around the globe can trace the origins of a single piece (or bulk packages) of fresh produce tagged by HarvestMark via the Internet or a cell phone. HarvestMark provides comprehensive data of where the produce came from and the intermediate locations the produce traveled through to get to the consumer. Another advantage of HarvestMark's traceability is the versatile ability to locate "bad" produce. If a batch of fresh produce arrives with a parasite, for instance, the batch itself could be traced to its origin to prevent further harvesting or shipping. The secure codes are printed beside the common barcodes of fresh produce that are distributed. A batch of apples, for instance, will be packaged and scanned with precise data of its origin along with any other information released by the apple distributing company. Once the apples are in the consumer's hands, the buyer can visit www.harvestmark.com to check the history of a specific batch.

Since January 2005, Wal-Mart has required its top 100 suppliers to apply RFID labels to all shipments. Another Wal-Mart division, Sam's Club, has required that, starting 31 January 2008, every full single-item pallet shipped to its distribution center or directly to one of its stores must bear an EPC Gen 2 RFID tag. However, there is no international standard on RFID code. There is an effort to develop a uniform electronic product code that can be read by any system in the world.

Fresh produce traceability guidelines have also been issued by the Produce Marketing Association (PMA) in conjunction with Canada to standardize the practice. The aim of the guidelines is to provide a common approach to tracking and tracing fresh produce by means of an internationally accepted numbering and barcoding system – the European Article Numbering-Uniform Code Council (EAN-UCC) system. However, the use of common identification and communication standards will significantly improve the accuracy and speed of access to information about the production and provenance of fresh produce.

C. Product temperature and moisture monitoring

To achieve full temperature control, one of the most important issues is the integrity of the cold chain. Cold chain logistics may best be defined as the maintenance of produce temperature throughout the demand–supply chain from harvest to the consumer. Poor cold chain management will have a negative impact on product quality, especially delicate, perishable produce such as fresh horticultural products. Softening, bruising, unwanted ripening, bacterial growth and texture degradation can all lead to spoilage, or even rejection of the consignment. There are five things that successful logistics businesses have in common, they:

- know the product;
- plan the logistics chain;
- know their partners;
- get the basics right;
- know the market.

For example, a simple product like broccoli takes 39 steps along the cold chain – with as many as 23 operators and 21 stages involved along the way – to reach its consumer. Logistics management has become so crucial that to have the situation under control, businesses have to plan the flight and fly the plan.

Murphy (2005) reported that to maintain product integrity, produce must be maintained within very close temperature limits under fluctuating temperature environments. For example, bagged lettuce has become a staple in most grocery stores. As the product distribution network and geographic range expanded, so did its logistical challenges. However, this produce must be picked, washed, packaged and shipped within a matter of days in order to ensure that it arrives at a customer's location while still fresh. Maintaining the proper temperature is critical, as well as ensuring that the bags do not get crushed on the way.

The key to success requires that the produce maintains cold and consistent temperature across the entire life of the product. With only a 15- to 21-day shelf life, speed of delivery and visibility are key success factors in ensuring how to know precisely where the product is at all times, and how long it has been since that product was picked. The guiding rule of thumb for getting product out of the warehouse is FIFO (first in, first out) and FEFO (first expire, first out) processes.

To ensure produce quality and shelf life, an unbroken cold chain must be maintained. Temperature indicators (TIs) indicate whether the product temperature has exceeded a set value, whereas, time–temperature indicators (TTIs) measure both time and temperature and integrate them into a single visible result (IIR, 2004). They indicate the cumulative time–temperature history of the products. They are primarily based on three technologies (color change, diffusion and radio frequency) to indicate or integrate temperature history. For example, 3M Freeze Watch™ will activate when temperatures fall below −4°C, and 3M MonitorMark Time/Temperature Tags will integrate exposed integrated time and temperature information. LeBlanc and Stark (2001) discussed temperature limits in different parts of the world and various temperature monitoring systems available on the market, and how this time and temperature information related to food quality.

The moisture content of produce should also be carefully controlled. For example, a moisture control liner developed by CSIRO from Australia is a simple bag that fits inside a normal carton or box. By keeping humidity high, these liners can reduce moisture loss significantly during long-distance transport. Simple wraps could be used on pallets of properly cooled fruit that are to be carried at non-ideal temperatures, and double the time the produce temperature remains in the required range. The freight transportation network is complex. Yet, at the end of the day, customers will only judge performance by what is delivered to their hands. It is the physical transfer of the product in a manner that not only maintains quality and condition, but also meets the timeframes required by the customer, that determines the survival of the business.

Another crucial configuration is the rules about which products can and cannot be packed together on the same pallet, even when they are part of a single order. This optimizes loading and scheduling of trucks and ensures the maintenance of the highest quality during transportation, since the logistics correctly palletizes the products to meet particular transportation needs. McGregor (1989) developed compatibility and sensitivity tables for fresh produce during transit and storage. Thompson and Kader (2004) further simplified the information into three groups, based on their temperature and humidity requirements. Tables 19.1 and 19.2, compiled based on the

Table 19.1 Shelf life and compatibility information of fresh vegetables[1]

Vegetables	Temperature			Relative humidity (RH)			Ethylene		Chilling or freezing sensitive[2]	Shelf life (days)
	0–3°C	5–10°C	13–18°C	Less than 75%	85–95%	Greater than 95%	Produce	Sensitive		
Alfalfa sprouts	√					√				14–42
Artichoke	√					√				10–16
Arugula	√					√		√		5–7
Asparagus	√					√		√		10–21
Basil		√			√			√		5–7
Beans; fava, lima	√					√				7–14
Beans; snap, green, wax		√			√				c	7–10
Beet	√					√				120–150
Belgian endive	√					√		√		10–14
Bitter melon			√		√				c	10–14
Bok choy	√					√		√		7–10
Boniato			√		√			√	c	180–270
Broccoli	√					√		√		10–14
Broccoflower	√					√		√		14–21
Brussels sprouts	√					√		√		21–28
Cabbage	√					√		√		90–180
Cactus leaves (nopales)		√			√					7–10
Calabaza		√			√				c	60–90
Carrot	√					√		√	f	28–180
Cassava			√		√					21–28
Cauliflower	√					√		√	f	14–21
Celeriac	√					√				180–240
Celery	√					√		√	f	35–49

Table 19.1 Continued

Vegetables	Temperature			Relative humidity (RH)			Ethylene		Chilling or freezing sensitive[2]	Shelf life (days)
	0–3°C	5–10°C	13–18°C	Less than 75%	85–95%	Greater than 95%	Produce	Sensitive		
Chard	√					√		√		
Chayote		√			√			√	c	
Chinese cabbage	√					√		√		60–90
Chinese turnip	√					√				120–150
Collard	√					√		√		
Corn; sweet, baby	√					√				5–8
Cowpea (Southern pea)		√			√					
Cucumber		√			√			√	c	10–14
Cut vegetables	√					√				14–21
Daikon	√					√		√		120
Dry onion			√		√				f	180–350
Eggplant		√			√			√	c	10–14
Endive-chicory	√					√		√		14–21
Escarole	√					√		√		14–21
Fennel	√					√		√		10–14
Garlic	√			√						90–210
Ginger			√		√				c	60–90
Green onion	√					√		√		7–10
Herbs (not basil)		√				√		√		5–7
Horseradish	√					√				240–350
Jerusalem artichoke	√					√				180–350
Jicama			√		√				c	60–90
Kailon	√					√		√		
Kale	√					√		√		10–14
Kiwano (horned melon)		√			√				c	
Kohlrabi	√					√				45–60
Leek	√					√		√		60–90
Lettuce	√					√		√	f	14–21
Lettuce, Romaine	√					√				14–21
Long bean		√								
Malanga		√			√			√	c	
Mint	√					√		√		
Mushroom	√				√					5–7
Mustard greens	√					√		√		

(Continued)

Table 19.1 Continued

Vegetables	Temperature			Relative humidity (RH)			Ethylene		Chilling or freezing sensitive[2]	Shelf life (days)
	0–3°C	5–10°C	13–18°C	Less than 75%	85–95%	Greater than 95%	Produce	Sensitive		
Onion	√			√						30–180
Okra		√			√			√	c	7–10
Parsley	√					√		√	f	30–60
Parsnip	√					√				90–120
Peas	√					√		√	f	7–10
Pepper; bell		√			√				c	14–21
Pepper; hot	√			√						14–21
Potato		√			√				c	56–140
Pumpkin			√	√					c	84–160
Quince	√					√				60–90
Radicchio	√					√				14–21
Radish	√					√			f	10–21
Rutabaga	√					√				120–180
Rhubarb	√					√				14–28
Salsify	√					√				90–120
Satsuma	√				√					56–84
Scorzonera	√					√				
Shallot	√					√		√		180–240
Snow pea	√					√		√		
Spinach	√					√		√	f	10–14
Sprouts	√				√					5–10
Squash; Summer, (soft rind)		√				√		√	c	7–14
Squash; Winter, (hard rind)		√		√					f	30–180
Sweet pea	√					√		√		
Sweet potato			√		√			√	c	120–210
Swiss chard	√					√		√		7–14
Taro (dasheen)			√		√				c	90–120
Tomatillo		√			√				c	21
Tomato; green			√		√			√	c	21–28
Tomato; ripe, partially ripe		√			√			√	c	7–14
Turnip	√					√				120
Turnip greens	√					√		√		10–14
Waterchestnut	√					√				30–60
Watercress	√					√		√		14–21
Winged bean		√			√					
Yam			√		√			√	c	180–240

[1]Information compiled from Ashby (1995), McGregor (1989), Wilson et al. (1999), Boyhan et al. (2004), and Thompson and Kader (2004).

[2]c for both chilling and freezing sensitive and f for freezing sensitive.

Table 19.2 Shelflife and compatibility information of fresh fruits[1]

Fruits	Temperature			Relative humidity (RH)			Ethylene		Chilling sensitive[2]	Shelf life (days)
	0–2°C	7–10°C	13–18°C	Less than 75%	85–95%	Greater than 95%	Produce	Sensitive		
Apple	√				√		√			90–350
Apricot	√				√		√			21–28
Atemoya			√				√		c	14–21
Avocado; ripe	√				√		√			14–21
Avocado; unripe		√			√			√		28–42
Babaco		√			√					28–56
Banana			√		√		√		c	21–35
Barbados cherry	√				√					14–21
Blackberry	√				√					7–14
Blueberry	√				√					10–18
Boysenberry	√				√					2–5
Breadfruit			√		√		√			14–21
Cactus pear; tuna		√			√					28–56
Caimito	√				√					21–35
Calamondin		√			√					14–28
Canistel			√		√		√			10–21
Cantaloupe		√			√		√		c	14–21
Carambola		√			√					21–35
Casaba melon			√		√					21–28
Cashew apple	√				√					
Cherimoya			√		√		√		c	14–21
Cherry; sweet	√				√					14–28
Coconut	√				√					90–150
Cranberry		√			√				c	60–120
Crenshaw melon			√		√		√			14–21
Currant	√				√					14–21
Custard apple		√			√		√			
Date	√				√					240–350
Dewberry	√				√					
Durian; ripe		√			√		√			
Elderberry	√				√					14–21
Feijoa		√			√					
Fig	√				√					7–10
Fresh-cut fruits										
Gooseberry	√				√					

(Continued)

Table 19.2 Continued

Fruits	Temperature			Relative humidity (RH)			Ethylene		Chilling sensitive[2]	Shelf life (days)
	0–2°C	7–10°C	13–18°C	Less than 75%	85–95%	Greater than 95%	Produce	Sensitive		
Granadilla		√			√		√			
Grape	√				√					56–180
Grapefruit			√		√			√		28–56
Guava		√			√		√		c	7–21
Honeydew melon			√		√		√			14–21
Jaboticaba			√		√					
Jackfruit			√		√					
Juan canary melon		√			√		√			
Kiwifruit	√				√		√	√		90–150
Kumquat		√			√					
Lemon		√			√			√	c	120–180
Lime		√			√			√		42–56
Limequat		√			√					7–10
Loganberry	√				√					
Longan	√				√					21–35
Loquat	√				√					21–28
Lychee	√				√					
Mamey			√		√		√			21–35
Mandarin		√			√				c	21–28
Mango; ripe		√			√		√			14–28
Mangosteen			√		√		√		c	35–49
Nectarine	√				√					
Olive		√			√				c	90–120
Orange		√			√					60–90
Papaya			√		√		√		c	14–21
Passion fruit		√			√				c	14–35
Peach	√				√		√			14–28
Pear (Asian & European)	√				√					60–180
Pepino		√			√					
Persian melon			√		√		√			
Persimmon			√		√		√			35–84
Pineapple		√			√				c	14–28
Plantain			√		√		√		c	21–35
Plum; ripe	√				√		√			14–28
Plumcot; ripe	√				√		√			
Pomegranate	√				√				c	
Prune	√				√		√			

Table 19.2 Continued

Fruits	Temperature			Relative humidity (RH)			Ethylene		Chilling sensitive[2]	Shelf life (days)
	0–2°C	7–10°C	13–18°C	Less than 75%	85–95%	Greater than 95%	Produce	Sensitive		
Pummelo		√			√					30–60
Quince	√				√		√			60–90
Rambutan			√		√					14–21
Raspberry	√				√					5–7
Sapodilla			√		√		√			35–56
Sapote			√		√		√			14–21
Soursop			√		√		√			7–10
Strawberry	√				√					7–14
Sugar apple		√			√					14–21
Tamarillo		√			√				c	35–63
Tamarind		√			√					42–63
Tangelo		√			√				c	21–35
Tangerine		√			√					14–28
Ugli fruit		√			√					
Watermelon			√		√					14–21

[1]Information compiled from McGregor (1989), Ashby (1995), Wilson et al. (1999), Boyhan et al. (2004), and Thompson and Kader (2004).
[2]c for both chilling and freezing sensitive.

information available in the literature; include storage temperature, humidity, ethylene and chilling sensitivity, and shelf life for vegetables and fruits, respectively. Both tables can be used to show how different produce should be handled during transit and storage.

III. Refrigeration systems and refrigerant types

Nearly all current refrigeration systems use vapor compression technology. However, some small seasonal produce operations may use total-loss refrigerants, such as carbon dioxide or liquid nitrogen. A detailed review of refrigeration principles and systems can be found in Hung (1991). However, many new developments in refrigerants address environmental concerns. For example, most of domestic refrigerators now use R-134a; commercial refrigeration, cold storage and refrigerated transportation use R410A, R407C, R507 or HFC-134a as refrigerants. Because of environmental concerns and advances in technology, there is also renewed interest in inorganic compounds, such as ammonia (R717) and CO_2 (R744) as refrigerants.

As reported in the literature, lowering the respiration rate of fresh vegetables is essential to preserving market quality. The most important technology for lowering respiration rates remains proper cooling of produce within hours of harvest (Jones, 1996). Proper cooling preserves product quality by:

1. inhibiting the growth of decay-producing microorganisms;
2. restricting enzymatic and respiratory activity;
3. inhibiting water loss; and
4. reducing ethylene production (Hardenburg et al., 1986).

In general, harvesting should be done in the early morning hours to minimize field heat. Harvested produce should avoid direct exposure to sun, or field-cool before transport to packing or transportation facilities. Produce will then be cooled to safe storage temperatures. Produce should be shipped to market as soon as possible, and practice first-in-first-out (FIFO) rotation. Refrigerated loading and unloading areas should be used. Trucks should be cooled before loading, and load pallets should be loaded towards the center of the truck. Insulating plastic strips should be used in the truck and in the loading dock. Produce should be moved rapidly to the storage area, at the appropriate temperature, and displayed at the appropriate temperature range.

A. Systems for field chilling at processing and packing locations

All fresh horticultural crops are living organisms, even after harvest, and they must remain alive and healthy until they are either processed or consumed (Fraser, 1998). The energy needed to continue living comes from food reserves in the product itself. The process by which these reserves are converted into energy is called respiration. Heat energy is released during respiration, but the rate varies depending on the type and variety of product, the level of maturity, the amount of injury and the product temperature.

Product temperature has the greatest influence on respiratory activity. Rapid, uniform cooling, as soon as possible after harvest to remove field heat is critical in lowering the respiration rate. This reduces the rate of deterioration, and helps provide longer shelf life. Lowering the temperature also reduces the rate of ethylene production, moisture loss (wilting) and growth of microorganisms. A rule of thumb is that a one-hour delay in cooling reduces a product's shelf life by one day. The resulting economic loss exceeds the increased cost of expedited handling of the produce by more frequent deliveries from the field to the cooling facility for initiation of forced-air cooling. This is not true for all crops, but is especially true for highly perishable crops in hot weather.

Many products are field- or shed-packed before being cooled. Wire-bound wood or nailed crates or wax-impregnated fiberboard boxes are used for packed products that are cooled with water or ice after packing. Cooling of products packed in shipping containers and stacked in unitized pallet loads is especially important to ensure air circulation around and through the packaging.

Room cooling means produce is simply placed in a cold storage room and cools slowly and non-uniformly, mainly through conduction and natural convective contact with refrigerated air. However, a cold room is normally used to store previously cooled produce, and does not have the capacity to remove heat from the uncooled produce. Most cold rooms will increase in temperature after each fresh batch of warmer produce is added. A compromise is to form a cooling area, by partitioning part of the storage using a tarpaulin suspended from the ceiling. This helps reduce temperature fluctuations, but should only be considered as a temporary measure.

Forced-air cooling can quickly remove field heat from freshly-picked produce. High capacity fans are used to pull refrigerated air through the produce. Rapid and uniform cooling is achieved by the forced-convective contact of the high-speed, refrigerated air with the warm produce. Pulling air rather than blowing it through is preferable, because air flow is more uniform using this method. With proper container design and orientation, produce can be rapidly and uniformly cooled in baskets, boxes, bins, or bags. Forced-air cooling simply does a better job with refrigerated air in cold storage.

Hydrocooling occurs by flowing chilled water over the produce and rapidly removing heat. It is usually at least ten times faster than forced-air cooling in removing heat from produce, but is less energy-efficient. This cooling is not suitable for produce that is delicate and sensitive to wetting, such as most berries.

Top-icing is simply placing crushed ice over produce in boxes or containers, where liquid icing injects a slurry of water and ice into the produce packages. It is an effective method for dense produce, such as broccoli, that cannot be cooled easily by forced-air cooling. Another advantage of icing is the residual effect, which further removes heat generated from respiration. In general, 1 kg of ice can cool about 3 kg of produce from 30°C to 5°C (Anonymous, 1992).

Vacuum cooling is obtained by placing produce inside a vacuum chamber and applying a vacuum, causing water to evaporate from the produce surface, and hence lowering the produce temperature. It is an effective cooling method for produce with a high surface-to-volume ratio, such as leafy vegetables. To prevent wilting due to moisture loss during vacuum cooling, produce can be presprayed with water.

Many factors influence the rate of cooling, such as:

1. the density of produce in the container (the less dense the produce pile, the faster the cooling);
2. the container type, orientation and venting characteristics (if air passes uniformly and evenly around the produce, cooling is faster);
3. the volume to surface area of the produce (the lower the ratio, the faster the cooling, e.g. cherries cool quicker than melons);
4. the travel distance of the cooling air (the shorter the distance, the faster the cooling of the overall pile);
5. the airflow capacity (the higher the airflow, the faster the cooling).

The {7/8} cooling time is a standard industry term that describes the time to remove seven-eighths (87.5%) of the temperature difference between the starting produce temperature and the temperature of the cooling medium (refrigerated air, in the case of forced-air cooling). It is a convenient method of indicating when produce has come as close as practical to the temperature of the cooling medium. For example, if a 32°C peach cooled using 0°C air reaches 4°C in 9 hours, the {7/8} cooling time is 9 hours. That is, a 28°C temperature drop would occur from a 32°C difference between the produce and the air. The {7/8} cooling time is, theoretically, three times as long as the {1/2} cooling time. Therefore, the same peach that took 9 hours to cool to 4°C would take only 3 hours to reach 16°C, the temperature at the {1/2} cooling time, if everything else remained the same. For practical purposes, one can estimate when a product will be {7/8} cool by knowing other cooling times. In general, the {7/8} cooling time is 7.5, 4.5, 3, 1.5 times longer than the {1/4}, {3/8}, {1/2}, {3/4} cooling times, respectively.

Crops with very high respiration rates (asparagus, broccoli, leaf lettuce, spinach, sweet corn, mushrooms) at harvest temperatures must be cooled rapidly and as soon as possible (less than 90 minutes) after harvest. Most of these crops are traditionally hydrocooled, iced, or vacuum-cooled. However, all of them can be forced-air cooled, provided cooling is done quickly with high airflow rates and high RH, to reduce the danger of drying out. Crops which have high respiration rates at harvest temperatures (blueberries, raspberries, strawberries, sweet cherries, cauliflower, snap beans, head lettuce) should be forced-air cooled as quickly as practicable (less than 3 hours) after harvest. Crops with moderate respiration rates at harvest temperatures (apples, cabbage, cantaloupes, celery, peaches, plums, peppers and squash) still need to be cooled within 4–5 hours to avoid quality loss.

Portable ice plants, hydrocoolers, vacuum coolers, forced-air coolers, and package-icing machines are available for use in fields. This equipment is useful for remote or small-scale operations that cannot justify investment in a fixed-cooling facility. Mounted on skids or dollies, the equipment can follow the harvest from field to field, and be shared by many growers.

Since many tropical products are sensitive to chilling injury, care must be taken not to cool or store the products below the recommended temperature. Often the visible effects of chilling injury are delayed until the product is offered for retail sale. These effects include failure to ripen properly, pitting, decay, watery breakdown and discoloration in fruits and vegetables. Flowers and plants lose florets or foliage, fail to open, discolor, or wilt. A detailed discussion of the latent damage has been described by Hung (1993).

All produce are also sensitive to decay. Cooling equipment and water should be sanitized continuously with a hypochlorite solution, to eliminate decay-producing organisms. Care must also be taken not to allow produce to warm up after cooling. Condensation on produce surfaces should be avoided to prevent the spread of decay.

B. Systems for land trucking, air freight and sea freight transportation

After cooling, produce must be properly loaded and transported at or near the recommended storage temperature and RH, to maintain quality. The design and condition of the transport equipment, such as insulation and air circulation systems, and the loading method used, are critical to maintaining produce quality (Ashby, 1995). The mode of transportation and the carrier should be chosen carefully.

Mechanical refrigeration systems usually use diesel generated electric power both on the road and aboard ocean vessels. Van containers are plugged into electrical power at depots and aboard ships. Cryogenic refrigeration using liquid or gaseous nitrogen or carbon dioxide is vented into the cargo compartment. Some products, such as leafy green vegetables, are not compatible with carbon dioxide refrigeration. Dry ice, the solid form of carbon dioxide, can be located in special trays or compartments in the cargo area or within individual shipping containers to control the temperature. Direct contact with dry ice will also injure fresh products. Wet ice uses ice within individual shipping containers or on top of a load of containers, either as a supplement to, or instead of, mechanical refrigeration. Many airlines refuse to handle shipping containers with wet ice, due to the risk of expensive damage from leaking containers. Airlines that do permit wet ice require it to be placed in sealed polyethylene bags inside a leak-proof container with a moisture absorbent pad. Gel refrigerant uses frozen containers of chemical eutectic gel to maintain temperature within shipping containers. This is the refrigeration system preferred by most airlines. During transportation, proper ventilation through fresh air exchange in the refrigeration system, or separate venting to protect products from a build-up of carbon dioxide or ethylene, is also needed. Modified atmosphere sometime provides added benefit to extend shelf life. It is achieved by adding a specific percentage of nitrogen or carbon dioxide gas to pallet bags or the cargo compartment of refrigerated trailers or van containers, to reduce product decay, respiration and ripening of certain products.

The following transportation equipment is available:

- Air cargo containers: for air and highway transport.
- Air cargo pallets with netting: for air and highway transport.
- Highway trailers: for highway transport only.
- Piggyback trailers: for rail, highway and roll-on/roll-off ocean transport.
- Van containers: for rail, highway and lift-on/lift-off ocean transport.
- General cargo ocean vessels: handling palletized or individual shipping containers in refrigerated holds of ships.
- Rail boxcars: handling palletized or individual shipping containers.

For each transport mode, there is specialized refrigerated equipment to control and maintain the temperature. This equipment was designed to maintain temperature, not to cool the product. The majority of these transport refrigeration units use vapor-compression refrigeration with HFC refrigerants (IIR, 2003). Some use total-loss refrigerants, such as carbon dioxide (dry ice). Road transport units may operate either from the vehicle engine or from an independent diesel engine. The refrigeration unit of small- to mid-size trucks can be run directly from the truck engine however, the refrigeration unit for one mid- to large-truck (12 to 28 feet long) is usually run by a separate diesel engine. Trailer compartments can be further divided into single compartments (one set temperature) or multiple compartments (with a different temperature setting for each compartment). Rail units may operate on electricity supplied from a generator wagon or its own diesel engine. Marine refrigeration is usually electrically-driven from the ship's generator. Refrigerated equipment is rare for air transportation which commonly uses dry ice. However, some battery-operated systems are available for air transport (IIR, 2003). Most of the units are also equipped with temperature recording devices, and data can be downloaded or up-linked when in transit.

The performance of the refrigerated transportation unit is impacted by structural design, such as thermal bridging, refrigeration system location and air distribution systems, door openings and protection, and fresh air exchange. The performance of a transport system is highly dependent on the way it is loaded, and sufficient space must be allowed between items (pallets or cartons) for chilled air to circulate. However, excessive space should be avoided to prevent short-circuiting.

Refrigerated trailers and van containers are recommended for most high volume produce with transit and storage lives of one week or more. After transit, there must be enough shelf life remaining for marketing. Carriers utilizing trailers and containers can offer a door-to-door service. This reduces handling, exposure, damage and theft of the products.

Many products are shipped in non-refrigerated air containers or on air cargo pallets. This requires close coordination at the origin and destination airports, to protect the products when flights are delayed. Cold storage facilities at airports are needed to ensure product quality. Refrigerated air containers are available, and should be used when possible.

C. Systems for produce at grocery stores and display cases

Fresh produce received at the grocery store should be kept in storage rooms or display cases at the same optimal temperature and humidity condition as at storage warehouses and during transportation. Care should also be taken to prevent mechanical damage during handling, with proper rotation (FIFO). Kader and Thompson (2001) suggested maintaining quality and preventing chilling injury by providing three storage rooms at different temperature settings (0°C to 2°C, 7° to 10°C and 13° to 18°C), with humidity at 85% to 95%. These storage rooms should have good air circulation and fresh air exchange, to maintain proper temperatures and prevent ethylene build-up.

Produce stored at refrigerated temperatures should be displayed in refrigerated cases. However, produce which does not lose moisture quickly, e.g. apples, can be displayed at ambient store temperature. Refrigerated display cases should be properly maintained, with an easy-to-read, accurate thermometer to prevent quality deterioration due to insufficient or ineffective cooling of the surface area of the produce. To protect produce from excessive moisture loss, automatic sprayers have been installed in many display cases. A list of produce which will benefit from misting while on display can be found in Kader and Thompson (2001). However, many supermarkets report significant shrinkage of produce displayed at the front portion of their display cases which is beyond the reach of the refrigerated air and spray. Produce loss due to wilting and drying caused by heat from the grocery store is estimated at approximately $1.00 per foot of display case per day. To combat this problem, open refrigerated display cases are often shielded with covers made of woven aluminum or some other kind of night covers. Special lighting (e.g. Promolux lighting) for produce display cases is also available which produces true color visual appeal, and less heat and radiation, hence prolonging produce shelf life.

D. Home refrigerators

Refrigeration is now part of our way of life. It would be inconceivable for it to be any other way. It has even become an essential ingredient and a *sine qua non* in improving our quality of life. Domestic refrigerators vary in size, are usually set at 4°C to 5°C, require 60 to 140 watts of electrical power and contain 40 to 180 grams of refrigerant. Most produce should be stored in sealed crisper drawers. In general, vegetables require higher humidity, while fruits prefer lower humidity conditions. However, produce that ripens after harvest should not be stored in a refrigerator. For example, tomatoes will lose flavor and aroma when stored at refrigerated temperatures. Tropical fruits like bananas and mangos should never be refrigerated.

Some high-end refrigerators have multiple temperature zones/drawers with humidity controls. Some refrigerator manufacturers have planned to incorporate RFID technology to track items in refrigerators, which can also be set to check whether any item is stored at an inappropriate temperature or condition.

E. The cooling chain summary

Cool chain management is essential for preserving the harvested quality of fresh produce. Effective cool chain management begins on the farm and ends in the refrigerator at home. Brief overviews of fruit and vegetable storage and transport systems can be found in the *Encyclopedia of Agricultural, Food, and Biological Engineering* (Hellevang, 2003; Hellickson, 2003; Tao, 2003). In general, any effort to reduce the breaks in the cool chain will have a positive effect on optimizing the shelf life and quality of fresh produce. Temperature management is one of the most important factors affecting the quality of fresh produce. There is an optimum storage temperature for all products. This implies a number of steps where refrigeration is essential, such as:

1. harvest while it is cool in the field;
2. transport to the packing house where they are regularly cooled. Most storage rooms do not have the refrigeration capacity for rapid cooling, and cooling should be done by a separate operation using special equipment;
3. transport in refrigerated vehicles;
4. hold in a cold environment during storage and packing;
5. keep produce on display in a shop or a supermarket under cool conditions;
6. keep at the appropriate temperature by the consumer at home.

IV. Storage and packaging

Throughout the cold chain, produce will need to be stored or held for short periods of time. The optimal storage environment to protect quality, such as temperature and humidity, is different for each item. However, it may not be practical to maintain every item separately, and recommendations on the compatibility of different fruits and vegetables have been reported (Boyhan et al., 2004; Thompson and Kader, 2004).

Many products of tropical or subtropical origins are sensitive to low temperatures, while produce with high respiration rates and moisture loss are sensitive to low humidity. If stored under lower than recommended temperatures, this produce will suffer chilling or freezing injury, which often only becomes apparent after the products warm up. Several types of insulating pallet covers are available to protect chilling-sensitive commodities when transported with non-chilling-sensitive commodities at temperatures below their threshold chilling temperatures. Dehydration is another important issue; too much moisture loss will result in wilting and shriveling. Some products can be waxed, film-wrapped, package-iced, or top-iced or maintaining desirable humidity will prevent damage.

Ethylene is a chemical produced by many plants which has a physiological function such as hormone regulating growth and stimulating ripening. During transport or storage, fruits and vegetables that produce a large volume of ethylene will cause premature ripening of produce sensitive to ethylene. Ethylene absorbing pads with potassium permanganate or frequent exchange with outside fresh air to reduce ethylene concentration can be used to control ethylene.

Mixing several produce items into one load is common however, selection of compatible products with regard to temperature, humidity, ethylene production, sensitivity to ethylene and odor production and absorption should be considered. Tables 19.1 and 19.2 listed compatibility information for vegetables and fruits, respectively.

The primary function of food packaging is to protect the food from external hazards. Similarly, the package itself should not affect the food in any way. Some common shipping containers by commodity can be found in Boyette et al. (1996). Different packaging materials have different barrier properties to protect the food from ingress of gas, light and water vapor that will potentially result in deterioration of color, oxidation of lipids and unsaturated fats, and a general loss of sensory qualities. Such barrier properties also protect against the loss of moisture from produce to the external environment, thereby eliminating dehydration and weight loss. In addition to protection, a barrier encloses the product and provides a means of handling (e.g. shipping containers) or provides nutritional and required labeling information (e.g. consumer packaging). Packaging must also be able to withstand handling during loading and unloading, compression from the overhead weight of other containers, impact and vibration during transportation and high humidity during cooling, transit, and storage.

Many different types of packaging materials have been used for produce and are summarized in USDA Agriculture Handbook 668 (McGregor, 1989). They are:

- wood bins, crates (wire-bound, nailed), baskets, trays, lugs, pallets;
- paper bags, sleeves, wraps, liners, pads, excelsior and labels;
- plastic bins, boxes, trays, bags (mesh, solid), containers, sleeves, film wraps, liners, dividers and slip sheets;
- foam boxes, trays, lugs, sleeves, liners, dividers and pads;
- different types of construction materials are used in the design of fresh produce packages. They include: fiberboard, wood, wraps, plastic films, paper and polystyrene foam liners.

Fresh produce is exempt from the FDA nutrition labeling requirement. However, the FDA has a voluntary nutrition labeling program through the use of shelf labels, signs and posters. Labeling of consumer packages is mandatory under FDA regulations, and requires the name of product, net weight, and name and address of the manufacturer, packer or distributor; processed items must list all ingredients. The current US Farm Security and Rural Investment Act of 2002 requires country of origin information for fresh produce. However, the implementation of this regulation has been delayed until 30 September 2008.

V. Developing trends

In June 2002, the US Congress passed a new Public Health Security and Bioterrorism Preparedness and Response act which required all food facilities (i.e. domestic and foreign) doing business or shipping food to the US to register with the FDA (FDA, 2002). The FDA also requires a prior notice on shipments coming to the US before it arrives. This law also requires persons who manufacture, process, pack, transport, distribute, receive, hold, or import food to establish and maintain records to enable tracing of the product. To help tracing the product, a global trade item number (GTIN) is a globally-recognized protocol for assigning item numbers. It is used in at least 26 different industries in about 100 countries. The code, which forms part of the data that can be held on RFID tags, can provide an accurate, efficient and cheap means of controlling the flow of product and data using an all-numeric 14-digit identification system. GTIN is not a single number to be used by companies, but a standard protocol which, if followed correctly, allows suppliers to identify and buyers to track products. Once companies store GTIN numbers on their systems automatic data capture, such as scanning for RFID or barcodes, will reveal all the information the 14-digit code represents. In a recent case study, the Produce Marketing Association (PMA) evaluated the use of GTIN along the supply chain to improve logistics. The PMA recommends that the fruit and vegetables sector adopt the use of GTIN as a means of automating traceability and to cut costs.

Following threats of terrorism globally, another trend is using "Tamper–Evident" packaging. The United Fresh Fruit & Vegetable Association (FFVA) however, has expressed some reservations on such a recommendation. The FFVA contends that as an industry that markets highly perishable and living, breathing products, tamper-evident packaging would not be feasible for the vast majority of produce available in the marketplace. Tamper-evident packaging would also dramatically alter how consumers select produce, which remains a sensory experience of touch and smell. The fresh fruit and vegetable industry, and the retail supermarket industry, have found that bulk fresh produce displays are still the best way for consumers to make their purchasing decisions. Since produce is highly perishable, the produce industry also believes most fresh produce is likely to exit from the food distribution pipeline before public health authorities even learn of an outbreak and start a trace back investigation. The produce industry believes the emphasis should be on prevention, rather than tracking records after the fact.

On packaging and labeling, most of the produce is still packed in cartons or bulk packages. Labeling which contains the name and address of the food marketer is required and allows investigators to identify the source of the product, and then look into the general agricultural and handling practices of the grower–shipper to further enhance prevention, should systemic problems be identified. One new technology to address annoying labels on individual produce such as apples is using laser light to label individual fruit. Traditional labels/stickers on individual fruit either fall off easily from the produce during distribution, or are too difficult to remove by the consumer before consumption. The Natural Light Labeling system developed by Duran Wayland uses a concentrated beam of light to remove the pigment from the outer layer of skin and reveal a contrasting color underneath. It can etch logos, PLU's country of origin, lot and batch numbers, and virtually any information a producer wants to put on. This technology has been submitted to the FDA for approval.

Today, many produce items are also being offered in convenience packaging, such as salads in a bag or pre-cut small vegetables. Cut fruits are also being offered in plastic cups or other molded packaging. For these products, the packaging is intended for the consumer's convenience and is uniquely designed to meet the quality control needs of the fruit or vegetable it contains. The design of current packaging materials for fresh fruits and vegetables allows for proper cooling, ventilation and product integrity, but cannot be considered tamper-evident packaging. The unique shape, size and form in which fresh produce comes does not lend itself to tamper-evident packaging. More importantly, fresh produce is a living product with various respiration rates that would require various types of packaging materials. Confining the respiratory gases within the package can have a very negative impact upon produce quality and product safety. Available packaging technology does not afford any enhancements that the product does not currently have in its natural form.

Another trend is toward third party certification with internationally recognized programs like organic, non-GMO, fair-trade, ISO 14 000 for environmental, GAPs and GMPs, HACCP, ISO 22 000 for food safety, and ISO 9000 for food quality and management. GAPs is a program that informs growers and farm workers about the microbial risks associated with fresh produce and assists them to control these risks.

Key areas of the GAPs program are prior land use, adjacent land use, water quality and use practice, soil fertility management, wildlife, pest and vermin control, worker hygiene and sanitary practices, and harvesting and cooling practices. GMPs are the part of the quality assurance program that ensures that foods are consistently produced and controlled in such a way that meets the quality standards appropriate to their intended use, as required by the FDA. It is concerned with both production and quality control. These programs can help ensure quality and safety of produce, and speed up transportation and inspection through the cold chain. Refrigeration is one critical component to ensure produce quality and safety, and meets the requirements of many certification programs mentioned above. A similar effort in the US by the USDA Agricultural Marketing Service on their "Good Agricultural Practices and Good Handling Practices Audit" and the "Plant Systems Audit" programs help improve the inspection processes of fruits and vegetables at packing houses and processing plants.

Another program called Safe Quality Food (SQF) is a management program that incorporates GAPs, GMPs, HACCP, Codex requirements and local food safety regulations. It is a fully-integrated food safety and quality management protocol designed specifically for the food industry. It includes a safety standard, training and independent auditing and certification that enables a supplier to verify food has been produced, processed, prepared and handled in accordance with global standards. It is administered by the SQF Institute, a division of the Food Marketing Institute (FMI). Over 4000 companies operating in the Asia–Pacific, Middle East, US, Europe and South American regions have implemented SQF. It is a HACCP-based third-party audited food safety and quality program implemented by suppliers. The SQF 1000 is for use by primary producers, such as for fresh produce. It enables a primary producer to demonstrate that they can supply food that is safe and meets the quality specified by a customer.

Increasingly, webcams are installed in refrigeration rooms, allowing clients to watch the produce being loaded and packaged in the cold room via the Internet. An automated shipment tracking system is another innovative service.

The Danish Environmental Protection Agency (Bertelsen and Christensen, 2003) published a report on the use of natural refrigerants in supermarkets. The report focused on the energy consumption and installation costs of using propane and CO_2 in supermarkets. Most of the published reports were using CO_2 as a secondary refrigerant. Earlier studies documented the excellent thermo-physical and thermo-dynamic properties of CO_2 and propane or CO_2 and other artificial refrigerant cascade systems. Since CO_2 is a naturally existing substance in the atmosphere, its long-term influences on the environment have been well-investigated, with no unforeseen threats to the environment. Another report by Sawalha (2005) indicated over 100 installations of CO_2 systems in Scandinavian countries. Technical drawbacks of natural refrigerant systems are that several of the natural refrigerants cannot be used directly in the supermarket, due to their undesirable properties as regards flammability and toxicity. For this reason, indirect systems need to be designed where these refrigerants exchange heat with a secondary refrigerant (brine), which is then pumped from the engine room to the refrigerated and freezer display cases. Measurements and analyses made so far of this type of refrigeration system for supermarkets have proved however, that the “price” of replacing unwanted gases will be an increase in energy consumption of 5–10%.

Most of the discussion in this chapter was focused on the postharvest cold chain. However, postharvest technologists can only maintain quality, not improve it. Preharvest factors can also influence produce quality during and after harvest (Hewett, 2006), and should be considered for the overall system.

References

Anonymous (1992). Maintaining the quality of North Carolina fresh produce: Crushed and liquid ice cooling. North Carolina Agricultural Extension Publication, AG–414–5. http://www.bae.ncsu.edu/programs/extension/publicat/postharv/ag-414-5/

Ashby, H. (1995). Protecting perishable foods during transport by truck. USDA Handbook, No. 669.

Bertelsen, P., Christensen, K. (2003). Use of natural refrigerants in supermarkets. Danish Environmental Protection Agency, Environmental Project No. 835.

Bollen, A.F., Ridden, C.P., Opara, L.U. (2006). Traceability in postharvest quality management. IJPTI, 1(1), 93–105.

Boyette, M.D., Sanders, D.C., Rutledge, G.A. (1996). Packaging requirements for fresh fruits and vegetables. North Caroline State University, Agricultural Extension publication, AG–414–8.

Boyhan, G.E., Hurst, W.C., Kelley, W.T., Krewer, G.W., Taylor, K.C. (2004). Postharvest handling and transportation of fruits and vegetables. The University of Georgia, Cooperative Extension Services Fact Sheet 100.

Bureau of Labor Statistics, U.S. (2006). Truck transportation and warehousing, Department of Labor, Career Guide to Industries, 2006–07 edn, available at http://www.bls.gov/oco/cg/cgs021.htm Accessed 29 December 2006.

Christopher, M., Lee, H.L. (2001). Supply chain confidence: the key to effective supply chains through improved visibility and reliability. Vatera Inc, Global Trade Management.

Engedi, J. (2007). New traceability technology for fresh produce. HarvestMark, July 10. http://www.harvestmark.com/news.html

FDA (2002). Public health security and bioterrorism preparedness and response act of 2002. http://www.fda.gov/oc/bioterrorism/bioact.html

Fearne, A., Hughes, D. (1999). Success factors in the fresh produce supply chain: insights from the UK. Supply Chain Management, 4(3), 120–128.

Fraser, H.W. (1998). Tunnel forced-air coolers for fresh fruits and vegetables. Ontario Ministry of Agriculture and Rural Affairs.

Hardenburg, R.E. et al. (1986). The commercial storage of fruits, vegetables and florist and nursery stocks. USDA/ARS, Agr. Handbook 66.

Hellevang, K. (2003). Vegetable storage system. In: The Encyclopedia of Agricultural, Food, and Biological Engineering, D.R. Heldman (ed.). Marcel Dekker, Inc., New York, NY, USA, pp. 1116–1123.

Hellickson, M.L. (2003). Fruit storage systems. In: The Encyclopedia of Agricultural, Food, and Biological Engineering, D.R. Heldman (ed.). Marcel Dekker, Inc., New York, NY, USA, pp. 422–424.

Hewett, E.W. (2006). An overview of preharvest factors influencing postharvest quality of horticultural products. Int. J. Postharvest Tech. Innov., 1(1), 4–15.

Hubner, W., Sauvé, P. (2001). Liberalising Scenarios for International Air Transport.

Hung, Y.-C. (1991). Food freezing. In: Encyclopedia of Food Science and Technology, Y.H. Hui (ed.). John Wiley & Sons, New York, NY, USA, pp. 1041–1050.

Hung, Y.-C. (1993). Latent damage: a systems perspective. In: Postharvest Handling: A Systems Approach, R. Shewfelt, S. Prussia (eds). Academic Press, Inc., pp. 211–224.

IIR (2003). Refrigerated transport: progress achieved and challenges to be met. The 16th informatory note on refrigerating technologies. International Institute of Refrigeration, Paris, France. http://www.iifiir.org/en/doc/1014.pdf

IIR (2004). Temperature indicators and time-temperature integrators. The 3rd informatory note on refrigeration and food. International Institute of Refrigeration, Paris, France. http://www.airah.org.au/downloads/2005-05-02.pdf

Jones, S. (1996). When time is of the essence. Progressive Grocer, 75(2), 105.

Kader, A.A., Thompson, J. (2001). Grocery store display storage. Perishable Handling Quarterly, 107, 6–7.

Katzorke, M., Lee, B.W. (1998). Creating world class supply chains, 41st APICS International Conference Proceedings, pp. 107–110.

LeBlanc, D., Stark, R. (2001). The cold chain. In: Advances in Food Refrigeration, Da-Wen Sun. Leatherhead Publishing, Surrey, UK, pp. 326–365.

Luo, W., Findlay, C. (2002). Analysis of logistics service sector in China: implications of accession to the WTO. Paper prepared for the Authors Workshop on WTO Accession and Poverty Reduction, Beijing, China, October 26–27.

Marks, C., Bean, R. (2006). Shanghai's logistics infrastructure paves access for U.S. Produce. FAS (Foreign Agricultural Service) Worldwide. United States Department of Agriculture. An online review of Foreign Agricultural Service initiatives and services. http://www.fas.usda.gov/info/fasworldwide/2006/04-2006/ShanghaiFruit.pdf

McGregor, B.M. (1989). Tropical Products Transport Handbook. USDA Handbook, No. 668.

Murphy, J.V. (2005). Earthbound farm gets a fresh solution for its perishables supply chain. Global Logistics & Supply Chain Strategies, November.

Sawalha, S. (2005). Using CO_2 in supermarket refrigeration. ASHRAE Journal, 47(8), 26–30.

Tao, Y. (2003). Fruit transport system. In: The Encyclopedia of Agricultural, Food, and Biological Engineering, D.R. Heldman (ed.). Marcel Dekker, Inc., New York, NY, USA, pp. 425–430.

Tarnowski, J. (2006). The produce supply chain challenge. Progressive Grocer, Executive Insight Series, pp. 99–105. http://www.progressivegrocer.com/progressivegrocer/images/pdf/CH_Robinson_PG_PDF.pdf

Thompson, J.F., Kader, A.A. (2004). Wholesale distribution center storage. In: The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks. USDA Agricultural Handbook, No. 66.

Thomson, G., Morgan, W., Winkler, S., Chew, M., Frisina, C., Jaeger, J. (2001). Diversifying Asian vegetable markets. RIRDC Publication No 01/01, Rural Industries Research & Development Corporation, RIRDC Project No. DAV-128A. Level 1, AMA House, 42 Macquarie Street, Barton, ACT 2600, Australia.

20

Postharvest Handling under Extreme Weather Conditions

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I. Introduction

The modern era of informatics and high-technology communications has allowed many growers, shippers and retailers to learn and implement practices and technologies that have had success elsewhere in the world. There have been many examples where technological protocols were "copied on the local level," and the results were similar to those previously experienced. However, we are also continually reminded that what is done at one site cannot be transmitted directly to another, even when similar cultivars are grown. The interesting point, and the good news for those working to improve postharvest quality of produce, is that a successful plan of production and handling to maintain quality may only need simple adjustments to produce good standards in other operations. It is paramount to stress the importance of environmental factors occurring during the hours before and immediately after harvest, particularly when those factors involve extreme conditions prevalent in places such as low deserts and rainy tropics.

Research has shown the direct effects of environmental conditions during the hours before harvest on postharvest quality (Herppich et al., 2001; Fonseca, 2006). A single stress event can produce major physical changes in the physiology and anatomy of the plant upon recovery. For example, trichomes were formed in feverfew plants

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after recovering from a wilting event (Fonseca et al., 2005), and grafted watermelon produced adventitious roots and aerenchyma to adapt to a single flooding (Yetisir et al., 2006). Environmental factors encountered during handling of produce that can affect final quality include extremely low or high temperatures, rain and extremely low relative humidity (RH). It is possible that in the future, with more urban areas coexisting with production fields and orchards, other factors may become more important, such as environments with high emissions of CO_2, as well as atmosphere with low pressure and high ethylene content.

II. Postharvest handling in the tropics

Postharvest losses encountered in tropical areas with a high incidence of rainfall are likely the highest in the world. Losses in developing countries along the tropical belt are estimated to be about 50% (FAO, 1989). Typical losses of underutilized fruits, such as Safou in central Africa, range from 40 to 50% (Silou et al., 2007). In Costa Rica, mango losses due to anthracnose in the central distribution market may range from 14% in the dry season to 84% during the rainy season (Arauz et al., 1994).

Rainfall, evaporation, minimum and maximum temperature during the three days before harvest is significantly correlated to sensitivity of Hawaiian-grown papaya to quarantine heat treatments (Paull, 1995). Interestingly, there was no significant relationship between solar radiation and mean temperature. The author concluded that fruit that were exposed on the day of harvest, or during the three days before harvest, to minimum temperatures higher than 22.4°C showed improved tolerance to quarantine heat treatments. This induced-tolerance to postharvest heat treatments has been associated with heat shock proteins (Key et al., 1985; Paull and Chen, 1990).

High RH and temperatures around 30°C can enhance wound healing of citrus fruits (Stange et al., 1993; Kinay et al., 2005). This is a major reason for the recommendation that degreening treatments occur in high RH and controlled temperatures (Kinay et al., 2005). This beneficial effect is associated with a fast wound healing rate, triggered by the formation of lignin and the induction of antifungal compounds, such as scoparone and scopoletin (Stange et al., 1993). The proliferation and/or penetration in the fruit by pathogens, such as *Penicillium digitatum*, *P. italicum* and *Geotrichum candidum* is reduced when curing is induced under high RH and temperatures around 30°C (Plaza et al., 2003). High temperatures during postharvest storage are commonly associated with high transpiration rates and subsequent degradation of quality traits. However, in the case of herbs such as marjoram even temperatures as high as 30°C do not affect oil accumulation, but rather can stimulate synthesis (Bottcher et al., 1999).

Temperatures and light intensity in tropical areas fluctuate less than in hot, dry or temperate climates. Although it is not completely clear how the low daily temperature fluctuation impacts the postharvest quality of fruit (Woolf and Ferguson, 2000), some studies suggest that shelf life of vegetative tissue may be significantly impacted by the time of day of harvest. In tropical countries, the production of shoot-tip cutting for export to temperate countries is a major industry. It has been found that late harvests (e.g. after 4 pm) improve storage quality and subsequent rooting response, an effect that was attributed to higher endogenous carbohydrate status (Rapaka et al., 2007). On the other hand, vegetative tissue is particularly sensitive to storage temperature during the hours after harvest, which may be dependent on the time of the day or harvest if cooling facilities are not available. Chlorophyll degradation significantly increases in leafy vegetables, such as Valeriana lettuce (Ferrante and Maggiore, 2007) and fresh-cut rocket and spinach (Ferrante et al., 2004), when storage temperature increases by only 6°C.

Diurnal changes in metabolism may explain the prolonged shelf life obtained with harvest during the late hours of the day. Xyloglucan endotransglusylase-hydrolase, a cell wall modifying protein, is more active during the late hours of the day, suggesting a role in preventing cell degradation during postharvest (Rose et al., 2002). Moreover, leaf–water relations are also known to fluctuate during the day. For example, stomata opening occurs in response to light and temperature which affects CO_2 uptake productivity and assimilation of carbon productions (Taylor and Davies, 1985). The "turgor" hypothesis is another factor that can partially explain the importance of weather conditions at harvest. It is agreed by many that prolonged shelf life may augment with increased turgor, which may be also improved with postharvest calcium treatments (Clarkson et al., 2005; Rico et al., 2007). Rapid cooling at sunset inhibits the export of sugars from the leaves (Koroleva et al., 2002) to the fruit, which results in increased osmotic and turgor pressure.

Extreme rainy conditions can have direct implications on plant disease and food safety. Clinical pathogens that invade fruit and vegetables generally benefit from high RH encountered in the field and during postharvest storage, with some exceptions, such as the case of *E. coli* O157:H7 (Stine et al., 2005). Another exception is the Hepatitis A virus, which is quite stable in the environment (Sobsey, 1991), with the longest survival having been reported at low RH (Bidawid et al., 2000; Sattar et al., 2000). In contrast, high RH has been found to afford Salmonella longer survival on the surface of tomato plants (Rathinasabapathi, 2004). Because of the potential risk with added moisture in tissue at harvest (Fonseca, 2006), it is probably wise to schedule harvest for periods when the rain stops and there has been enough time to dry water from the surface of the tissue to be harvested.

Additional concerns exist in the tropics when extreme weather conditions prevail, because efficiency of postharvest operations may decline faster as field workers in charge of harvest, selection or classification may be more at risk of dehydration (Nag et al., 2007).

III. Postharvest handling in the desert

The deserts, which may be present from sea level to 3500 meters, are places where large quantities of produce are grown (Houston, 2006). In all deserts, to different degrees, cold nights and/or high temperatures during the day prevail during certain times of the year. Such conditions may be even more extreme than usual during times which may coincide with the harvest of edible tissue. Production of plant crops in the desert often includes high sunlight intensity, low RH and high temperatures, depending on the season in which the crop is planted, which in some cases is inadequate to support even microbial life (McKay et al., 2003).

Low relative humidity is of particular concern, since fresh-harvested commodities tend to lose weight rapidly at low RH. Changes in water status alter the general conditions of the product with economic losses being due to both decreased quality and product weight (Kays, 1999). Most fruits and vegetables become unmarketable with a loss of 5% to 10% of their initial weight (Robinson et al., 1975). The rate of water loss and subsequent weight are clearly dependent on factors such as temperature and RH. The water status of the product at harvest, in addition to extreme environmental conditions during postharvest, may affect quality.

Water activity, the differential between vapor pressure of water in food and vapor pressure in pure water, affects the water loss rate of a fresh commodity. Higher water activity (or less negative water potential) implies higher amount of water that could be easily released to the environment in the form of water vapor pressure (Labuza, 1980). Lettuce with extremely high water activity showed lower shelf life, particularly if accompanied by extremely low RH during postharvest handling (Fonseca, 2006). The loss of membrane integrity associated with desiccations, leads to loss of cellular compartmentation, which consequently allows polyphenol oxidase and polyphenol substrates to mix in the damaged cells, resulting in tissue browning (Vamos-Vigyazo, 1981). Color retention and quality of beans was found to be higher when the product had lower moisture content. While initial moisture content of near 14% yielded shelf life of lower than 10 days, initial moisture content of near 11% produced shelf life of above 100 days (Karathanos et al., 2006).

Quality of crops and tree fruits harvested in late spring or early fall may often be challenged by high temperatures in the desert. Satsuma mandarins subjected to 30°C for 3–5 days after harvest increased the soluble solids content/titrateable acidity ratio by essentially lowering the acidity levels (Burdon et al., 2007). Malic and citric acid continued to decrease during storage at 10°C after storage at 30°C. In the same study, mandarins that were exposed to 65% RH produced a weight loss of >8.5%, while fruits that were exposed to the same temperature but at 95% RH had less than 4% weight loss. The short exposure to high temperature in postharvest also increased the quality by reducing puffiness. These results show the potential benefit of keeping fruits at room temperatures in deserts. However, the common low RH associated with these places raises concerns because it may cause premature shriveling. Good results have been obtained by keeping mist on patios where harvested products are temporarily stored before entering the packinghouse (Fonseca and Cinco, 2006). Reduction of pitting in cherries by more than 25% was obtained by using reflective tarps at harvest and during postharvest handling (Schick and Toivonen, 2002).

Herbs in particular suffer great weight loss when conditions at harvest include high temperatures. The rate of transpiration in herbs is commonly >100% higher than that of vegetable species showing intensive respiration (Ryall and Lipton, 1983). Freshly harvested Saint-John's Wort shows a Q_{10} of 2.60 over the range 10–20°C and 1.93 over the range 20–30°C (Bottcher et al., 2003). However, for herbs that are dried, the rapid loss of water did not commonly affect the key active compounds (Bottcher et al., 2003; Fonseca et al., 2006).

The quality of asparagus spears clearly varies depending on the weather conditions prevalent during the growth cycle (Bhowmik et al., 2002), but postharvest conditions may be more critical in influencing final quality. In a greenhouse study, the variability in the monthly temperature during the growth of asparagus did not consistently show an affect on breaking force, regardless of the subsequent storage conditions. However, a clear relationship was found between the temperature during postharvest storage and the breaking force of shear asparagus spears (Bhowmik et al., 2003). High temperatures at harvest time can affect level of decay during postharvest as observed in France with Star Ruby grapefruit (Pailly et al., 2004). Clearly, crops such as broccoli, beans, peas and asparagus harvested at an over-mature stage will be prone to excessive accumulation of fiber content, a factor that will become more pronounced if weather conditions include high temperatures (Sams, 1999).

Extremely high temperatures at harvest impact hormonal levels in the marketed, edible portion of agricultural perishables. Abscisic acid (ABA) is known to fluctuate during the day. ABA seems to peak before the maximum light intensity or prior to the onset of the maximum daily temperatures (Correia et al., 1997; Fonseca et al., 2005). This could be explained by the high rate of photo-oxidation during late morning and afternoon hours, which exceeds that rate of synthesis of ABA (Simkin et al., 2003). It has been shown that higher ABA levels at harvest result in a shorter vase-life of cut roses (Garello et al., 1995). The accumulation of ABA is tissue-specific, as light sources have caused changes in ABA levels in rose petals, but not in their leaves (Garello et al., 1995).

Desert crops are particularly exposed to conditions that pose at least a mild stress. Water stress is one of the most common stresses that plants encounter due to excess of transpiration during certain periods of plant growth. Changes in water availability during late phases of growth are so dramatic that a single stress event can trigger alterations to the anatomy of a leaf. Formation of trichomes was observed in feverfew upon recovery from a single wilting event (Fonseca et al., 2005). If plants are under severe stress at the moment of harvest, due to extreme weather conditions or abuse through agricultural practices, the result on the postharvest quality is commonly negative. For example, french fries made from potatoes grown under stress have shown undesirable texture (Iritani, 1981). However, in some cases, mild water stress at harvest under desert conditions has resulted in clear benefits for the quality of intact and fresh-cut produce such as lettuce (Fonseca, 2006).

Moisture is such a critical factor that a modified atmosphere packaging line in a carton, described as Moisture Control Technology, reduced chilling injury by 42%, albedo breakdown by 54% and reduced moisture loss by 83% in navel oranges shipped overseas. This technology, which kept moisture levels above 98%, did not cause mold growth or abnormalities in the fruit skin (Henriod, 2006), even though high humidity environments are often conducive to pathogen growth (Artés et al., 1995). The effect of high relative humidity storage in reducing the expression of chilling injury has also been reported in a number of chill-sensitive crops, including cactus fruits (Schirra et al., 1997), cucumber (Wang and Qi, 1997) and mango (Pesis et al., 2000). Low relative humidity at harvest or during storage also caused increased degradation of key nutritional compounds such as vitamin C (Nunes et al., 1998). When a mist was induced during the hours prior to harvest, the low temperature breakdown of kiwifruit occurring during postharvest storage was reduced or eliminated, depending on the maturity of the fruit at harvest. This was associated with higher accumulation of chilling time before harvest (Sfakiotakis et al., 2005).

Some studies suggest that the time of the year at which harvest takes place may be critical in the shelf life of crops. Increase of dry and fatty matter, polyphenol and antioxidant composition in cauliflower was obtained in a year when plants were subjected to stress conditions (Lo Scalzo et al., 2007). In the same study it was suggested that early harvested product was more suitable for storage due to the higher ration of unsaturated as compared to saturated fatty acids. Regardless of the location of apple fruits in the canopy of the tree, time of the year affected the concentration of ripening-associated pigments. For example, in a November harvest content of lutein in apples was lower and violaxanthin higher than in a June harvest (Solovchenko et al., 2006).

Another factor to consider when handling fruits and vegetables in desert conditions is light. Light intensity during postharvest storage is an issue that has been overlooked for a long time; however, it could have a significant effect on final quality, particularly when excess intensity reaches the product. It is now known that harvested product may respond to light in ways that can dramatically affect quality. Solanine content in potatoes exposed to sunlight was increased as high as eight times that found in potatoes stored in the dark (Haddadin et al., 2001). The concentration of solanine obtained with varieties grown in the desert and exposed to sunlight during harvest reached levels of 150 and 90 mg/100 g, far above what has been found in other markets (van Gelder, 1984). Levels of solanine above 20 mg/100 g of fresh tuber are considered toxic (Pihak and Sporns, 1992). Using materials to prevent light from reaching the product has been suggested. The use of reflective tarpaulins for covering bins containing recently-harvested cherries reduced the incidence of pitting in cherries by nearly 20% (Schick and Toivonen, 2002). In the case of cherries, water loss is faster in the stems (Seske, 1996), and the use of reflective tarpaulins for only four hours also increased moisture levels by over 15% (Shick and Toivonen, 2002).

IV. Effect of drastic changes occurring during postharvest handling

Adaptation of fruit and vegetables to extreme postharvest handling conditions (see also Chapter 19) may be affected by previous conditions occurring during preharvest or during early stages of handling and storage. The effect can be beneficial or detrimental. Cucumbers developed no symptoms of chilling injury during postharvest handling when preharvest temperatures in the greenhouse were 5°C higher, i.e. fruits grown at 27°C developed symptoms, cucumber grown at 32°C did not show any symptoms. Temperature sensitivity and ethylene production was reduced in the fruits from plants grown at the higher temperature. However, weight loss was significantly higher in cucumber grown at the higher temperature (Kang et al., 2002). In another study with cucumber, fruit stored at 36–40°C for 24 hours before refrigeration storage significantly reduced subsequent respiration and the appearance of pitting (Hirose, 1985).

Factors occurring before harvest affect the quality of produce. In particular, postharvest responses of fruit and vegetables to chilling stress are often greatly influenced by preharvest field temperature (Wang, 1982). These factors may be associated with biological agents, physiological mechanisms, mechanical damage, cultural practices, genetic variation or environmental factors (Kays, 1999). In fact, there are few postharvest disorders of fruits and vegetables that are not affected by preharvest factors (Ferguson et al., 1999). Chilling injury of tomatoes (Lurie et al., 1993; Sabehat et al., 1996) and avocados (Woolf et al., 1995) can be reduced by heat treatments applied immediately before storage. Moreover, exposure to high temperatures during the hours close to harvest may induce tolerance to low temperatures in postharvest storage (Ferguson et al., 1999). Treatment with air temperature at 36–40°C reduced chilling injury of Hass avocado fruit (Woolf et al., 1995; Florissen et al., 1996).

For high quality avocado the temperature and exposure to sunlight during preharvest is critical. For example, skin tissue on the side of the fruit exposed to the sun exhibited less chill injury and heat damage (Woolf et al., 1995). Tolerance of postharvest heat treatment is affected by air temperatures experienced in the field three days before harvest (Paull, 1995). Retention of nutrients may also be improved with higher preharvest temperature (Lee and Kader, 2000). Breakdown of vitamin C during postharvest storage was reduced when cucumber was grown at higher temperatures (Kang et al., 2002). However, very little information is available on assessing the importance of the temperature at which fruit is harvested on tolerance to postharvest heat treatment and subsequent storage. Changes in heat shock protein (hsp) gene expression and specific protein bands have reflected the diurnal temperature cycle (Woolf et al., 1999). In apple fruit, hsp gene expression followed a diurnal temperature cycle, with maximum levels 1–2 hours after the highest temperature of the day (Ferguson et al., 1998), suggesting that time of the day and conditions at harvest, particularly those associated with extreme conditions, will affect postharvest heat treatment and tolerance to low temperatures.

Fruit grown in the shady inner areas of the canopy have a greater incidence of chilling injury than fruit grown in the outer areas of the canopy. This finding indicates more efficient preharvest practices to allow higher light penetration would be beneficial (Crisosto et al., 1997). Practices which could be used may include pruning and leaf removal (Forlani et al., 2002).

Extremely high temperatures in destination markets during summer months may require adjustments in earlier steps in the postharvest chain to reduce deterioration of quality. Produce in transoceanic shipments often suffers from abrupt changes in temperature when arriving at the destination port (Figure 20.1). Cassava root for export markets stored at 15°C kept for a longer time than that stored at 10°C when the product was shipped during the summer season to the end market (Fonseca and Saborío, 2001). This was likely due to a higher transpiration rate and subsequent

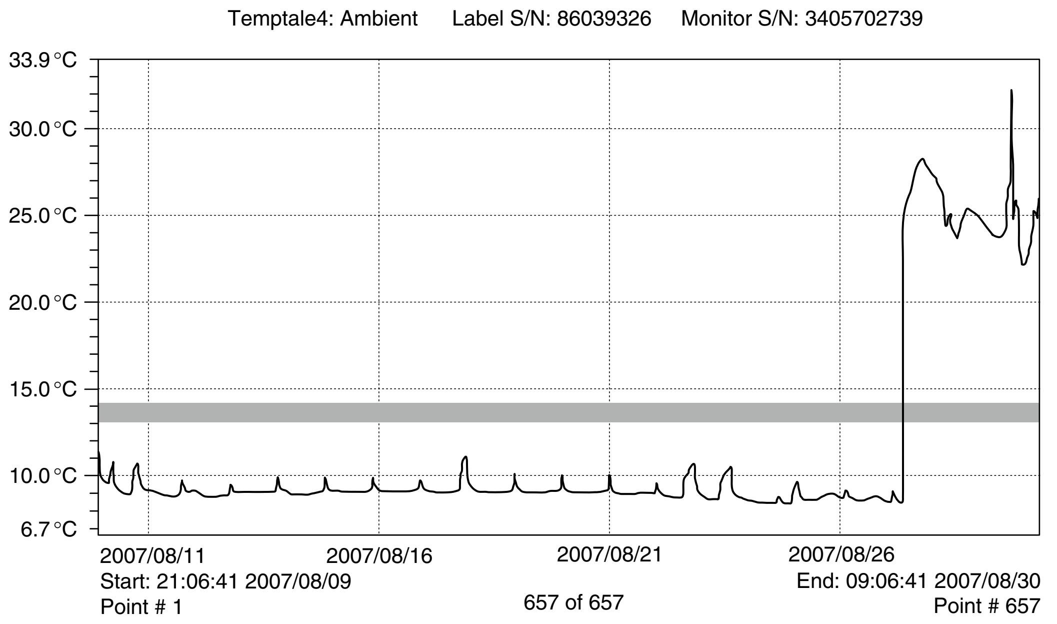

Figure 20.1 Record of temperature inside a commercial container with pineapples shipped during summer time. Note the abrupt temperature change the day the product arrived at a port in Europe.

condensation of water between the skin and paraffin wax in the product stored at lower temperatures, due to a drastic change with the extremely high ambient temperature on the patios of the brokers. The opposite was observed during the winter season. That is, low storage temperatures during transportation extended the shelf life of cassava root.

In some cases, shifts in RH have been the main problem associated with quality defects. When Navel oranges were transferred from low RH (45%) to high RH (95%), fruits developed rind staining. The symptoms developed more rapidly when fruit was exposed to low temperatures for prolonged periods. Interestingly, in this study, fruits that were transferred from 30°C to 20°C or 12°C had the same amount of water loss as those transferred from low to high relative humidity and showed no symptom of rind staining (Alferez et al., 2003).

The development of rind staining when transferring fruits from low RH to high RH is likely due to the fact that flavedo cells recover water activity more quickly than inner albedo cells, which eventually causes depressed flavedo and collapsing in the adjacent albedo (Agusti et al., 2001). This symptom can be followed by the peculiar staining and browning of the flavedo observed after several days, probably due to oxidation (Lafuente and Sala, 2002). The development of peel pitting occurred in white grapefruit when the fruit was transferred from 30% to 90% RH. The opposite, i.e. transferring from high to low RH, did not produce pitting (Alferez and Burns, 2003). In parallel with browning of the flavedo, oil glands became deformed and began to collapse, also causing pitting. Weight loss increased when fruits were washed before storage, due to removal or redistribution of the natural fruit wax coating (Alferez and Burns, 2003).

The activities of antioxidant enzymes, such as catalase and ascorbate peroxidase, decreased under high RH (85–90%), whereas superoxide reductase increased and glutathione reductase decreased at low RH (55–60%), an indication of their possible role in lowering rind staining in Navelina oranges (Sala and Lafuente, 2004). These observations have important implications for the desert citrus industry, as harvesting may be done during extremely low RH, and the fruit may dehydrate before being stored in coolers, which are expected to be at high RH.

Extreme weather conditions trigger responses in plants that involve activity of enzymes and growth regulators. The protective function of enzymes against different stress conditions in plants has been reported (Jiang and Zhang, 2001; Rubio et al., 2002). The involvement of plant hormones in the stress-induced antioxidant system has also been reported (Ben-Amor et al., 1999; Jiang and Zhang, 2001; Michaeli et al., 2001; Arora et al., 2002). Ethylene applied exogenously to oranges resulted in better retention of glutathione reductase and reduced the incidence of rind staining. This suggests that glutathione reductase is involved in ethylene-induced rind staining tolerance (Sala and Lafuente, 2004).

The speed at which the product loses weight may change the threshold at which dehydration symptoms, such as shriveling and pitting, appear. With zucchini and cucumber, low RH at harvest without transference to a high RH induced peel pitting in just a few hours. Generally, pitting started to develop when weight loss reached a level of 4.5% and 4.7%, but symptoms were delayed when the loss of water was slow during postharvest (Fonseca and Cinco, 2006). The threshold at which aerobic respiration shifts to anaerobic respiration may also be affected in specific cases. The anaerobic compensation point may change with the age of the product (Boersig et al., 1988), which may be accelerated under high temperatures or high levels of ethylene.

The time of the day of harvest may critically affect the shelf life of horticultural crops. The shelf life of sweet basil increased by almost 100% when harvest was done late in the day compared to harvest done in the morning (Lange and Cameron, 1994), a reaction that could be due partially to changes in carbohydrate composition (King et al., 1988). Accumulation of carbohydrates increases during the day as a product of photosynthesis (Geiger and Servaites, 1994). Increased accumulation of carbohydrates reduces CO_2 sensitivity in lettuce (Forney and Austin, 1988; Varoquaux et al., 1996) and chilling sensitivity in tomato seedlings (King et al., 1988).

Improved shelf life due to increased extensible cell walls has been correlated to harvesting product during the late hours of the day. The same was found with leafy greens subjected to mechanical stress (Clarkson et al., 2003). Time of day of harvest has also been shown to affect the shelf life of commodities, particularly leafy greens (Forney and Austin, 1988; Moccia et al., 1998). Shelf life was extended by as much as six days in arugula and two days in lollo rosso and red chard, when the harvest was done at the end of the day (Clarkson et al., 2005).

The time of the month or the time of the day of harvest has been associated with produce quality. Pectin of albedo from grapefruits harvested in January in North

America showed more potency than that harvested in any other month during the season (November through January), and was associated with a high concentration of rhamnose (Liu et al., 2002).

A. Other important extreme environmental conditions

Freezing temperatures normally cause the rejection of the product however, in some cases the product can still be harvested, but care needs to be taken. The extent of the damage is a function of minimum temperature, the rate of drop in temperature, the duration of exposure and the susceptibility of the product (Kays, 1999). With leafy crops, freezing results in a limp, wilted product, especially if harvesting occurs when crops still have ice on the surface of their leaves. To avoid this, lettuce growers cover fields the night before harvest, a practice that also allows field work during the early hours of the day (Figure 20.2).

Freezing injury can occur during the hours before and after harvest. Frost occurs through the sublimation of water vapor on objects that are below 0°C. Kays (1999), based on information provided by Reiger (1989), suggested the terms radiative and advective freezing, as these can be caused by different conditions and the symptoms may or may not be the same. In radiative freezing, thermal energy moves from the air to the vegetation, soil and other objects, whereas in advective freezing the flow of thermal energy is in the opposite direction (Reiger, 1989). For most fruits and vegetables, freezing occurs one to several degrees below the freezing point of water, due to the presence of solutes within the aqueous medium of the cells (Kays, 1999). Extremely high or low temperatures directly affect the firmness of a number of apple varieties (Johnston et al., 2001).

Figure 20.2 Desert lettuce growers cover fields that will be harvested after a cold night when an accumulation of ice on the surface of the plants is forecast.

The combination of stress factors in real conditions is an area that has just begun to be examined by researchers. Stresses may affect plant metabolism in a different manner when applied individually however, it is not entirely clear how they affect plant metabolism when occurring simultaneously. It is now known that exposure to elevated carbon dioxide reduces the deleterious effects of water stress by increasing drought avoidance and drought tolerance mechanisms (Wall et al., 2006). Transcripts expressed during drought and heat shock when the stress was posed separately were different from transcripts expressed when plants underwent both stresses at the same time (Rizhsky et al., 2002). The effect of combined stress factors appears to involve a specific protein (WRKY domain), which is enhanced by plants when subjected to drought and heat shock or drought and cold stress (Pnueli et al., 2002).

Plant injury due to exposure to pollutants has been increasing during the last decades. Ions of heavy metals, such as Ag, Dd, Cd, Se, Co, Mg, Mn, Ni and Zn, may be introduced to the plant through soil amendments, runoff, or contaminated irrigation water (Kays, 1999). The impact of high accumulation of contaminants on the nutrition and safety of produce is clear. However, how visual quality and shelf life is affected by short exposure to metal and other chemical contaminants before harvest is not as clear. Plums grown under increased ozone levels soften more rapidly during postharvest storage than plums in ambient air or in an atmosphere with reduced ozone, which was attributed to differences in the thickness of the wax deposition and cuticle during storage (Crisosto et al., 1993). In this area of metals and potential toxic compounds, selenium (Se) is a singular case. Despite potential risk if high levels are present, in most cases exposure to high levels of Se affects plant growth, but at low concentrations it may delay senescence (Xue et al., 2001) and potentially increase shelf life. An important suggested effect of Se may be the amelioration of shock produced by high incidence of UV-B as it occurs in the summer and in tropical regions (Shanker, 2006).

Plants may adjust well to high CO_2 concentration in the future (Davis et al., 2002), and this is likely to occur in proximity to urban areas. In sites where produce is handled with high risk of pollutant contamination, it is likely that high production of ethylene occurs (Grant and Menzies, 1983), which evidently will affect ripening in high-ethylene producers and will affect coloration in highly sensitive products (Saltveit, 1999).

Production at high elevations may carry some intrinsic problems. High altitude environments are characterized by increased solar radiation, rapid temperature changes and lower partial pressures of gases, including reduction of the 90% oxygen saturation commonly seen in altitudes below 2500 meters (Streb et al., 1998). Alternate respiration is common in plants growing at high elevations (Kumar et al., 2007), which may be connected to the smaller size of plants grown at high elevations (Purohit, 2003). However, whether this has any implication in postharvest is unclear. It is possible that increased organic acids play an important role in adaptation to high altitudes (Kumar et al., 2007) which may also have an affect on postharvest quality. Often, agricultural operations at high altitudes occur under greenhouse conditions and movement of product is commonly indoors where oxygen levels may vary. Hypoxic acclimation to extreme low oxygen atmosphere during postharvest storage is a successful practice for increasing tolerance to ultra-low oxygen levels (El-Mir et al., 2001). However, very little has been studied on the effect of acclimation at higher oxygen concentrations (e.g. 15%).

Quality and quantity of light during postharvest handling of produce may have a significant effect on the final quality. The effect of high light intensity is predominantly thermal in nature, but light bleaching of chlorophyll can occur (Kays, 1999). Chlorophyll degradation was more pronounced in broccoli plantlets stored for six weeks under red or blue light than that in white light or in darkness. However, enhanced soluble sugar and survival rate after the acclimatization stage was obtained with all light treatments (Kubota et al., 1997). Several reports have shown the direct impact of using films that change the infrared–red light ratio (Wilson et al., 1998). Light intensity may also reduce the growth of fungal microorganisms, such as *Botrytis cinerea* and *Monillia fructigena*, in strawberries (Marquenie et al., 2003).

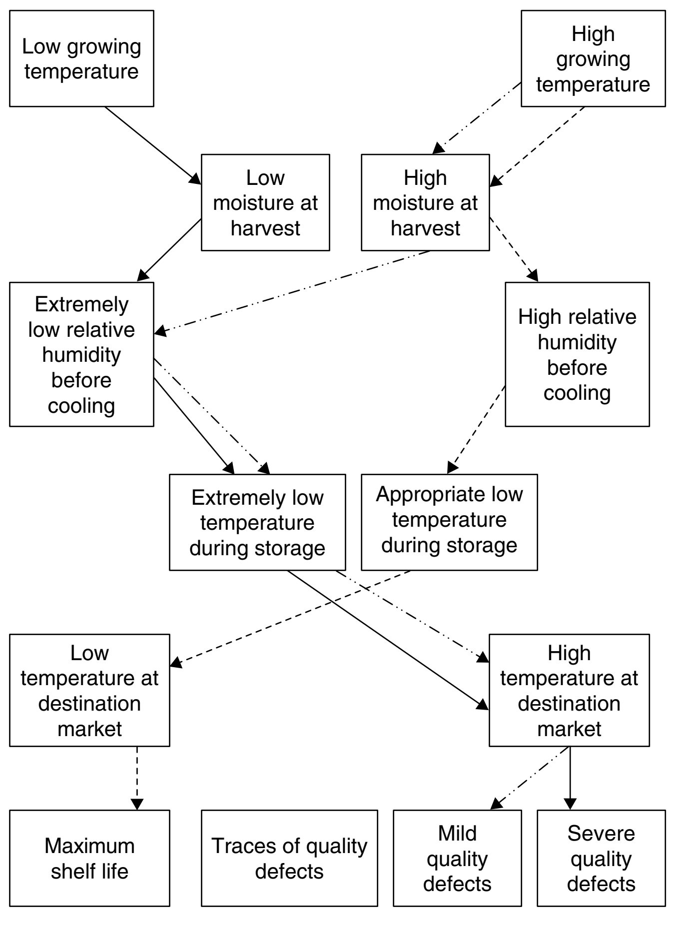

Figure 20.3 Several potential "routes" (of many probable scenarios) that could be taken by harvested tissue (e.g. cucumber fruit) across all the steps between field and destination market. This illustrates how the impact of extreme weather conditions on final quality may be altered by multiple factors (proposed scheme based on references listed in this chapter).

It is clear that some crops and varieties are impacted by day length during the growth of the plant, as in the case of some varieties of onions (Boyhan et al., 2005).

V. Final remarks

Even when following strict quality control programs, harvested products could still be subjected to stress-producing conditions during handling and storage. The stress can be a result of a single environmental factor, or the outcome of a combination of factors encountered throughout different stages of production and handling. Extreme weather conditions may cause severe losses to growers, especially when operations fail to manage quality in other steps, or when conditions are part of multiple failures. If environmental conditions at harvest and during postharvest handling differ, the result may range from severely-affected products to maximum-quality products (Figure 20.3). Although it is not possible to eliminate losses due to environmental conditions, the extent of these losses can be reduced through a better understanding of the nature of the problem and by being proactive with implementing potential solutions. Extreme weather conditions differ in nature and affect different commodities in various ways. However, based on studies described in this chapter, some general conclusions can be drawn (Table 20.1). Research has shown that single extreme weather factors can be highly detrimental to the final quality of the marketed commodity. It is also clear that the potential negative impact may be ameliorated when the product is previously exposed to determined conditions.

Table 20.1 Extreme environmental conditions encountered during different postharvest steps and factors that influence the impact of those conditions on quality of the final product

Extreme environmental conditions	Potential negative impact	Factor that may enhance or reduce the impact
Extremely low relative humidity at harvest	Rapid water loss and early development of dehydration symptoms.	Water activity/potential at harvest affects the weight loss. Product with extremely high water activity shows symptoms of dehydration more quickly.
Extremely high relative humidity at harvest	Excess moisture on surface of product can result eventually in large loss of water and oxidation of tissue. It can also produce condensation of water vapor in packages, affording ideal conditions for proliferation of pathogens.	Depending on the product, a time dedicated to release excess water may aid in prolonging shelf life.
Extremely low temperature at harvest/early day hours	Freezing damage. Early day hours produce higher incidence of leaf abscission of vegetative cuttings.	Materials used to cover crops or equipment to elevate the air temperature are currently used commercially.

(Continued)

Table 20.1 Continued

Extreme environmental conditions	Potential negative impact	Factor that may enhance or reduce the impact
Extremely high temperature/ sunlight intensity at harvest/ late day hours	Accumulation of undesired compounds in certain crops such as potatoes. Reduced production of ethylene and subsequent loss of leaves during transition.	Use of transpirants and rapid movement of product from field to refrigeration conditions is used to ameliorate potential negative effects.
Extremely low temperature during postharvest handling	Chilling injury	Temperature during the growth of the plant can affect sensitivity. Plants grown in higher temperatures better tolerate the chilling temperatures. Postharvest heat treatments may aid in reducing sensitivity as well.
Extremely high temperature during postharvest handling	Occurrence of proliferation of plant pathogens. Microorganisms in general will be afforded better conditions to grow.	Risk is reduced if a good pre-harvest program to control diseases is in place, and relative humidity previous to harvest was not high.
Extremely high temperature at destination port	Abrupt raise in respiration and transpiration of the product. Condensation of water in product packages and spaces between wax and cuticles. Potential for microorganisms growth.	Higher temperature and transpiration during transition may reduce problems by reducing condensation. Packages, films and coatings with sufficient permeability for gas diffusion is an option.

(Source: References listed in this chapter)

Bibliography

Agusti, M., Almela, V., Juan, M., Alferez, F., Tadeo, F.R., Zacarías, L. (2001). Histological and physiological characterization of rind breakdown of Navelate sweet orange. Ann. Bot., 88, 415–422.

Alferez, F., Burns, J.K. (2003). Postharvest peel pitting at non-chilling temperatures in grapefruit is promoted by changes from low to high relative humidity during storage. Postharvest Biol. Technol., 32, 79–87.

Alferez, F., Agusti, M., Zacarias, L. (2003). Postharvest rind staining in Navel oranges is aggravated by changes in storage relative humidity: effect on respiration, ethylene production and water potencial. Postharvest Biol Technol., 28, 143–152.

Arauz, L.F., Wang, A., Duran, J.A., Monterrey, M. (1994). Causas de pérdidas poscosecha de mango a nivel mayorista en Costa Rica. Agronomia Costarricense, 18, 47–51.

Arora, A., Sairam, R.K., Srivastava, G.C. (2002). Oxidative stress and antioxidative system in plants. Curr. Sci., 82, 1227–1238.

Artés, F., Rodríguez, M.C., Martínez, J.A., Marín, J.G. (1995). Influence of fungicide treatment and storage conditions on mould and yeast activity on "Satsuma" mandarin. Int. J. Refrig., 18, 63–66.

Ben-Amor, M., Flores, B., Latché, A., Bouzayen, M., Pech, J.C., Romojaro, F. (1999). Inhibition of ethylene biosynthesis by antisense ACC oxidase RNA prevents chilling injury in Charentais cantaloupe melons. Plant Cell Environ., 22, 1579–1586.

Bhowmik, P.K., Matsui, T., Kawada, K., Suzuki, H. (2002). Changes in storage quality and shelf life of green asparagus over an extended harvest season. Postharvest Biol. Technol., 26, 323–326.

Bhowmik, P.K., Matsui, T., Suzuki, H., Kosugi, Y., Alam, A.K., Enriquez, F.G. (2003). Pre- and postharvest fiber development in green asparagus as related to temperature during growth, storage and handing. Food Agric. Environ., 1, 50–53.

Bidawid, S., Farber, J.M., Sattar, S.A. (2000). Contamination of foods by food handlers: experiments on hepatitis A transfer to food and its interruption. Appl. Environ. Microbiol., 66, 2759–2763.

Boersig, M.R., Kader, A.A., Romani, R.J. (1988). Aerobic–anaerobic respiratory transition in pear fruit and cultured pear fruit cells. J. Amer. Soc. Hort. Sci., 113, 869–873.

Bottcher, H., Gunther, I., Bauermann, U. (1999). Physiological postharvest responses of marjoram (*Majorana hortensis* Moench). Postharvest Biol. Technol., 15, 41–52.

Bottcher, H., Gunther, I., Kabelitz, L. (2003). Physiological postharvest responses of common Saint-John's wort herbs (*Hypericum perforatum* L.). Postharvest Biol. Technol., 29, 342–350.

Boyhan, G.E., Purvis, A.C., Randle, W.M., Torrance, R.L., Jefferson, M., Hardison, G., Hill, R.C., Paulk, J.T. (2005). Harvest and postharvest quality of short-day onions in variety trials in Georgia, 2000–2003. HorTechnology, 15, 422–431.

Burdon, J., Lailu, N., Yarsley, C., Osman, S., Billing, D., Boldingh, H. (2007). Postharvest conditioning of Satsuma mandarins for reduction of acidity and skin puffiness. Postharvest Biol. Technol., 43, 102–114.

Clarkson, G.J.J., O'Byrne, E.E., Rothwell, S.D., Taylor, G. (2003). Identifying traits to improve postharvest processability in baby leaf salad. Postharvest Biol. Technol., 30, 287–298.

Clarkson, G.J.J., Rothwell, S.D., Taylor, G. (2005). End of day harvest extends shelf life. Hortscience, 40, 1431–1435.

Correia, M.J., Rodríguez, M.L., Ferreira, M., Pereira, J.S. (1997). Diurnal change in the relationship between stomatal conductance and abscisic acid in the xylem sap of field-grown peach trees. J. Exp. Bot., 48, 1727–1736.

Crisosto, C.H., Rezlaff, W.A., Williams, L.E., DeJong, T.M., Zoffoli, J.P. (1993). Postharvest performance evaluation of plum (*Prunus salicina* Lindel., "Casselman") fruit grown under three ozone concentrations. J. Am. Soc. Hort. Sci., 118, 497–502.

Crisosto, C.H., Johnson, R.S., De Jong, T., Day, K.R. (1997). Orchard factors affecting postharvest stone fruit quality. HortScience, 32, 820–823.

Davis, M.A., Pritchard, S.G., Mitchell, R.J., Prior, S.A., Rogers, H.H., Runion, G.B. (2002). Elevated atmospheric CO_2 affects structure of a model regenerating longleaf pine community. J. Ecol., 90, 130–140.

El-Mir, M., Gerasopoulos, G., Metzidakis, I., Kanellis, A.K. (2001). Hypoxic acclimation prevents avocado mesocarp injury caused by subsequent exposure to extreme low oxygen atmospheres. Postharvest Biol. Technol., 23, 215–226.

FAO (1989). Prevention of postharvest food losses fruits, vegetables and root crops, a training manual. FAO training Series No. 17/2, FAO, Rome, Italy.

Ferguson, I.B., Snelgar, W., Lay-Yee, M., Watkins, C.B., Bowen, J.H. (1998). Heat shock response in apple fruit in the field. Aust. J. Plant Physiol., 25, 155–163.

Ferguson, I., Volz, R., Woolf, A. (1999). Preharvest factors affecting physiological disorders of fruit. Postharvest Biol. Technol., 15, 255–262.

Ferrante, A., Incrocci, L., Maggini, R., Serra, G., Tognoni, F. (2004). Colour changes of fresh-cut leafy vegetables during storage. J. Food Agric. Environ., 2, 40–44.

Ferrante, A., Maggiore, T. (2007). Chlorophyll *a* fluorescence measurements to evaluate storage time and temperature of *Valeriana* leafy vegetables. Postharvest Biol. Technol., 45, 73–80.

Florissen, P., Ekman, J.S., Blumenthal, C., McGlasson, W.B., Condroy, J., Holford, P. (1996). The effects of short heat-treatments on the induction of chilling injury in avocado fruit (*Persea Americana* Mill.). Postharvest Biol. Technol., 8, 129–141.

Fonseca, J.M., Rushing, J.W., Rajapakse, N.C., Thomas, R.L., Riley, M.B. (2005). Parthenolide and abscisic acid synthesis in feverfew are associated but environmental factors affect them dissimilarly. J. Plant Physiol., 162, 485–494.

Fonseca, J.M. (2006). Postharvest quality and microbial population of head lettuce as affected by moisture at harvest. J. Food Sci., 71, M45–49.

Fonseca, J.M., Saborío, D. (2001). Postharvest technology of waxed cassava (*Manihot esculenta* L.) for export markets (Spanish). National Press of Costa Rica.

Fonseca, J.M., Cinco, R. (2006). Evaluation of commercial alternatives to reduce postharvest pitting of organically grown zucchini and cucumber. Acta Hort., 712, 291–297.

Fonseca, J.M., Rushing, J.W., Thomas, R.L., Riley, M.B., Rajapakse, N.C. (2006). Post-production stability of parthenolide in feverfew (*Tanacetum parthenium*). J. Herbs Spices Med. Plants, 12, 139–152.

Forlani, M., Basile, B., Cirillo, C., Iannini, C. (2002). Effects of harvest date and fruit position along the tree canopy on peach fruit quality. Acta Hortic., 592, 459–466.

Forney, C.F., Austin, R.K. (1988). Time of day at harvest influences carbohydrate concentration in crisphead lettuce and its sensitivity to high CO_2 levels after harvest. J. Amer. Soc Hort. Sci., 113, 581–583.

Garello, G., Ménard, C., Dansereau, B., Le Page-Degivry, M. (1995). The influence of light quality on rose flower senescense: involvement of abscisic acid. Plant Growth Regul., 16, 135–139.

Geiger, D.R., Servaites, J.C. (1994). Diurnal regulation of photosynthetic carbon metabolism in C-3 plants. Annu. Rev. Plant Physiol., 45, 235–256.

Grant, W.B., Menzies, R.T.O. (1983). A survey of laser and selected optical systems for remote measurement of pollutant gas concentrations sulfur dioxide, ozone, nitrogen dioxide, ethylene, methane. J. Air Pollution Control Assoc., 33, 187–194.

Haddadin, M.S.Y., Humeid, M.A., Qaroot, F.A., Robinson, R.K. (2001). Effect of exposure to light on the solanine content of two varieties of potato (*Solanum tuberosum*) popular in Jordan. Food Chemistry, 73, 205–208.

Henriod, R.E. (2006). Postharvest characteristics of navel oranges following high humidity and low temperature storage and transport. Postharvest Biol. Technol., 42, 57–64.

Herppich, W.B., Linke, M., Landahl, S., Gzik, A. (2001). Preharvest and postharvest responses of radish to reduced water supply during growth. Acta Hort., 553, 89–90.

Hirose, T. (1985). Effects of pre- and interposed warming on chilling injury, respiratory rate and membrane permeability of cucumber fruit during cold storage. J. Japan Soc. Hort. Sci., 53, 459–466.

Houston, J. (2006). Evaporation in the Atacama Desert: An empirical study of spatio-temporal variations and their causes. J. Hydrology, 330, 402–412.

Iritani, W.M. (1981). Growth and preharvest stress and processing quality of potatoes. Am. Potato J., 58, 71–80.

Jiang, M., Zhang, J. (2001). Effect of abscisic acid on active oxygen species antioxidative defense system and oxidative damage in leaves of maize seedlings. Plant Cell Physiol., 42, 1265–1273.

Johnston, J.W., Hewett, E.W., Banks, N.H., Harker, F.R., Hertog, M.L.A.T.M. (2001). Physical change in apple texture with fruit temperature: effects of cultivar and time in storage. Postharvest Biol. Technol., 23, 13–21.

Kang, H.M., Park, K.W., Saltveit, M.E. (2002). Elevated growing temperatures during the day improve the postharvest chilling tolerance of greenhouse-grown cucumber (*Cucumis sativus*) fruit. Postharvest Biol. Technol., 24, 49–57.

Karathanos, V.T., Bakalis, S., Kyritsi, A., Rods, P.S. (2006). Color degradation of beans during storage. Int. J. Food Properties, 9, 61–71.

Kays, J.K. (1999). Preharvest factors affecting appearance. Postharvest Biol. Technol., 15, 233–247.

Key, J.L., Kimpel, J., Vierling, E., Lin, C.Y., Nagao, R.T., Czarnecka, E., Schoffl, F. (1985). Physiological and molecular analysis of the heat shock response in plants. In: Changes in Eukariotic Gene Expression in Response to Environmental Stress, B.G. Atkinson, D.B. Walden (eds). Academic Press, New York, NY, USA, pp. 327–348.

Kinay, P., Yildiz, F., Sen, F., Yildiz, M., Karacali, I. (2005). Integration of pre- and post-harvest treatments to minimize *Penicilium* decay of Satsuma mandarins. Postharvest Biol. Technol., 37, 31–36.

King, A.I., Joyce, D.C., Reid, M.S. (1988). Role of carbohydrates in diurnal chilling sensitivity of tomato seedlings. Plant Physiol., 86, 764–768.

Koroleva, O.A., Tomos, A.D., Farrar, J., Pollock, C.J. (2002). Changes in osmotic and turgor pressure in response to sugar accumulation in barley source leaves. Planta, 215, 210–219.

Kubota, C., Rajapakse, N.C., Young, R.E. (1997). Carbohydrate status and transplant quality of micropropagated stored under different light environments. Postharvest Biol. Technol., 12, 165–173.

Kumar, N., Vyas, D., Kumar, S. (2007). Plants at high altitude exhibit higher component of alternative respiration. J. Plant Physiol., 164, 31–38.

Labuza, T.P. (1980). The effect of water activity on reaction kinetics of food deterioration. Food Technol., 34, 36–41.

Lafuente, M.T., Sala, J.M. (2002). Abscisic acid and the influence of ethylene, humidity and temperature on the incidence of postharvest rind staining Navelina oranges (*Citrus sinensis* L. Osbeck) fruits. Postharvest Biol. Technol., 25, 49–57.

Lange, D.D., Cameron, A.C. (1994). Postharvest shelf life of sweet basil (*Ocimum basilicum*). HortScience, 29, 102–103.

Lee, S.K., Kader, A.A. (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biol. Technol., 20, 207–220.

Liu, Y., Ahmad, H., Luo, Y., Gardiner, D.T., Gunasekera, R.S., McKeehan, W.L., Patil, B.S. (2002). Influence of harvest time on citrus pectin and its *in vitro* inhibition of fibroplast growth factor signal transduction. J. Sci. Food Agric., 82, 469–477.

Lo Scalzo, R., Bianchi, G., Genna, A., Summa, C. (2007). Antioxidant properties and lipidic profile as quality indexes of cauliflower (*Brassica oleracea* L. var. *botrytis*) in relation to harvest time. Food Chemistry, 100, 1019–1025.

Lurie, S., Klein, J.D., Watkins, C.B., Ross, G.S., Boss, P.K., Ferguson, I.B. (1993). Prestorage heat treatments of tomatoes prevent chilling injury and reversibly inhibit ripening. Acta Hort., 343, 283–285.

Marquenie, D., Geeraerd, A.H., Lammertyn, J., Soontjens, C., Van Impe, J.F., Michiels, C.W., Nicolaï, B.M. (2003). Combinations of pulsed white light and UV-C or mild heat treatment to inactivate conidia of *Botrytis cinerea* and *Monilia frutigena*. Int. J. Food Microbiol., 85, 185–196.

McKay, C.P., Friedmann, E.I., Gómez-Silva, B., Cáceres-Villanueva, L., Andersen, D.T., Landheim, R. (2003). Temperature and moisture conditions for life in the extreme arid region of the Atacama Desert: four years of observations including the El Niño of 1997–1998. Astrobiology, 3, 393–406.

Michaeli, R., Philosoph-hadas, S., Riov, J., Ratner, K., Meir, S. (2001). Chilling-induced leaf abscission of ixora coccinea plants. III. Enhancement by high light via increased oxidative processes. Physiol. Plant., 113, 338–345.

Moccia, S., Frezza, D., Chiesa, A. (1998). Time of day at harvest effect on postharvest lettuce quality. Agr. Trop. Subtrop., 31, 83–86.

Nag, P.K., Nag, A., Ashtekar, S.P. (2007). Thermal limits in men in moderate to heavy work in tropical farming. Industrial Health, 45, 107–117.

Nunes, M.C.N., Brecht, J.K., Morais, A.M.M.B., Sargent, S.A. (1998). Controlling temperature and water loss to maintain ascorbic acid in strawberries during postharvest handling. J. Food Sci., 63, 1033–1036.

Pailly, O., Tison, G., Amouroux, A. (2004). Harvest time and storage conditions of "Star Ruby" grapefruit (*Citrus paridisi* Macf.) for short distance summer consumption. Postharvest Biol. Technol., 34, 65–73.

Paull, R.E. (1995). Preharvest factors and the heat sensitivity of field-grown ripening papaya fruit. Postharvest Biol. Technol., 6, 167–175.

Paull, R.E., Chen, N.J. (1990). Heat shock response in field grown, ripening papaya fruit. J. Am. Soc. Hortic. Sci., 115, 623–631.

Pesis, E., Aharoni, D., Aharon, Z., Ben-Arie, R., Aharoni, N., Fuchs, Y. (2000). Modified atmosphere and humidity packaging alleviates chilling injury symptoms in mango fruit. Postharvest Biol. Technol., 19, 93–101.

Pihak, L.C., Sporns, P. (1992). Glycoalkaloid concentration of potato tubers following exposure to daylight. J. Agric. Food Chemistry, 40, 2533–2540.

Plaza, P., Usall, J., Texido-Vinas, T. (2003). Control of green and blue mold by curing on oranges during ambient and cold storage. Postharvest Biol. Technol., 28, 195–198.

Pnueli, L., Hallak-Herr, E., Rozenberg, M., Cohen, M., Goloubinoff, P., Kaplan, A., Mittler, R. (2002). Mechanisms of dormancy and drought tolerance in the desert legume *Retama raetam*. Plant J., 31, 319–330.

Purohit, A.N. (2003). Plant form and functional behaviour along the altitudinal gradient in mountains. J. Plant Biol., 20, 231–235.

Rapaka, V.K., Faust, J.E., Dole, J.M., Runkle, E.S. (2007). Effect of time of harvest on postharvest leaf abscission in Lantana (*Lantana camara* L. "Dallas Red") unrooted cuttings. HortScience, 42, 304–308.

Rathinasabapathi, B. (2004). Survival of Salmonella Montevideo on tomato leaves and mature green tomatoes. J. Food Prot., 67, 2277–2279.

Reiger, M. (1989). Freeze protection for horticultural crops. Hortic. Rev., 11, 229–231.

Rico, D., Martín-Diana, A.B., Frías, J.M., Henehan, G.T.M., Barry-Ryan, C. (2007). Effect of ozone and calcium lactate treatments on browning and textura properties of fresh-cut lettuce. J. Sci. Food Agric., 86, 2179–2188.

Rizhsky, L., Liang, H., Mittler, R. (2002). The combined effect of drought stress and heat shock on gene expression in tobacco. Plant Physiol., 130, 1143–1151.

Robinson, J.E., Browne, K.M., Burton, W.G. (1975). Storage characteristics of some vegetables and soft fruits. Ann. Appl. Biol., 81, 399–408.

Rose, J.K.C., Braam, J., Fry, S.C., Nishitani, K. (2002). The XTH family of enzymes involves in xyloglucan endotransglucosylation and endohydrolysis: Current perspectives and a new unifying nomenclature. Plant Cell Physiol., 43, 1421–1435.

Rubio, M.C., Gonzalez, M.C., Minchin, F.R., Webb, K.J., Arrese-Igor, C., Ramos, J., Becana, B. (2002). Effects of water stress on antioxidant enzymes of leaves and nodules of transgenic alfalfa overexpressing superoxide dismutase. Physiol. Plant., 115, 531–540.

Ryall, A.L., Lipton, W.J. (1983). Handling, transportation and storage of fruits and vegetables, 2nd edn, Vegetables and Melons 1. AVI, Westport, CT, USA.

Sabehat, A., Weiss, D., Lurie, S. (1996). The correlation between heat-shock protein accumulation and persistence and chilling tolerance in tomato fruit. Plant Physiol., 110, 531–537.

Sala, J.M., Lafuente, M.T. (2004). Antioxidant enzymes activities and rind staining in "Navelina" oranges as affected by storage relative humidity and ethylene conditioning. Postharvest Biol. Technol., 31, 277–285.

Saltveit, M.E. (1999). Effect of ethylene on quality of fresh fruits and vegetables. Postharvest Biol. Technol., 15, 279–292.

Sams, C.E. (1999). Preharvest factors affecting postharvest texture. Postharvest Biol. Technol., 15, 249–254.

Sattar, S.A., Tetro, J., Bidawid, S., Farber, J. (2000). Foodborne spread of hepatitis A: recent studies on virus survival, transfer and inactivation. Can. J. Infect. Dis., 11, 159–163.

Schick, J.L., Toivonen, P.M.A. (2002). Reflective tarps at harvest reduce stem browning and improve fruit quality of cherries during subsequent storage. Postharv. Biol. Technol., 25, 117–121.

Schirra, M., Agabbio, M., D'Aquino, S., McCollum, T.G. (1997). Postharvest heat conditioning effects on early ripening "Gialla" cactus pear fruit. HortScience, 32, 702–704.

Seske, L. (1996). Respiration and storage potential in Norwegian-grown sweet cherries. Acta Hort., 410, 357–362.

Sfakiotakis, E., Chlioumis, G., Gerasopoulos, D. (2005). Preharvest chilling reduces low temperature breakdown incidence of kiwifruit. Postharvest Biol. Technol., 38, 169–174.

Shanker, A.K. (2006). Countering UV-B stress in plants: Does selenium have a role. Plant Soil, 282, 21–26.

Silou, T., Massamba, D., Maniongui, J.G., Maloumbi, G., Biyoko, S. (2007). Postharvest losses by natural softening of safou pulp (*Dacryodes edulis*) in Congo-Brazzaville. J. Food Eng., 79, 392–400.

Simkin, A.J., Zhu, C., Kuntz, M., Sandmann, G. (2003). Light-dark regulation of carotenoid biosynthesis in pepper (*Capsicum annum*) leaves. J. Plant Physiol., 160, 439–443.

Sobsey, M.D., Oldhan, C.E., McCall, D.E. (1991). Comparative inactivation of hepatitis A virus and other enteroviruses by iodine. Water Sci. Technol., 24, 331–337.

Solovchenko, A.E., Avertcheva, O.V., Merzlyak, M.N. (2006). Elevated sunlight promotes ripening-associated pigment changes in apple fruit. Postharvest Biol. Technol., 40, 183–189.

Stange, R.R., Midland, S.A., Simms, J.J., Eckert, J.W. (1993). Evidence that wound gum, not lignin, is deposited in infection-resistant injuries of Citrus peel. Acta Hort., 343, 347–352.

Stine, S.W., Song, I., Choi, C., Gerba, C.P. (2005). Effect of relative humidity on preharvest survival of bacterial and viral pathogens on the surface of cantaloupe, lettuce and bell peppers. J. Food Prot., 68, 1352–1358.

Streb, P., Shang, W., Feieraband, J., Bligny, R. (1998). Divergent strategies of photoprotection in high-mountain plants. Plant Physiol., 207, 313–324.

Taylor, G., Davies, W.J. (1985). The control of leaf growth of Betula and Acer by photoenvironment. New Phytol., 101, 259–268.

Vamos-Vigyazo, L. (1981). Polyphenol oxidase and peroxidase in fruits and vegetables. CRC Crit. Rev. Food Sci. Nutr., 15, 49–127.

van Gelder, W.M.J. (1984). A new hydrolysis technique for steroid glycoalkaloids with unstable aglycones from Solanum spp. J. Sci. Food Agric., 35, 487–494.

Varoquaux, P., Mazollier, J., Albagnac, G. (1996). The influence of raw material characteristics on the storage life of fresh-cut butterhead lettuce. Postharvest Biol. Technol., 9, 127–139.

Wall, G.W., Garcia, R.L., Kimball, B.A., Hunsaker, D.J., Pinter, P.J., Long, S.P., Osborne, C.P., Hendrix, D.L., Wechsung, F., Wechsung, G., Leavitt, S.W., LaMorte, R.L., Idso, S.B. (2006). Interactive effects of elevated carbon dioxide and drought on wheat. Agron. J., 98, 354–381.

Wang, C.Y. (1982). Physiological and biochemical responses of plant to chilling stress. HortScience, 17, 173–186.

Wang, C.Y., Qi, L. (1997). Controlled atmosphere storage affects quality and chilling susceptibility of cucumbers. J. Food Qual., 20, 559–566.

Wilson, S.B., Iwabuchi, K., Rajapakse, N.C. (1998). Responses of broccoli seedlings to light quality during low-temperature storage *in vitro*: II. Sugar content and photosynthetic efficiency. HortScience, 33, 1258–1261.

Woolf, A.B., Watkins, C.B., Bowen, J.H., Lay-Yee, M., Maindonald, J.H., Ferguson, I.B. (1995). Reducing of external chilling injury in stored "Hass" avocado fruit by dry heat treatments. J. Am. Soc. Hort. Sci., 120, 1050–1056.

Woolf, A.B., Bowen, J.H., Ferguson, I.B. (1999). Preharvest exposure to the sun influences postharvest responses of "Hass" avocado fruit. Postharvest Biol. Technol., 15, 143–153.

Woolf, A.B., Ferguson, I.B. (2000). Postharvest responses to high fruit temperatures in the field. Postharvest Biol. Technol., 21, 7–20.

Xue, T., Hartikainen, H., Piironen, V. (2001). Antioxidative and growth-promoting effect of selenium in senescing lettuce. Plant Soil., 237, 55–61.

Yetisir, H., Caliskan, M.E., Soylu, S., Sakar, M. (2006). Some physiological and growth responses of watermelon [*Citrullus lanatus* (Thunb.) Matsum and Nakai] grafted onto *Lagenaria siceraria* to flooding. Env. Exp. Bot., 58, 1–8.

21

Advanced Technologies and Integrated Approaches to Investigate the Molecular Basis of Fresh Produce Quality

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I. Introduction

The quality of horticultural products can be defined using a number of descriptors, and measured by several parameters related, in general, to physico-chemical properties and aimed at providing specific information on external or internal traits of the produce. For fruit in particular, besides shape, size and the absence of defects (mainly

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due to diseases and disorders), and without considering socioeconomic issues, the purchase decision is often dictated by external parameters such as color and, at least for some commodities, aroma (Kays and Paull, 2004). A further quality evaluation occurs during or following consumption, when properties such as flavor and texture are considered. In addition, there is today a growing emphasis on nutritional value and safety for human health (see Chapters 3 and 5). Most of these quality attributes are the result of biochemical and structural modifications determined by a combination of gene expression, protein synthesis and metabolite concentration dynamically regulated by different factors, including development and environment. In fruit, the transition from the immature to the mature stage is a crucial step involving the acquisition of edible traits and organoleptic quality. The changes occurring during fruit ripening represent a wide spectrum of different biochemical processes (Seymour et al., 1993), and since the advent of molecular biology it has become clear that ripening is a highly complex, genetically-controlled developmental phase (Seymour and Manning, 2002). Ripening is strongly influenced by environmental factors that are also of paramount importance after harvest from the mother plant. Throughout the postharvest chain (from grower to consumer) environmental parameters affect metabolism, and consequently, the shelf life and taste life of ripening fruit, as well as of other horticultural fresh produce represented by immature fruit, leaves, inflorescences, stems, tubers and roots.

The main goal of postharvest biologists is precisely that of elucidating the relationship existing between storage conditions and components of metabolism. Given that most postharvest phenotypes are genetic traits associated with one or more genes, understanding the genetic determinants that confer quality traits in fruit and other commodities is crucial for the development of new postharvest technologies. For years, researchers have studied one gene at a time, in isolation from the wider context of other genes. A number of investigations have been done on specific structural and regulatory genes involved in quality-related metabolic pathways in different horticultural produce. As the molecular mechanisms of phenotypes and the biological basis of quality are complex, new methods of analyzing genes and their products *en masse* offers a wider view of biological events and allows study of the network through which genes, proteins and metabolites are related and communicate. The recent development of high-throughput techniques and new biotechnological approaches covering a broad field of disciplines (chemistry, physics, biology, physiology, computer science, robotics) has also opened up the genomics era in plant research. Genomics aims to study the organisms' genome and understand its structure and function. It is traditionally divided into two basic areas, structural genomics and functional genomics (also called the post-genomics era) (Hoquette, 2005). While the former has the goal of describing the physical nature of genomes, the latter is related to the expression of genes and their functional characterization, and allows the detection of genes that are turned on or off at any given time depending on endogenous (e.g. development) or exogenous (e.g. environment) factors (Eggen, 2003). Several technologies have emerged and are now available for measuring transcript abundance in parallel fashion, and for describing expression profiling in a particular sample (cell or tissue). An analysis of the transcriptome is a representation of all of the genes expressed, and this approach is known as transcriptomics. Besides RNA, targets of functional genomics studies are also proteins (proteomics) and metabolites (metabolomics). Functional genomics analyses are highly complementary in determining gene functioning: if transcriptional profiling describes gene expression patterns and gene regulatory networks, proteomics provides qualitative and quantitative information about proteins, and metabolomics is aimed at profiling the range of metabolites present in a sample at a given time, or under certain conditions (Roessner et al., 2001; Rossignol, 2001). This multidisciplinary approach is a prerequisite for the development of systems biology (Gutierrez et al., 2005), and involves a great change in our understanding of the molecular mechanisms of phenotypes, including the complex interplay of genetic and environmental factors (Collins et al., 2003). As the pproductivity and quality attributes of horticultural produce are determined by a dynamic combination of gene transcription, protein function and metabolite concentration that is temporally and spatially regulated during development and by the environment (Dandekar, 2003), coordinated approaches of transcriptomics, proteomics and metabolomics are essential for elucidating their molecular basis, as well as the complex interplaying mechanisms operating during postharvest and affecting both storage and flavor life.

A major challenge in modern horticultural science is to characterize the network of genes (and their products) controlling development and modulating quality before and after harvest. In tomato, the model species for perishable fruit studies, discoveries in the last few years have begun to shed light on the molecular basis of the ripening syndrome and its developmental control (Giovannoni, 2004). Most of the recommended postharvest environmental conditions represent a stress, resulting in physical and/or chemical changes in the cells of the produce. The importance of stress management during the postharvest period necessitates an understanding of how plant and plant parts respond to stress in terms of metabolic changes, starting with modulation of gene expression. In these contexts, genomics approaches and tools, such as high-throughput DNA-based technologies and mRNA(cDNA) sequencing, expressed sequence tags (EST) databases, microarray platforms and expression profiling, proteomics and metabolomics technologies are offering a completely new spectrum of possibilities, not only to dissect complex gene networks, but also as a support tool for decisions concerning applications, treatments or destinations for specific batches.

Transcriptional control of developmental programs, in entire organs, single cells or in response to environmental stimuli, has been widely studied using modern expression profiling techniques in *Arabidopsis*, the first plant to be fully sequenced at a whole genome level (Arabidopsis Genome Initiative, 2000) and the first species where microarray has been used to measure gene expression (Schena et al., 1995). Besides the model species *Arabidopsis*, microarray platforms and crop species-specific gene expression databases have also been developed for horticultural species (e.g. Solanaceae Gene Expression Database), and an increase in these and other genomics tools and information is expected following the genome sequencing of grapevine, the first fruit crop to be fully sequenced (The French–Italian Public Consortium for Grapevine Genome Characterization, 2007) and other horticultural crops that are currently the subjects of sequencing projects. Given that the use of cross-species hybridization to DNA microarray, in which the target RNA and microarray probe are from different species, has increased in the past few years (Bar-Or et al., 2007), more basic information will also become available for those species that lack a representative microarray platform and other genomics tools.

II. Analysis of the transcriptome

Among different "omics" techniques, transcriptional profiling approaches are more commonly used, as they are readily affordable for many laboratories (Brady et al., 2006). Large-scale transcripts analysis is the first step, together with transcript localization, to dissect complex processes such as those characterizing the developmental stage transition and the postharvest life of horticultural produce.

Transcripts profiling is based on two strategies. In the first, sequence tags from a given RNA sample are generated. In the second strategy, cDNA populations corresponding to transcripts present in a specific organ, development phase, or induced by different stimuli are hybridized with a large number of targets immobilized on various substrates (e.g. different microarray types).

Considering the first strategy, the most straightforward and unbiased way to analyze a transcriptome is the sequencing of cDNA libraries and quantitative analysis of the resulting ESTs (Bush and Lohmann, 2007). ESTs of 200–900 nucleotides, 15-nucleotide tags used in serial analysis of gene expression (SAGE), and 17–20 nucleotide tags produced by massively parallel signature sequencing (MSSP) are the results of different applied techniques. Differences, advantages and troubleshooting for these techniques are fully discussed by Meyers et al. (2004). There are few examples of SAGE and MSSP applied to investigate transcriptome changes in horticultural crops (http://www.ncbi.nlm.nih.gov/projects/geo/), while ESTs are largely produced from many of these plants (http://www.ncbi.nlm.nih.gov/dbEST/dbEST_summary.html). *In silico* EST analyses have been used extensively to study fruit development and ripening and, to a lesser extent, the postharvest behavior and responses to different storage conditions. *In silico* expression analysis is based on comparisons of tag frequencies in different libraries corresponding to an exact digital representation of the copy number of a transcript in the examined tissue. Large EST collections have been produced from many cDNA libraries of different tissues of several fruit species, including apple, grapevine, melon and tomato, where specific analyses of the sequence pool have been performed in relation to fruit development, and genes likely to be involved in the ripening process have been identified. Pioneering work on EST analysis in relation to fruit ripening has been done by Fei et al. (2004) in tomato, where a digital expression analysis protocol has been developed. A comparative analysis of tomato sequences with grape EST data resulted in the identification of common transcription factors associated with ripening of both fruit species. In apple, following the acquisition of extensive EST data, the biochemical pathway involved in biosynthesis of precursors for volatile esters has been analyzed at gene expression level, and a subset of genes that may participate in generating flavor and aroma components in mature fruit identified (Park et al., 2006), as well as the presence of health-associated compounds (Newcomb et al., 2006). Analysis and annotation of 146 075 ESTs from different *Vitis* species have been performed by da Silva et al. (2005). Considering in particular *Vitis vinifera*, a number of ESTs and unigenes with putative functions in berry development have been identified in Cabernet Sauvignon and Muscat Hamburg varieties. Gene ontology (GO) classification indicates that GO categories corresponding to transport and cell organization biogenesis, which are associated with metabolite movement and cell wall structural changes during berry ripening, are highly represented in berry tissues (Peng et al., 2007). Terol et al. (2007) assembled more than 54 000 ESTs from five *Citrus* cultivars and produced a unigene set of about 13 000 putative different transcripts involved in the most important metabolic pathways known to affect fruit quality. An EST database (MELONGEN) for melon functional genomics from eight normalized cDNA libraries of different tissues of melon has been produced by Gonzales-Ibeas et al. (2007), and a number of genes potentially controlling disease resistance and fruit quality traits have been identified. In two *Prunus* species, peach (ESTree Consortium, 2005) and apricot (Grimplet et al., 2005), ESTs have been isolated exclusively from cDNA libraries of pericarp tissues, thus providing more specific information on genomics aspects of stone fruit development and ripening.

Specifically considering postharvest aspects, an EST project on nectarines is currently in progress with the aim of studying genetic factors responsible for chilling injuries during cold storage (http://www.genomavegetal.cl). Within the framework of this project, an open source data management system, named JUICE, has been developed by Latorre et al. (2006) to organize and analyze the large amount of data generated in this and other EST projects.

Traditionally, ESTs have been obtained by Sanger-sequencing, but the associated costs have severely limited this approach. Two new high-throughput sequencing techniques, 454 and Solexa™, have recently overcome this limitation. In fact, in spite of low read lengths (about 30–40 bases for Solexa™ and tags of 80–120 base for 454) the high-throughput, 1 gigabase per run for Solexa™ and 25 megabases per run for 454, ideally suits expression-profiling purposes (Bentley, 2006**)**. Short tags are sufficient to identify a transcript unambiguously, and so problems arising from assembling short tags into larger contigs can be ignored. Given these technical advantages, an increasing number of EST databases of horticultural crops will be produced in the near future. The availability of complete genome sequences permits the direct comparison of tags to genomic sequence and further extends the utility of the data.

A second strategy for transcript profiling is a hybridization-based technology where cDNA populations corresponding to transcripts present in a specific organ, a development phase or induced by different stimuli, are hybridized with a large number of targets immobilized on various substrates (microarray platforms). With this technique the expression of thousands of genes is simultaneously analyzed at a reasonable cost. The expression level of any gene represented on the array can be deduced from the fluorescence intensity of the corresponding probe, which is recorded by laser scanning. This represents a primary caveat of the array method, because a validation of gene expression is mandatory. Microarray platforms have been extensively reviewed by Rensink and Buell (2005) and are summarized in Box 21.1. For fruit crops, microarray platforms developed are mainly home-brewed, permitting robust, reproducible results to be obtained and to focus solely on the biology of interest. cDNA-based arrays, developed in the early days of global transcriptome analysis, have been replaced by those oligo-based arrays that have increased laboratory-to-laboratory reproducibility (Busch and Lohmann, 2007). Following the pioneering work of Aharoni et al. (2000) who, using a cDNA microarray, identified a novel alcohol acyltransferase (SAAT) gene responsible for flavor biogenesis in ripening strawberry, some other cDNA-based arrays have been produced and used for transcript profiling during fruit ripening. Alba et al. (2005), using TOM1 microarray, identified 869 genes that are differentially expressed in developing tomato pericarp, 37% of these genes are altered in their expression into Nr (never-ripe) mutants in which sensitivity to ethylene is reduced and ripening is inhibited. The crucial role of ethylene in modulating gene expression has been also observed in pear fruit by Fonseca et al. (2004), who detected main changes in expression profiles corresponding to the cessation of growth at maturity and entry into the climacteric phase. Forment et al. (2005) developed a cDNA microarray with 6875 putative unigenes from a large citrus EST collection that has been used to study expression changes during ripening of *Citrus clementina*, thus highlighting key physiological processes such as those

Box 21.1 Basic definitions in microarray technology (modified from Rensink and Buell, 2005)

Probe: gene-specific DNA spotted on the array that will hybridize with the target.

Target: total RNA or mRNA is isolated and converted to single-strand cDNA. Target labeling is performed by direct incorporation of a fluorescent dye or by coupling the dyes to a modified nucleotide.

Array platforms

On-slide synthesized arrays: probes are synthesized on the array surface using DNA synthesis chemistry. The activation for oligonucleotide elongation is achieved using a mask (**Affymetrix**) or maskless (**Nimblegen**) method. Alternatively, the reagents are delivered to each spot using ink-jet technology (**Agilent**) or, more recently, chemical reagents are generated by means of an electrochemical reaction controlled by an array of individually addressable microelectrodes located on the chip (**Combimatrix**).

Spotted cDNA arrays: clones from a cDNA library are amplified by polymerase chain-reaction (PCR) using generic primers for the vector. PCR products are purified and spotted on glass slides using a robotic arrayer.

Spotted long oligonucleotide arrays: oligonucleotides ranging from 50 to 70 bases are synthesized for a unique region of the genes of interest. Oligonucleotides are spotted on glass slides using a robotic arrayer.

concerning citrate utilization (Cercos et al., 2006). Oligo-based microarrays have been produced for grape (3175 Oligos, Terrier et al., 2005), peach (4806 oligos, Trainotti et al., 2006) and apple (15 720 oligos, Schaffer et al., 2007). For the grape platform, 50-mer oligos have been selected in the 3' non-coding region (UTR), thus allowing differential expression profiles of isogenes to be distinguished. This approach demonstrated that five isogenes of xyloglucan endotransglycosylase (XET) belong to four clusters characterized by different expression profiles. Berry softening has been confirmed as the earliest sign in ripening induction, thus determining that expression timing of XET isogenes, as well as that of other genes encoding cell wall hydrolases, is an essential step to dissect the signal network regulating this important event. μPEACH 1.0 is a 70-mer oligo-microarray developed starting from EST sequences mainly obtained from cDNA libraries of ripening peach fruits. This tool has been used to investigate molecular events occurring at the transition from preclimacteric to early climacteric stage (Trainotti et al., 2006). More than 260 genes resulted induced, while about 100 appeared down-regulated. A coordinated increase of transcripts corresponding to genes involved in carotenoid biosynthesis characterizes the transition from immature to mature stage. Among the differentially transcribed genes, some are involved in ethylene biosynthesis, perception and signal transduction, some are implicated in cell wall metabolism, and 19 targets encoding regulators of gene expression are present. In particular, six members of the Aux/IAA family are highly up-regulated when ripening proceeds. Using the same microarray on mature peaches treated with exogenous ethylene and auxin, Trainotti et al. (2007) pointed out the importance of the cross-talk between these two hormones at ripening onset in peach fruit. The role of ethylene in aroma production of apples has been assessed using a (55-mer) oligo-microarray with samples of untransformed and ACC oxidase antisense Royal Gala fruit (Schaffer et al., 2007). This approach allowed the expression profile of a repertoire of 179 candidate genes to be described that might be involved in the production of aroma compounds. Among these only 17 were typically affected by ethylene, suggesting that only certain points of the aroma biosynthesis pathways are regulated by the hormone. Often the first step, and in all pathways the last steps, contained enzymes that were ethylene-regulated. This analysis suggests that the initial and final enzymatic steps with the biosynthetic pathways are important transcriptional regulation points for aroma production in apple. In climacteric fruit, one of the keys for delaying ripening and maintaining quality after harvest is to inhibit or reduce ethylene biosynthesis and/or perception. Altered levels of ethylene biosynthesis may be induced by treatments with other hormones, as observed in several ripening fruit species using Jasmonates (JA) (Fan et al., 1998a,b; Kondo et al., 2007). The effects of JA treatments in preclimacteric peaches were analyzed by using μPEACH 1.0 (Ziosi et al., 2008). The ripening delay induced by JA was accompanied by a down-regulation of ACC oxidase and cell-wall related genes, and an up-regulation of several stress- and defense-related genes.

1-Methylcyclopropene (1-MCP) is an inhibitor of ethylene action that, at very low concentration, is effective in prolonging storage life of several climacteric fruit (Sisler and Serek, 1997). Its effects vary in relation to species, cv and application time (Watkins, 2006), for instance bananas and apples are more sensitive to 1-MCP than fruits belonging to *Prunus* species such as peach and nectarine, where the ethylene inhibitor maintains its effects for only a few hours after the end of the incubation period, when a quick recovery of ripening parameters occurs (Tonutti et al., 2007). Dal Cin et al. (2006) compared the responses of peaches and apples to 1-MCP at physiological and molecular level, and concluded that the different behavior of the two species to the ethylene action inhibitor might be related to differences in terms of ethylene receptor ratio, expression and/or turn-over. Large-scale analyses of transcripts have been performed on 1-MCP treated nectarines using μPEACH 1.0 (Ziliotto et al., 2008). The results clearly show that the presence of 1-MCP markedly changes transcript profile considering that only 9 genes (instead of 90, in control samples) showed, in comparison to fruit at harvest, significant changes at the end of the 24-hour incubation period, and 102 targets were differently affected when comparing fruit maintained for 24 hours in air and in 1-MCP-enriched atmosphere. A number of these differentially expressed targets correspond to genes with a role in hormone (ethylene, but also auxin and ABA) metabolism and regulating transcription. The fast recovery of ripening parameters (softening, in particular) observed 48 hours after the end of the incubation period is the result of a change in the expression of about 50% of the 102 targets, including genes involved in ethylene perception (ETR2) and transcription regulation (EIL1-like) (Ziliotto et al., 2008).

Only a few studies have been published on large-scale analysis of transcriptome in relation to different environmental storage conditions. In a cross-species hybridization experiment, the cDNA microarray TOM1 was used by Ponce-Valadez et al. (2005) to study the effect of high CO_2 concentration on the evolution of volatile substances (ethanol, acetaldehyde and ethyl acetate) and gene expression during storage of two strawberry cultivars, based on the observation that tomato fruits stored in a CO_2 atmosphere change their transcriptome (Rothan et al., 1997). This study indicated that the transcriptional changes in the two cultivars differ by the genes involved, only 5 out of 232 being common, and by the amplitude of the responses. Due to the correlation of gene responses and fruit characteristics after storage (e.g. the higher transcription observed for gene-encoding cell wall enzymes in the cultivars undergoing softening), a number of genes putatively involved in conferring different CO_2 sensitivity to strawberry fruits have been identified for functional analysis. Low temperature is the key factor for successful postharvest management of horticultural produce (see Chapters 10 and 19), but the appearance of cold-related physiological disorders is often a major constraint in prolonged cold storage. Fruit of many species may undergo chilling injuries (CI), showing symptoms such as pitting, discoloration, necrotic areas, woolly and dry flesh. Customized microarrays are now being developed to investigate the molecular mechanism responsible for this behavior. Pons et al. (2005), using a subset of the Spanish citrus EST repertoire (Gonzalez-Candelas et al., 2005), printed a cDNA microarray to highlight changes in gene expression associated to CI of Fortune mandarin. They discovered that a group of fruit-specific genes is activated in response to cold and different storage pretreatments, thus allowing this gene set to be used as a molecular tool for identifying the best storage practices, and helping in the selection of new cold-resistant cultivars.

The same approach has been used to investigate the molecular mechanism underlying tolerance to CI in peach (Granell et al., 2007). For this goal a cDNA microarray, named CHILLPEACH™, has been developed by selecting targets from a database

(ChillpeachDB) containing 8144 cDNA sequences obtained from the mesocarp of sensitive and tolerant peaches.

Postharvest loss of quality is related to processes in which ripening-related genes show significant alteration in their expression. These genes can be used as markers and thus, provide a support to mathematical models designed to predict quality changes in agro-products. Within this context, two interesting examples are transcriptome analysis in apples showing mealiness symptoms (van Wordragen et al., 2003) and cassava roots exhibiting rapid postharvest physiological deterioration (PPD) (Reilly et al., 2007). In both cases, genes differentially expressed have been identified and associated to specific cellular processes (reactive oxygen species turnover, cell wall repair, programmed cell death, ion, water or metabolite transport, signal transduction or perception, stress response, metabolism and biosynthesis, and activation of protein synthesis) activated during postharvest. A nylon macroarray containing 847 non-redundant ESTs from a ripe peach fruit cDNA library has been developed by Gonzáles-Agüero et al. (2008). Gene expression changes in peach fruit ripened for 7 days at 21°C (juicy fruit) were compared with those stored for 15 days at 4°C and then ripened for 7 days at 21°C (woolly fruit). A total of 106 genes were found to be differentially expressed between juicy and woolly fruit. Data analysis indicated that the activity of most of these genes ($> 90\%$) was repressed in the woolly fruit. Besides confirming the importance of cell wall genes, this transcriptomic study highlighted that changes in endomembrane trafficking might also play a role in the appearance of this postharvest physiological disorder in peaches and nectarines.

III. Other "omics" technologies

A. Proteomics

Genome-scale studies based on DNA-chips represent an appropriate strategy, particularly as a first step, given the cost:benefit ratio. However, reliance on this technique as the sole tool for profiling gene expression has a number of limitations. Probably the most important of these is that changes in mRNA levels do not always correspond to changes in translation of cognate proteins (Gygi et al., 1999; Ideker et al., 2001). To study quantitative and qualitative characteristics of global protein expression, including polypeptide synthesis, degradation, post-translational modification, compartmentalization and interactions with other cell components, proteomics, or the study of the protein complement of the genome, promises to span the gap between genomic DNA sequence and biological state (Rose and Saladié, 2005). To reach this goal new or improved techniques have been developed for high-resolution protein separation (e.g. bidimensional gel electrophoresis, 2-DE) and rapid, automated protein identification (e.g. a mass spectrometry platform called matrix-assisted laser desorption/ionization time-of-flight, MALDI-TOF). These techniques applied in plant and, in particular, fruit-ripening studies have been reviewed in detail by Rose et al. (2004). Two strategies are mainly used. The first is comparable to the EST approach, because it is based on protein profiling in order to separate, sequence and catalog as many proteins as possible; the second can be termed comparative proteomics, where the aim is to characterize differences between different protein populations. This approach is analogous to comparative DNA microarray profiling. In both cases the goal of proteomics analysis, meant as the identification of proteins, is largely dependent on the availability of an appropriate DNA sequence dataset (Heazlewood and Millar, 2003). Tomato and grapevine are undoubtedly the crop species in which the most advanced functional genomics infrastructures and proteomics tools for studying fruit ripening and quality traits have been applied. In tomato, by using 2-DE, a comparative analysis of the fruit pericarp proteome allowed 1791 well-resolved spots to be selected showing differential accumulation during cell division, cell expansion and fruit-ripening stages (Faurobert et al., 2007). Ninety spots have been identified and most of these, showing an increasing accumulation at ripening, are related to carbohydrate metabolism or oxidative processes. A comparison between protein accumulation and expression profile of corresponding mRNA, done on ripe tomatoes using cDNA TOM1 microarray (Alba et al., 2005), highlighted the presence of some discrepancies between transcriptomics and proteomics data. Indeed, 40% of the 90 identified varying spots corresponded to sequences present on TOM1 that had been classified as unchanged. These differences are the result of post-transcriptional and translational processes that modulate the quantity, temporal expression and localization of proteins.

In support of this, recent results have shown that, even though a strong relationship was observed between ripening-associated transcripts and specific metabolite groups (organic acids and sugar phosphates), post-translational mechanisms dominate metabolic regulation during tomato fruit development (Carrari and Fernie, 2006). Similar results have been reported for grape, where a proteome analysis on whole berries revealed that all proteins detected showed some change in the accumulation pattern, while only a fraction of genes (ranging between 13% and 25%) displayed an altered expression level (Giribaldi et al., 2007). These data suggest that translational and post-translational processes add a higher degree of complexity to the dynamic patterns of gene expression. An example of this behavior is the protein accumulation of ACC synthase (ACS), the rate-limiting enzyme of ethylene biosynthesis. Expression of ACS does not change during grape berry development (Chervin et al., 2004; Pilati et al., 2007), but the protein concentration peaks at véraison, when a slight increase in ethylene production occurs together with changes in transcription of other genes related to ethylene biosynthesis, perception and action (Deluc et al., 2007). Working on specific fruit tissues appears to be crucial for functional genomics studies, given that marked differences have been detected in protein profiling when different tissues of ripening grape berry, such as mesocarp and epicarp, are compared. When the proteome analysis was performed on ripe berry skin (Deyteux et al., 2007), proteins related to biotic and abiotic stresses, together with those involved in anthocyanin synthesis, appeared to be highly represented in the over-expressed set, unlike the mesocarp proteome where predominant proteins were related to energy metabolism, in particular sugar metabolism and transport (Sarry et al., 2004).

These differences have also been confirmed at transcriptional level by profiling the gene repertoire represented on the *Vitis vinifera* GeneChip (Affymetrix® Inc.) in skin, mesocarp and seed (Grimplet et al., 2007). However, even when samples corresponding to a specific fruit tissue are analyzed, complex molecular aspects and process interplays are evident. The increase of a β-1–3 glucanase protein, observed at ripening in grape berry skin (Deyteux et al., 2007), is accompanied by the up-regulation of the corresponding gene (Grimplet et al., 2007), but no changes were observed in the activity (Robinson et al., 1997). These observations suggest that this protein, together with other pathogenesis-related (PR) proteins, may be a form of protective mechanism induced during ripening so that the grapes have a pool of defensive enzymes present to respond rapidly in case of a pathogen attack.

Many PRs accumulating in ripe fruit are potential allergens and their danger can be evaluated by a proteomic approach termed "allergenomics." With allergenomics, it is possible to detect and catalog as allergens those proteins, separated by 2-DE, that are specifically interacting with a patient immunoglobulin E, and also to analyze the quantitative and qualitative change in the antigens. This strategy has been used to identify a new isoform of Pru av 1, the major cherry allergen (Reuter et al., 2005), and can be usefully extended to other species belonging to the *Rosaceae* family where proteome analysis revealed an accumulation of potential allergens during fruit ripening (Abdi et al., 2002; Guarino et al., 2007).

Proteomics techniques can be addressed to study processes strictly related to fruit quality. Within this context, the analysis of citrus proteome performed by Katz et al. (2007) is a good example. This approach established that, in mature juice-sac cells, the decline in acidity is a consequence of the use of citric acid for the synthesis of amino acid and sugar. This process, together with the increase in an invertase and sugar transporters, is part of a mechanism that maintains juice-sac cell sugar homeostasis. In tomato fruit, cytosolic NAD-dependent malate dehydrogenase (cMDH) and mitochondrial malate dehydrogenase (mMDH) isoforms are the main enzymes involved in malic acid concentration regulation (Miller et al., 1998). Quantitative evaluation of spot densities related to intact cMDH and mMDH indicated a down-regulation in the transition from green to breaker stage in the commercial elite ecotype Ailsa Craig (AC). An opposite trend was observed in the local ecotype San Marzano (SM). The specific maintenance of these enzymes in SM has been related to the peculiar sweet and non-acid taste of this local ecotype (Rocco et al., 2006). These data open another interesting field of application for proteomic studies: identification of possible candidates for segregate analysis. A comparison of the mesocarp proteome in six different grapevine cultivars highlighted that most detected proteins were common, but some (an enolase, a vacuolar invertase and alcohol dehydrogenase) are differentially expressed (Sarry et al., 2004).

B. Metabolomics

A better understanding of the correlation between genes and the functional phenotype of an organism is the true goal of all functional genomics strategies, and metabolomics has emerged as a methodology that makes an important contribution to the understanding of complex molecular interaction in biological systems (Hall et al., 2002; Bino et al., 2004). As transcriptomics and proteomics aim to study the products of gene transcription and translation, the goal of metabolomics is that of quantifying and identifying all metabolites present within the cell under a given set of conditions

(Withfield et al., 2004) using different approaches, such as metabolite target analysis, metabolite profiling and metabolomic fingerprinting (Fiehn, 2002). Metabolites in plants function in many resistance and stress responses and contribute to color, taste and aroma. It has been estimated that plants contain from 100 000 to 200 000 different chemical compounds, most the result of secondary metabolism (Pichersky et al., 2000; Dellapenna, 2001), and this makes the plant metabolome quite complex. Thanks to the development of high-throughput analyses, based on improvements in mass spectrometry (MS) methods and in computer hardware and software capable of interpreting large datasets (Last et al., 2007), the identification and quantification of these small molecules is becoming much easier. Besides gas (GC) or liquid (LC) chromatography coupled with MS (Villas-Boas et al., 2005; Glinksi and Weckwerth, 2006), another method used for fingerprinting and profiling metabolites in plants is nuclear magnetic resonance (NMR) spectroscopy (Krishnan et al., 2005; Ratcliffe and Shachar-Hill, 2005). The identification and quantification of a high number of metabolites in many different samples makes it possible to study dynamic changes in the metabolic networks, and their control by environmental and genetic factors (Weckwerth, 2003). Since high-throughput methods to perform metabolite profiling or fingerprinting have only been developed within the last decade, there are still very few metabolomics applications in plant biology and horticultural produce in particular and, in general, are aimed at the phenotypic description of one species or genetic variants (cultivars) of a species.

Starting from the early studies on potato tuber by Roessner et al. (2000, 2001), who simultaneously detected 150 compounds using GC/MS, Tolstikov and Fiehn (2002) and Tolstikov et al. (2003) applied LC/MS to metabolome profiling of *Cucurbita maxima*. Aharoni et al. (2002), using high resolution Fourier transform mass spectrometry (FTMS), reported the presence of almost 6000 different masses in strawberry fruit, and assigned a putative empirical chemical formula to about half of them: differences in both primary and secondary metabolites resulted as being present in different strawberry tissues. Most of the metabolomics studies on fruit have been conducted on tomato. Tikunov et al. (2005) used a comparative multivariate analysis based on the profiles of all volatiles produced by fully-ripe red fruit belonging to 94 contrasting tomato genotypes. The analysis, based on solid phase microextraction GC-MS, revealed a total of 322 different compounds in the entire genotype set and pointed out that these compounds can be grouped in clusters according to the common biochemical precursor or metabolic pathway: Phe derivatives (phenolic and phenylpropanoid volatiles), Leu and Ile derivatives, lipid derivatives and isprenoid derivatives. This work provides new information on the heterogeneity in biochemical composition and metabolite content within tomato varieties. To explore the genetic basis of tomato fruit biochemistry, Schauer et al. (2006) used a high-throughput GC/MS metabolite profiling approach in parallel with whole-plant phenotype characterization. Many metabolic QTLs that affect numerous compounds in a metabolic pathway have been defined and a total of 899 single-metabolite QTLs identified. Metabolic changes have been detected in tomato flesh and seeds in relation to crucial changes in fruit growth and development using both untargeted and targeted metabolic profiling (Mounet et al., 2007). The compositional changes have been related to physiological processes occurring in each tissue, in particular high metabolic changes have been observed in flesh tissue during the transition from cell division to cell expansion, and in relation to the onset of ripening. A map of the different metabolite concentrations at different stages of development for both seeds and flesh has been established. The potential of metabolomics has been exploited to evaluate the effects of transgenesis in tomato (Roessner et al., 2003; Long et al., 2006; Fraser et al., 2007), different approaches to engineer the tomato flavonoid biosynthetic pathway resulted in expected and unexpected metabolic effects revealed through targeted and untargeted metabolite profiling (Bovy et al., 2007).

Given that refrigeration is the basis of postharvest technology, an interesting study is that done on *Arabidopsis* to characterize the freezing tolerance response, and to understand the function of transcription factors (CRT/DRE-binding factor, CBF) involved in the cold response regulatory pathway (Cook et al., 2004). Extensive cold-induced changes in the metabolome and the concentration of about 400 metabolites resulted as being significantly influenced by the CBF-mediated cold response pathway. Up to now, only a limited number of metabolic profiling studies have been conducted in relation to storage conditions and the postharvest evolution of quality parameters in horticultural produce. GC/MS analysis of volatile metabolites has been used to discriminate postharvest diseases (Vikram et al., 2006). Carrots inoculated with *Erwinia carotovora* subs. *carotovora* produced higher amounts of volatile compounds than those induced by other pathogens and seven compounds appeared to be disease-specific. Disease-discriminatory volatile metabolites have also been detected in onion bulbs and apples (Vikram et al., 2004, 2005) inoculated with postharvest pathogens. In potato, several volatile metabolites resulted as unique following inoculation with *Erwinia* spp., and were not detected in fungus-inoculated or control tubers (Lui et al., 2005). The discriminant analysis models developed appear to have a promising potential for early detection of postharvest diseases in horticultural produce.

The maturation of metabolomics as the next cornerstone of functional genomics depends on the establishment of databases (Summer et al., 2003; Bino et al., 2004). A metabolite database (MoToDB) dedicated to LC/MS-based metabolomics of tomato fruit has been developed by Moco et al. (2006). This database (http://applied-bioinformatics.wur.nl) contains all information (retention time, calculated accurate masses, PDA spectra, MS/MS fragments) on metabolites detected in ripe tomato fruit using LC/MS. This tool appears to be of great help in studying the dynamics of metabolome, to elucidate mutants and gene function based on differential metabolic profiles, and to decipher the biological relevance of each metabolite.

IV. Towards genomics networks and global profiling analysis in horticultural produce

The expansion of genomics resources and the rational organization of databases will facilitate a systems approach and a wider use of bioinformatics platforms in important horticultural crops other than model species. The Solanaceae Genomics Network (SGN; http://sgn.cornell.edu) is an example of a database rapidly developing into a comprehensive resource for comparative biology between members of this family and other closely related plants (Mueller et al., 2005). A preliminary comparative approach has been carried out with tomato, pepper and eggplant fruit. The use of tomato microarrays allowed groups of candidate expressed sequence tags, which are useful as orthologous markers, to be identified, as well as genes implicated in fruit ripening of these heterologous species (Moore et al., 2005). Following the completion of the tomato sequencing project and the implementation of the SGN database, a dramatic increase in biological data concerning quality aspects of these and other Solanaceae species, such as potato, is expected in the near future.

Most of the research carried out so far using profiling technologies in horticultural produce have concentrated on the use of genomics tools in isolation. However, the metabolic complexity characterizing these products suggests that, in the future, integrated analysis will be necessary to study and understand metabolic activity during development and in relation to different storage conditions. Integration of genomics datasets resulting from the application of transcript and protein abundance, metabolite accumulation and metabolic flux analysis, will be crucial to unravel the mechanisms that link genotypes to phenotypes and are responsible for quality traits (Sweetlove and Fernie, 2005). Within this context, and as a preliminary step in this direction, Alba et al. (2005) combining genotype, transcript and targeted metabolite analyses have elucidated the ethylene-regulated transcriptome of tomato fruit and the role of the gaseous hormone in carotenoid accumulation in ripening fruit. This integrated approach indicates that pigmentation during tomato ripening is the result of a complex regulation system dependent on ethylene and the Nr^+ receptor, a dramatic increase in carotenoid metabolic flux, and the temporal change of the expression of specific structural genes involved in the carotenoid biosynthetic pathway. Temporal changes of 92 metabolites (sugars, sugar alcohol, organic acids, amino acids, vitamins, pigments) in parallel with transcript level have been evaluated throughout tomato fruit development (Carrari et al., 2006). Combination of metabolite and transcriptomic data revealed that transcript abundance is less strictly coordinated by functional group than metabolite abundance, and this suggests that post-translational mechanisms dominate metabolic regulation. Nevertheless, there were some correlations between specific transcripts and metabolites, and several novel associations were identified that could provide potential targets for manipulation of fruit compositional traits. A strong relationship between ripening-associated transcripts and specific metabolite groups, such as TCA-cycle organic acids and sugar phosphates, was observed.

These examples make it clear that our understanding of plant metabolic networks will rely upon integrative (targeted and non-targeted) analyses. The continued technical improvement of post-genomic approaches that allow high-throughput cataloging in an abundance of transcripts, proteins and metabolites, suggests that important advancements will also be made in the future in the field of horticultural produce.

References

Abdi, N., Holford, P., McGlasson, B. (2002). Application of two-dimensional gel electrophoresis to detect proteins associated with harvest maturity in stone fruit. Postharvest Biol. Technology, 26, 1–13.

Aharoni, A., de Vos, R., Verhoeven, H., Maliepaard, C., Kruppa, G., Bina, R., Goodenowe, D. (2002). Nontargeted metabolome analysis by use of Fourier transform ion cyclotron mass spectrometry. OMICS, 6, 217–234.

Aharoni, A., Keizer, L.C., Bouwmeester, H.J., Sun, Z., Alvarez-Huerta, M., Verhoeven, H.A., Blaas, J., van Houwelingen, A.M., De Vos, R.C., van der Voet, H., Jansen, R.C., Guis, M., Mol, J., Davis, R.W., Schena, M., van Tunen, A. J., O'Connell, A.P. (2000). Identification of the SAAT gene involved in strawberry flavor biogenesis by use of DNA microarrays. Plant Cell, 5, 647–662.

Alba, R., Payton, P., Fei, Z., McQuinn, R., Debbie, P., Martin, G.B., Tanksley, S.D., Giovannoni, J.J. (2005). Transcriptome and selected metabolite analyses reveal multiple points of ethylene control during tomato fruit development. The Plant Cell, 17, 2954–2965.

Arabidopsis Genome Initiative (2000). Analysis of the genome sequence of the flowering plant *Arabidopsis thaliana*. Nature, 408, 796–815.

Bar-Or, C., Czosnek, H., Koltai, H. (2007). Cross-species microarray hybridizations, a developing tool for studying species diversity. Trends in Genetics, 23(4), 200–207.

Bentley, D.R. (2006). Whole-genome re-sequencing. Current Opinion Genetic Development, 16, 545–552.

Bino, R.J., Hall, R.D., Fiehn, O., Kopka, J., Saito, K., Draper, J., Nikolau, B.J., Mendes, P., Roessner-Tunali, U., Beale, M.H., Trethewey, R.N., Lange, B.M., Wurtele, E.S., Summer, L.W. (2004). Potential of metabolomics as a functional genomics tool. Trends in Plant Science, 9(9), 418–425.

Bovy, A., Schijlen, E., Hall, R.D. (2007). Metabolic engineering of flavonoids in tomato (*Solanum lycopersicum*), the potential for metabolomics. Metabolomics, 3, 399–412.

Brady, S.M., Long, T.A., Benfey, P.N. (2006). Unraveling the dynamic transcriptome. Plant Cell, 18, 2101–2111.

Busch, W., Lohmann, J.U. (2007). Profiling a plant, expression analysis in Arabidopsis. Current Opinion in Plant Biology, 10, 136–141.

Carrari, F., Baxter, C., Usadel, B., Urbanczyk-Wochniak, E., Zanor, M.I., Nunes-Nesi, A., Nikiforova, V., Centero, D., Ratzka, A., Pauly, M., Sweetlove, L.J., Fernie, A.R. (2006). Integrated analysis of metabolite and transcript levels reveals the metabolic shifts that underlie tomato fruit development and highlight regulatory aspects of metabolic network behaviour. Plant Phy., 142, 1380–1396.

Carrari, F., Fernie, A.R. (2006). Metabolic regulation underlying tomato fruit development. J. Exp. Bot., 57, 1883–1897.

Cercos, M., Soler, G., Iglesias, D.J., Gadea, J., Forment, J., Talon, M. (2006). Global analysis of gene expression during development and ripening of citrus fruit flesh. A proposed mechanism for citric acid utilization. Plant Mol. Biol., 62, 513–527.

Chervin, C., El-Kereamy, A., Roustan, J.P., Latché, A., Lamon, J., Bouzayen, M. (2004). Ethylene seems required for the ripening of grape, a non-climacteric fruit. Plant Sci., 167, 1301–1305.

Collins, F.S., Green, E.D., Guttmacher, A.E., Guyer, M.S. (2003). A vision for the future of genomics research. Nature, 422, 835–847.

Cook, D., Fowler, S., Fiehn, O., Thomashow, M.F. (2004). A prominent role for the CBF cold response pathway in configuring the low-temperature metabolome of Arabidopsis. Proc. Natl. Acad. Sci. USA, 101, 15243–15248.

Dal Cin, V., Rizzini, F.M., Botton, A., Tonutti, P. (2006). The ethylene biosynthetic and signal transduction pathways are differently affected by 1-MCP in apple and peach fruit. Postharvest Biol. Technol., 42, 125–133.

Dandekar, A.M. (2003). Technologies for manipulating quality and productivity traits in horticultural crops. Acta Hort., 625, 293–305.

da Silva, F.G., Iandolino, A., Al-Kayal, F., Bohlmann, M.C., Cushman, M.A., Lim, H., Ergul, A., Figueroa, R., Kabuloglu, E.K., Osborne, C., Rowe, J., Tattersall, E., Leslie, A., Xu, J., Baek, J., Cramer, G.R., Cushman, J.C., Cook, D.R. (2005). Characterizing the grape transcriptome. Analysis of expressed sequence tags from multiple *Vitis* species and development of a compendium of gene expression during berry development. Plant Phys., 139, 574–597.

Dellapenna, D. (2001). Plant metabolic engineering. Plant Phys., 125, 160–163.

Deluc, L.G., Grinplet, J., Wheatley, M.D., Tillett, R.L., Quidici, D.R., Osborne, C., Schooley, D.A., Schlauch, K.A., Cushman, J.C., Cramer, G.R. (2007). Transcriptomic and metabolite analyses of Cabernet Sauvignon grape berry development. BMC Genomics, 8. doi, 10.1186/1471-2164-8-429.

Deyteux, C., Geny, L., Lapailerie, D., Claverol, S., Bolneu, M., Doneche, B. (2007). Proteome analysis of grape skins during ripening. J. Exp. Bot., 58, 1851–1862.

Eggen, A. (2003). Basics and tools of genomics. Outlook Agr., 4, 215–217.

ESTree Consortium (2005). Development of an oligo-based microarray (μPEACH1.0) for genomics studies in peach fruit. Acta Hort., 682, 263–268.

Fan, X, Mattheis, J.P., Fellman, J.K. (1998a). A role for jasmonates in climacteric fruit ripening. Planta, 204, 444–449.

Fan, X., Mattheis, J.P., Fellman, J.K. (1998b). Responses of apples to postharvest jasmonate treatments. J. Am. Soc. Hort. Sci., 123, 421–425.

Faurobert, M., Mihr, C., Bertin, N., Pawlowski, T., Negroni, L., Sommerer, N., Causse, M. (2007). Major proteome variations associated with cherry tomato pericarp development and ripening. Plant Phys., 143, 1327–1346.

Fei, Z., Tang, X., Alba, R., White, J.A., Ronning, C.M., Martin, G.B., Tanksley, S.D., Giovannoni, J.J. (2004). Comprehensive EST analysis of tomato and comparative genomics of fruit ripening. Plant J., 40, 47–59.

Fiehn, O. (2002). Metabolomics – the link between genotypes and phenotypes. Plant Molecular Biology, 48, 155–171.

Fonseca, S., Hackler, L., Zvara, A., Ferreira, S., Baldè, A., Dudits, D., Pais, M.S., Puskas, L.G. (2004). Monitoring gene expression along pear fruit development, ripening and senescence using cDNA microarray. Plant Sci., 167, 457–469.

Forment, J., Gadea, J., Huerta, L., Abizanda, L., Agusti, J., Alamar, S., Alos, E., Andres, F., Arribas, R., Beltran, J.P., Berbel, A., Blazquez, M.A., Brumos, J., Canas, L. A., Cercos, M., Colmenero-Flores, J.M., Conesa, A., Estables, B., Gandia, M., Garcia-Martinez, J.L., Gimeno, J., Gisbert, A., Gomez, G., Gonzalez-Candelas, L., Granell, A., Guerri, J., Lafuente, M.T., Madueno, F., Marcos, J.F., Marques, M.C., Martinez, F., Martinez-Godoy, M.A., Miralles, S., Moreno, P., Navarro, L., Pallas, V., Perez-Amador, M.A., Perez-Valle, J., Pons, C., Rodrigo, I., Rodriguez, P.L., Royo, C., Serrano, R., Soler, G., Tadeo, F., Talon, M., Terol, J., Trenor, M., Vaello, L., Vicente, O., Vidal, C., Zacarias, L., Conejero, V. (2005). Development of a citrus genome-wide EST collection and cDNA microarray as resources for genomic studies. Plant Mol. Biol., 57, 375–391.

Fraser, P.D., Enfissi, E.M., Goodfellow, M., Eguchi, T., Bramley, P.M. (2007). Metabolite profiling of plant carotenoids using the matrix-assisted laser description ionization time-of-flight mass spectrometry. Plant J., 49, 552–564.

Giovannoni, J. (2004). Genetic regulation of fruit development and ripening. Plant Cell, 16(suppl.), S170–S180.

Giribaldi, M., Perugini, I., Sauvage, F-X., Schubert, A. (2007). Analysis of protein changes during grape berry ripening by 2-DE and MALDI-TOF. Proteomics, 7, 1768–3049.

Glinski, M., Weckwerth, W. (2006). The role of mass spectrometry in plant systems biology. Mass Spectrom. Rev., 25, 173–214.

González-Agüero, M., Pavez, L., Ibáñez, F., Pacheco, I., Campos-Vargas, R., Meisel, L.A., Orellana, A., Retamales, J., Silva, H., González, M., Cambiazo, V. (2008). Identification of woolliness response genes in peach fruit after postharvest treatments. J. Exp. Bot., 59, 1973–1986.

Gonzalez-Candelas, L., Sànchez-Torres, S., Alamar, B., Establés, A.R., Ballester, M.T., Sànchez-Ballesta, Y.L., Gosalbes, M.J., Zacarias, L., Marcos, J.F., Lafuente, M.T., Forment, J., Granell, A. (2005). Genomics approaches to postharvest biotic and biotic stresses of *Citrus* fruit. Acta Hort., 682, 247–254.

Gonzales-Ibeas, D., Blanca, J., Roig, C., Gonzales-To, M., Pico, B., Truniger, V., Gomez, P., Deleu, W., Cano-Delgado, A., Arus, P., Nuez, F., Garcia-Mas, J., Puigdomenech, P., Aranda, M.A. (2007). MELONGEN, an EST database for melon functional genomics. BMC Genomics, 8. doi, 10.1186/1471-2164-8-306.

Granell, A., Pons, C., Marti, C., Forment, J., Royo, C., Gradziel, T.M., Peace, C.P., Ogundiwin, E., Crisosto, C.H. (2007). Genomic approaches – Innovative tools to improve quality of fresh cut produce. Acta Hort., 746, 203–211.

Grimplet, J., Deluc, L.G., Tillett, R.L., Wheatlei, M.D., Schlauch, K.A., Cramer, G.R., Cushman, J.C. (2007). Tissue-specific mRNA expression profiling in grape berry tissues. BMC Genomics, 8. doi, 10.1186/1471-2164-8-187.

Grimplet, J., Romieu, C., Audergon, J.M., Marty, I., Albagnac, G., Lambert, P., Bouchet, J.P., Terrier, N. (2005). Transcriptomic study of apricot fruit (*Prunus armeniaca*) ripening among 13,006 expressed sequence tags. Physiologia plantarum, 125(3), 281–292.

Guarino, C., Arena, S., De Simone, L., D'Ambrosio, C., Santoro, S., Rocco, M., Scaloni, A., Marra, M. (2007). Proteomic analysis of the major soluble components in Annurca apple flesh. Molecular Nutr. Food Res., 51, 255–262.

Gutierrez, R.A., Shasha, D.E., Coruzzi, G.M. (2005). Systems biology for the virtual plant. Plant Phys., 138, 550–554.

Gygi, S.P., Rochon, Y., Franza, B.R., Aebersold, R. (1999). Correlation between protein and mRNA abundance in yeast. Mol. Cell. Biol., 19, 1720–1730.

Hall, R., Beale, M., Fiehn, O., Hardy, N., Sumner, L., Bino, R. (2002). Plant metabolomics, the missing link in functional genomics strategies. Plant Cell, 14, 1437–1440.

Heazlewood, J.L., Millar, A.H. (2003). Integrated plant proteomics – putting the green genomes to work. Funct. Plant Biol., 30, 471–482.

Hoquette, J.F. (2005). Where are we in genomics? Journal of Physiology and Pharmacology, 56(Supp.3), 37–70.

Ideker, T., Galitski, T., Hood, L. (2001). A new approach to decoding life, systems biology. Ann. Rev. Genom. Hum. Genet., 2, 343–372.

Katz, E., Fon, M., Lee, Y.J., Fhinney, B.S., Sadka, A., Blumwald, E. (2007). The citrus fruits proteome, insights into citrus fruit metabolism. Planta, 226, 989–1005.

Kays, S.J., Paull, R.E. (2004). Postharvest Biology. Exon Press, Athens, GA, USA.

Kondo, S., Yamada, H., Setha, S. (2007). Effects of jasmonates differed at fruit ripening stages on 1-aminocyclopropane-1-carboxylate (ACC) synthase and ACC oxidase gene expression in pears. J. Am. Soc. Hort. Sci., 132, 120–125.

Krishnan, P., Kruger, N.J., Ratcliffe, R.G. (2005). Metabolite fingerprinting and profiling using NMR. J. Exp. Bot., 56, 255–265.

Last, R.L., Jones, A.D., Shachar-Hill, Y. (2007). Towards the plant metabolome and beyond. Nature Reviews, 167–174.

Latorre, M., Silva, H., Saba, J., Guziolowski, C., Vizoso, P., Martinez, V., Maldonado, J., Morales, A., Caroca, R., Cambiazo, V., Campos-Vargas, R., Gonzalez, M., Orellana, A., Retamales, J., Meisel, L.A. (2006). JUICE, a data management system that facilitates the analysis of large volumes of information in an EST project workflow. BMC Bionformatics, 7, 513–524.

Long, M., Millar, D.J., Kimura, Y., Donovan, G., Rees, J., Fraser, P.D., Bramley, P.M., Bolwell, G.P. (2006). Metabolite profiling of carotenoid and phenolic pathways in mutant and transgenic lines of tomato, identification of a high antioxidant fruit line. Phytochemistry, 67, 287–292.

Lui, L.H., Vikram, A., Abu-Nada, Y., Kushalappa, A.C., Raghavan, G.S.V., Al-Mughrabi, K. (2005). Volatile metabolic profiling for discrimination of potato tubers inoculated with dry and soft rot pathogens. Amer. J. Potato Res., 82, 1–8.

Meyers, B.C., Galbraith, D.W., Nelson, T., Agrawal, V. (2004). Methods for transcriptional profiling in plants. Be fruitful and replicate. Plant Phys., 135, 637–652.

Miller, S.S., Driscoll, B.T., Gregerson, R.G., Gantt, J.S., Vance, C.P. (1998). Alfa malate dehydrogenase (MDH), molecular cloning and characterization of five different forms reveals a unique nodule-enhanced MDH. Plant J., 15, 173–184.

Moco, S., Bino, R.J., Vorst, O., Verhoeven, H.A., de Groot, J., van Beek, T.A., Vervoot, J., de Vos, C.H.R. (2006). A liquid chromatography-mass spectrometry-based metabolome database for tomato. Plant Phys., 141, 1205–1218.

Moore, S., Payton, P., Wright, M., Tanksley, S., Giovannoni, J. (2005). Utilization of tomato microarrays for comparative gene expression analysis in the Solanaceae. J. Exp. Bot., 56, 2885–2895.

Mounet, F., Lemarie-Chamley, M., Maucourt, M., Cabasson, C., Giraudel, J.L., Deborde, C., Lessire, R., Gallucci, P., Bertrand, A., Gaudilliere, M., Rothan, C., Rolin, D., Monig, A. (2007). Quantitative metabolic profiles of tomato flesh and seeds during fruit development, complementary analysis with ANN and PCA. Metabolomics, 3(3), 273–288.

Mueller, L.A., Solow, T.H., Taylor, N., Skwarecki, B., Buels, R., Binns, J., Lin, C., Wright, M.H., Ahrens, R., Wang, Y., Herbst, E.V., Keyder, E.R., Menda, N., Zamir, D., Tanksley, S.D. (2005). The SOL Genomics Network. A comparative resource for Solanaceae biology and beyond. Plant Phys., 138, 1310–1317.

Newcomb, R.D., Crowhurst, R.N., Gleave, A.P., Rikkerink, E.H.A., Allan, A.C., Beuning, L.L., Bowen, J.H., Gera, E., Jamieson, K.R., Janssen, B.J., Laing, W.A., McArtney, S., Nain, B., Ross, G.S., Snowden, K.C., Souleyre, E.J.F., Walton, E.F., Yauk, Y-K. (2006). Analyses of Expressed sequence Tags from apple. Plant Phys., 141, 147–166.

Park, S., Sugimoto, N., Larson, M.D., Beaudry, R., van Nocker, S. (2006). Identification of genes with potential roles in apple fruit development and biochemistry through large-scale statistical analysis of Expressed Sequence Tags. Plant Phys., 141, 811–824.

Peng, F.Y., Reid, K.E., Liao, N., Schlosser, J., Lijavetzky, D., Holt, R., Zapater, J.M.M., Jones, S., Marra, M., Bohlmann, J., Lund, S.T. (2007). Generation of ESTs in *Vitis vinifera* grape (Cabernet Sauvignon) and table grape (Muscat Hamburg) and discovery of new candidate genes with potential roles in berry development. Gene, 402, 40–50.

Pickersky, E., Gang, D. (2000). Genetics and biochemistry of secondary metabolites, an evolutionary perspective. Trends in Plant Science, 5, 439–445.

Pilati, S., Perazzolli, M., Malossini, A., Cestaro, A., Dematte, L., Fontana, P., Dal Ri, A., Viola, R., Velasco, R., Moser, C. (2007). Genome-wide transcriptional analysis of grapevine berry ripening reveals a set of genes similarly modulated during three seasons and the occurrence of an oxidative burst at veraison. BMC Genomics, 8. doi, 10.1186/1471-2164-8-428.

Ponce-Valadez, M., Watkins, C., Moore, S., Giovannoni, J.J. (2005). Differential gene expression analysis of strawberry cultivar responses to elevated CO_2 concentrations during storage using a tomato cDNA microarray. Acta Horticulturae, 682, 255–262.

Pons, C., Royo, C., Forment, J., Gadea, J., Lluch, Y., Granell, A., Zacarias, L., Lafuente, M.T., Kanellis, A.K. (2005). A customized citrus cDNA microarray and its use in postharvest. Acta Horticulturae, 682, 225–232.

Ratcliffe, R.G., Shachar-Hill, Y. (2005). Revealing metabolic phenotypes in plant, inputs from NMR analysis. Biol. Rev., 80, 27–43.

Reilly, K., Bernal, D., Cortés, D.F., Gòmez-Vàsquez, R., Tohme, J., Beeching, J. R. (2007). Towards identifying the full set of genes expressed during cassava post-harvest physiological deterioration. Plant Molecular Biology, 64, 187–203.

Rensink, W.A., Buell, C.R. (2005). Microarray expression profiling resources for plant genomics. Trends in Plant Science, 10, 603–609.

Reuter, A., Fortunato, D., Perono Garoffo, L., Napoletano, L., Scheurer, S., Giuffrida, M.G., Vieths, S., Conti, A. (2005). Novel isoforms of Pru av 1 with diverging immunoglobulin E binding properties identified by a synergistic combination of molecular biology and proteomics. Proteomics, 5, 282–289.

Robinson, S.P., Jacobs, A.K., Dry, I.B. (1997). A class IV chitinase is highly expressed in grape berries during ripening. Plant Phys., 114, 771–778.

Rocco, M., D'Ambrosio, C., Arena, S., Faurobert, M., Scaloni, A., Marra, M. (2006). Proteomic analysis of tomato fruits from two ecotypes during ripening. Proteomics, 6, 3781–3791.

Roessner, U., Hegemann, B., Lytovchenko, A., Carrari, F., Bruedigam, C., Granot, D., Fernie, A.R. (2003). Metabolic profiling of transgenic tomato plants overexpressing hexokinase reveals that the influence of hexose phosphorylation diminishes during fruit development. Plant Phys., 133, 84–99.

Roessner, U., Luedemann, A., Brust, D., Fiehn, O., Linke, T., Willmitzer, L., Fernie, A.R. (2001). Metabolic profiling allows comprehensive phenotyping of genetically or environmentally modified plant systems. Plant Cell, 13, 11–29.

Roessner, U., Wagner, C., Kopla, J., Trethewey, R.N., Willmitzer, L. (2000). Simultaneous analysis of metabolites in potato tuber by gas chromatography-mass spectrometry. Plant J., 23, 131–142.

Rose, J.K.C., Bashir, S., Giovannoni, J.J., Jahn, M.M., Saravanan, R.S. (2004). Tackling the plant proteome, practical approaches, hurdles and experimental tools. Plant J., 39, 715–733.

Rose, J.K.C., Saladié, M. (2005). Proteomic analysis and fruit ripening. Acta Hort., 682, 211–224.

Rossignol, M. (2001). Analysis of the plant proteome. Curr. Opin. Biotech., 12, 131–134.

Rothan, C., Duret, S., Chevalier, C., Raymond, P. (1997). Suppression of ripening-associated gene expression in tomato fruits subjected to a high CO_2 concentration. Plant Phys., 114, 255–263.

Sarry, J-E., Sommerer, N., Sauvage, F-X., Bergoin, A., Rossignol, M., Albagnac, G., Romieu, C. (2004). Grape berry biochemistry revisited upon proteomic analysis of the mesocarp. Proteomics, 4, 201–215.

Schaffer, R.J., Friel, E.N., Souleyre, E.J.F., Bolitho, K., Thodey, K., Ledger, S., Bowen, J.H., Ma, J-H., Nain, B., Cohen, D., Gleave, A.P., Crowhurst, R.N., Janssen, B.J., Yao, J-L., Newcomb, R.D. (2007). A genomics approach reveals that aroma production in apple is controlled by ethylene predominantly at the final step in each biosynthetic pathway. Plant Phys., 144, 1899–1912.

Schauer, N., Semel, Y., Roessner, U., Gur, A., Balbo, I., Carrari, F., Pleban, T., Perez-Melis, A., Bruedigam, C., Kopka, J., Willmitzer, L., Zamir, D., Fernie, A.R. (2006). Comprehensive metabolic profiling and phenotyping of interspecific introgression lines for tomato improvement. Nature Biotechnol., 24, 447–454.

Schena, M., Shalon, D., Davis, R.W., Brown, P.O. (1995). Quantitative monitoring of gene expression pattern with a complementary DNA microarray. Science, 270, 467–470.

Seymour, G.B., Manning, K. (2002). Genetic control of fruit ripening. In: Fruit Quality and its Biological Basis, M. Knee (ed.). Sheffield Academic Press Ltd, UK, pp. 253–274.

Seymour, G.B., Taylor, J.E., Tucker, G.A. (eds). (1993) Biochemistry of Fruit Ripening. Chapman & Hall, London, UK.

Sisler, E.C., Serek, M. (1997). Inhibitors of ethylene responses in plants at the receptor level, recent developments. Physiol. plant., 100, 577–582.

Summer, L.W., Mendes, P., Dixon, R.A. (2003). Plant metabolomics, large-scale phytochemistry in the functional genomics era. Phytochemistry, 62, 817–836.

Sweetlove, L.J., Fernie, A.R. (2005). Regulation of metabolic networks, understanding metabolic complexity in the systems biology era. New Phytologist, 168, 9–24.

Terol, J., Conesa, A., Colmenero, J., Cercos, M., Tadeo, F., Agusti, J., Alos, E., Andres, F., Soler, G., Brumos, J., Iglesias, D., Goetz, S., Legaz, F., Argout, X., Courtois, B., Ollitrault, P., Dossat, C., Wincker, P., Morillon, R., Talon, M. (2007). Analysis of 13,000 unique *Citrus* clusters associated with fruit quality, production and salinity tolerance. BMC Genomics, 8, doi, 10.1186/1471-2164-8-31.

Terrier, N., Glissant, D., Grimplet, J., Barrieu, F., Abbal, P., Couture, C., Ageorges, A., Atanassova, R., Leon, C., Renaudin, J.P., Dedaldechamp, F., Romieu, C., Delrot, S., Hamdi, S. (2005). Isogene specific oligo arrays reveal multifaceted changes in gene expression during grape berry (*Vitis vinifera* L.) development. Planta, 222, 832–847.

The French–Italian Public Consortium for Grapevine Genome Characterization (2007). The grapevine genome sequence suggests ancestral hexaploidization in major angiosperm phyla. Nature, 449, 463–468.

Tikunov, Y., Lommen, A., Ric de Vos, C.H., Verhoeven, H.A., Bino, R.J., Hall, R.D., Bovy, A.G. (2005). A novel approach for nontargeted data analysis for metabolomics. Large-scale profiling of tomato fruit volatiles. Plant Phys., 139, 1125–1137.

Tolstikov, V.V., Fiehn, O. (2002). Analysis of highly polar compounds of plant origin, combination of hydrophilic interaction chromatography and electrospray ion mass trap spectrometry. Anal. Biochem., 301, 298–360.

Tolstikov, V.V., Lommen, A., Nakanishi, K., Tanaka, N., Fiehn, O. (2003). Monolithic silica-based capillary reversed-phase liquid chromatography/electrospray mass spectrometry for plant metabolomics. Anal. Chem., 75, 6737–6740.

Tonutti, P., Bonghi, C., Ramina, A. (2007). Modulating effects of ethylene and ethylene inhibitors in the control of fruit ripening. In: Advances in Plant Ethylene Research, A. Ramina, C. Chang, J. Giovannoni, H. Klee, P. Perata, E. Woltering (eds). Springer, The Netherlands, pp. 407–416.

Trainotti, L., Bonghi, C., Ziliotto, F., Zanin, D., Rasori, A., Casadoro, G., Ramina, A., Tonutti, P. (2006). The use of microarray mPEACH1.0 to investigate transcriptome changes during transition from pre-climacteric to climacteric phase in peach fruit. Plant Sci., 170, 606–613.

Trainotti, L., Tadiello, A., Casadoro, G. (2007). The involvement of auxin in the ripening of climacteric fruits comes of age: the hormone plays a role of its own and has an intense interplay with ethylene in ripening peaches. J. Exp. Bot., 58, 3299–3308.

van Wordragen, M., Balk, P., Hall, R., Nijenhuis, M., van den Broeck, H., Vorst, O., Poelman., A. (2003). Applied genomics; an innovative tool to improve quality in chains. Predicting mealiness in apples, a case study. Acta Horticulturae, 604, 387–394.

Vikram, A., Hamzehzarghani, H., Kushalappa, A.C. (2005). Volatile metabolites from the headspace of onion bulbs inoculated with postharvest pathogens as a tool for disease discrimination. Canadian Journal of Plant Pathology, 27, 194–203.

Vikram, A., Lui, L.H., Hossain, A., Kushalappa, A.C. (2006). Metabolic fingerprinting to discriminate diseases of stored carrots. Annals of Applied Biology, 148, 17–26.

Vikram, A., Prithiviraj, B., Hamzehzargani, H., Kushalappa, A.C. (2004). Volatile metabolite profiling to discriminate diseases of McIntosh apple inoculated with fungal pathogens. Journal of the Science of Food and Agriculture, 84, 1333–1340.

Villas-Boas, S.G., Mas, S., Akesson, M., Smedsgaard, J., Nielsen, J. (2005). Mass spectrometry in metabolome analysis. Mass Spectrom. Rev., 24, 613–646.

Watkins, B.C. (2006). The use of 1-methylcyclopropene (1-MCP) on fruits and vegetables. Biotechnology Advances, 24, 389–409.

Weckwerth, W. (2003). Metabolomics in systems biology. Ann. Rev. Plant Biol., 54, 669–689.

Withfield, P.D., German, A.J., Noble, P.J. (2004). Metabolomics, an emerging post-genomic tool for nutrition. British Journal of Nutrition, 92, 549–556.

Ziosi, V., Bonghi, C., Bregoli, A.M., Trainotti, L., Biondi, S., Sutthiwal, S., Kondo, S., Costa, G., Torrigiani, P. (2008). Jasmonate-induced transcriptional changes suggest a negative interference with the ripening syndrome in peach fruit. J. Exp. Bot., 48, 581–591.

Ziliotto, F., Begheldo, M., Rasori, A. Bonghi, C., Tonutti, P. (2008). Transcriptome profiling of ripening nectarine (*Prunus persica* L. Batsch). Fruit treated with 1-MCP. J. Exp. Bot., 59, 2781–2791.

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Challenges in Postharvest Handling

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I. Postharvest handling

Consumers, producers, and marketers are key players in the fresh produce supply chain. Banks (Chapter 1) noted that expectations of each group focused on creation and appreciation of value. The systems approach was singled out because it links causes and effects: fresh produce handling and its quality. Consumers prefer quality, although as noted in several chapters (see Chapters 2, 3, 4, 8, 9, 11 and 18), the notion of quality is fluid and interpreted in many different ways. Therefore, efforts in postharvest handling are focused on value creation, including the protection, maintenance or enhancement of attributes, for which buyers are willing to pay (see Chapters 6, 10, 14, 19 and 20). Suppliers interpret consumer wants and innovate to meet consumer expectations. Innovation provides only a temporary competitive edge and it becomes a conventional practice once its use spreads. Growers and marketers reach for other means to gain competitive advantage, and adopt technology that is licensed or patented. Banks (Chapter 1) illustrated the "managed scarcity" with examples of patented pineapple or kiwifruit varieties. Licensing has also become a popular way to limit the supply of apples, e.g. Pink Lady™, while in the near future, more patented or licensed varieties of fruits and vegetables will be commercialized. Managed scarcity prevents price collapse, as noted by Banks. It also supports another consumer trend, namely the demand for a wider assortment of produce (see also Chapter 5). Earlier studies have shown that consumers who like produce will substitute another

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kind of produce for the one they wanted to buy, but that was unavailable, or did not match quality expectations or price.

The systems approach proposed in the original version of this book (Prussia and Shewfelt, 1993) advocates the awareness of the existence of other links in the supply chain. According to the systems approach concept, participants implicitly recognize the time sequence of the physical product movement and ownership transfer, and the associated transfer of risk of quality defects. The nature of quality defects, many of which affect the appearance and the internal quality of the produce, often require a passage of time before it can be visually detected during inspection (see also Chapters 8, 14, and 15). The time separation of cause and effect of quality defect opens the opportunity for underperformance at some links in the chain, because of the double pay-off; it may save costs in implementing specific postharvest services, while fetching potentially higher price by beating competitors in a given point in time. Any quality loss occurs later in the supply chain, and turns into a monetary loss for the firm which owns the produce at that particular stage. To recover the loss requires expense and allocation of time and management resources to trace the cause of quality deterioration, and the establishment of the timing of events that led to quality loss. A company may choose never to pursue this option, but would rather change suppliers.

The timing of quality deterioration has no immediate consequences if it remains undetected until the actual act of eating. A consumer will seldom exercise the right to demand that the produce be exchanged or the money returned. Rather, if the produce is often of poor quality, the low quality will induce a change in consumer preferences. For example, a decline in stone fruit consumption, especially peaches, is attributed to inconsistent quality (Byrne, 2005). Therefore, the economic consequences of narrow and short-term focus of the various links in the supply chain become visible only after an extended period of time, and become confounded by other factors. Suppliers are unable to separate the effects of poor quality from other factors, such as the relative improvement in produce selection, the entry of new varieties, etc.; with the exception of very short supply chains (see Chapter 11).

The systems approach is capable of reducing the incidence of quality loss discovery at a link upstream from where the quality loss was induced by poor handling. However, its implementation requires a shared goal across all supply links to supply the highest eating quality fresh produce. While the systems approach prescribes what ought to be done, it lacks ability to enforce the procedure. The systems approach provides a framework which is sufficiently flexible to depict the interaction among various stages in the supply chain (see also Chapter 6), infer the cause–effect relationships, and visualize innovation. It is static, but can become dynamic by sequential portrayal of the interactions. The enforcement of the interactions depicted by a systems approach is left to the market. The interaction of supply and demand determines the preferred produce quality by signaling the price paid for each bundle of quality attributes. Should the market fail to perform its function, consumers may shift their preferences to alternatives. But if the conditions are right a regulator, such as a government inspection service, may step in to enforce quality standards (see also Chapter 9). The systems approach is replaced by regulations which shift the attention away from understanding the interaction of links in the supply chain to the supervised application of standards.

II. The need for speed

Fresh produce, a living organism, is susceptible to deterioration (see also Chapters 2, 13 and 16). Deterioration occurs over time at a variable rate, e.g. leafy vegetables deteriorate faster than citrus fruit. The increased variety of fresh produce available to consumers is the result of incremental advances in transportation, cooling, packaging, storing, disease prevention and product development (see also Chapter 10), among others. The advances occurred in response to demand for solutions articulated by the industry, motivated by potential profits (see also Chapters 6, 16 and 21).

Traceability awakening

It is often the case that events external to the system (i.e. the fresh produce supply system) induce an internal change. The change in itself is too cumbersome, perceived as too disruptive and simply inconvenient to be initiated from within. The idea of traceability of a fresh produce shipment was forced on the industry by the consequences of the distribution, sales and consumption of produce contaminated with food-borne pathogens (see also Chapter 12). The immediate costs of these incidents resulted from the recall of suspected contaminated batches of produce. In some cases, the persons who became sick or their families sued the suppliers or distributors for damages, while the media reports led to a risk-averse reaction on the part of many consumers, who chose not to buy the type of produce linked to the outbreak. The shift in demand hurt sales of the affected produce for weeks or months at a time. The most vivid example of such outbreak was the distribution of fresh baby spinach contaminated with E. coli (CDCP, 2006).

Recurring fresh produce contamination increases the perception of risk associated with the intentional contamination of produce. Detection of intentional or unintentional produce contamination requires an immediate action on the part of the industry. The traditional fresh produce supply chain involves multiple handling points and numerous ownership transfers spread over time and space (see also Chapter 7). Pallets of fresh produce are often broken and reassembled in response to distributor needs. Such practices may conceal identification of the origin of produce, and prevent timely removal of the remaining portion of the shipment from the supply chain. Traceability can now become an enforcement mechanism facilitating the application of a true systems approach. To trace every box down the supply chain and tie the quality defects to a specific handling practice and location requires that there be a common language (see Chapter 1). The common language reflects the shared values and the desire for the creation of value in the marketplace. In this context, the trust and reputation that enable marketing of fresh produce become of formidable importance (see Chapter 1). The systems approach is sustainable because of the reciprocity depicted in the virtuous cycle and the traceability serves as a verification mechanism.

III. The systems approach forces interdisciplinary approach

Interdisciplinary efforts in production, harvest and protection of quality produce occur in response to the need to ensure the revenue flow to all participating supply chain links. Various links in the fresh produce supply system perform different functions, leading naturally to a fragmentation of the supply chain. Increasingly, researchers turn their attention to production conditions (see Chapter 20) and genetic makeup (see Chapters 16 and 21) to prevent or reduce quality deterioration (see also Chapter 13) or enhance desired attributes in fresh produce. Moreover, industry or international standards (see Chapter 9) establish new criteria for quality accounting for measures of taste or texture (see also Chapter 4). A new set of standards involves production techniques, such as organics, creating a major dichotomy in the type of fresh produce handled within the same supply chain. The fragmented supply chain offers opportunities for multiple transactions. The rapid sequence of ownership transfer is possible through the use of industry-accepted grading schemes.

Progress in the supply of quality fresh produce will be determined by interdisciplinary efforts. Sometimes, it will result from discoveries in one discipline, but wide application and commercialization will be necessary when other disciplines participate in the process. The source of scientific disciplinary discoveries are, generally, research universities. Applications are driven by the industry, which measures research results in monetary terms. The interdisciplinary nature of progress and the disciplinary nature of the discovery process must interact to ensure efficiency of knowledge transfer and applications.

Interdisciplinary teams are easily formed in the industry because of their task orientation, and often the sequential requirement of skills and expertise from various fields to commercialize a product. In academia, the recognition of interdisciplinary cooperation needs to be aware of the disciplinary character of the promotion and reward system. Disciplinary boundaries, stiffened by budgetary allocations, encourage treating other scientists as competitors and support the narrow approach to valuation of progress in discovery. Some universities apply rather simple techniques to overcome the single disciplinary orientation (Tadmor and Tidor, 2005; Coppola et al., 2007). The efforts seem to focus on communication enhancement, exchange of ideas, learning from what others have done and the results of their research. An interdisciplinary approach tends to be more risky than a narrow disciplinary view for the individual researcher, but more rewarding to the system in terms of real-world solutions.

IV. The future: science versus emotions

The fresh produce sector has been a target of consumer activism. The new forms of consumer activism include the concepts of “fair trade,” “food miles” (see also

Chapter 7) or pitch organic produce against that produced using conventional production techniques, among others. The arguments for issues promoted by various so-called consumer advocacy groups appear quite persuasive, and are driven by their emotional appeal. The ideas are popularized before any rigorous scientific verification has been applied, and often are used for the purpose of shifting demand to an emerging niche market. The scientific assessment of such concepts is often inconclusive or actually contradicts the notion being promoted. For example, in the case of "fair trade" labeling, a large number of suppliers using this label are from Mexico, a relatively well-off country, and very few are from a country like Ethiopia, which could benefit to a relatively large extent (Eyre, 2008).

Consumer activism, more emotional than rational, becomes a sociological phenomenon in societies that lead in scientific discovery. This dichotomy is explained by some as a form of protest against the feelings of alienation and lack of influence on the societal developments (Jacoby, 2008). Retailers, some of whom adopt the attitudes promoted by consumer groups, induce a change in the supply chain. They differentiate supply sources and create new subsystems within the produce industry. The economic efficiency of subsystems may be suboptimal, because a new niche market generates relatively less information, so dissemination and access to such information becomes costly or limited, and the price discovery mechanism is prone to under-perform in a market where the number of transactions is small. The sustainability of niche markets driven by consumer activism will depend on consumer attitudes, conditioned by their willingness to pay for fresh produce with a particular credence attribute.

The future of the produce market will be determined by the ability to supply fresh produce with clearly identifiable attributes to a specific consumer segment. Segments may form on the basis of individually acquired taste preference (see Chapter 4) rather than the sociodemographic profile. Individual differences also arise from increasing evidence of genetic predisposition to develop certain types of diseases or chronic conditions, which may require optimized diets including fresh fruits and vegetables containing functional and bioactive substances (see also Chapter 5), to prevent disease. Besides the medical function of fresh produce, knowledge about its properties is important and can be part of the semiotic function of food. The selection of health-benefiting fruits and vegetables, eaten during or off the growing season, signals aspects related to consumer self-portrayal or self-realization. Companies increasingly communicate social, ethical and environmental responsibility; see for example www.fabrikderzukunft.at or www.trigos.at.

Consumer behavior may be highly changeable in the foreseeable future, and it will affect the fresh fruit and vegetable market. The rational decision-making process constrained by available income will be challenged by perceived easily verifiable fresh produce, as well as credence attributes. To deliver traditional and new products under these highly volatile conditions is a real challenge to postharvest handling and the whole supply chain. The concept of systems approach may be used with increased frequency, because the effective supply response in a timely fashion will favor cooperation rather than competition. Otherwise the supply chain will fail to create and deliver value to its customers. These developments, and the possible shift of demand favoring increased fruit and vegetable consumption, will induce structural changes ultimately benefiting consumers.

Bibliography

Byrne, D.H. (2005). Trends in stone fruit cultivar development. HortTechnology, 15(3), 494–500.

CDCP (2006). Multiple states investigating a large outbreak of E. coli O157:H7 infections. Available online at www2a.cdc.gov/HAN/ArchiveSys/ViewMsgV.asp?AlertNum=00249 Accessed 23 April 2007.

Coppola, B.P., Banaszak Holl, M.M., Karbstein, K. (2007). Closing the gap between interdisciplinary research and disciplinary teaching. ACS Chemical Biology, 2(8), 518–520.

Eyre, C. (2008). Fairtrade branded unfair by UK think tank. Available online at www.foodnavigator.com/news/printNewsBis.asp? Accessed 9 March 2008.

Fletcher, A. (2007). Ethical food under threat from consumer confusion. Available online at www.foodnavigator.com/news/printNewsBis.asp? Accessed 9 March 2008.

Jacoby, S. (2008). The age of American unreason. Pantheon Books, New York, NY, USA.

Prance, L. (2007). Retailers on board the ethical foods drive. Available online at www.foodnavigator.com/news/printNewsBis.asp? Accessed 9 March 2008.

Prussia, S.E., Shewfelt, R.L. (1993). Systems Approach to Postharvest Handling. In: Postharvest Handling, A Systems Approach, R.L. Shewfelt, S.E. Prussia (eds). Academic Press, Inc., San Diego, CA, USA.

Tadmor, B., Tidor, B. (2005). Interdisciplinary research and education at the biology–engineering–computer science interface: A perspective. Drug Discovery Today, 10(17), 1183–1189.

Glossary/Acronyms

µm: micrometer
ABA: abscisic acid
AHC: Australian Horticultural Corporation
AI: autoinducers
AMC: aerobic mesophilic count
AOTF: acousto-optical tunable filters
AOX: antioxidant
AQIS: Australian Quarantine Inspection Service
ATO: Agricultural Trade Office
BEM: business excellence model
BFA: Biological Farmers Australia
BRC: British Retail Council
CA: controlled atmosphere (storage)
CAC: Codex Alimentarius Commission
CCP: critical control points
CFU: colony forming unit
CQL: Carrefour's quality line
CRA: comparative risk assessment
CSA: Community Supported Agriculture
CSCMP: Council of Supply Chain Management Professionals
DASH: dietary approaches to stop hypertension
DG: Directorate General
DOD: Department of Defense
DRI: dietary reference intake
DRIS: diagnosis and recommendation system
DSD: direct store deliveries
EC: European Commission
EC: European Council
EIP: environmentally identified products
EMA: equilibrium modified atmosphere

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ENZA: a marketing organization – formerly the New Zealand Apple & Pear Marketing Board
EPS: exopolymeric substance
EU: European Union
EurepGAP: The European Retailer Produce Working Group – Good Agricultural Practices
FACT: food action rating scale
FAO: Food and Agriculture Organization of the United Nations
FCOJ: frozen, concentrated orange juice
FCS: farm credit system
FEFO: first expire, first out
FFV: fresh fruits and vegetables
FFVA: The United Fresh Fruit & Vegetable Association
FIFO: first in, first out
FL: floating system
FMI: Food Marketing Institute
FMRI: functional magnetic resonance imaging
FSANZ: Food Safety Australia and New Zealand
FW: fresh weight
GAP: good agricultural practices
GC-MS: gas chromatography-mass spectrometry
GDP: gross domestic product
GHP: good hygiene practices
GI: geographic indication
GMP: good manufacturing practices
GSM: global system for mobile communications
GTIN: global trade item number
H_2O_2: hydrogen peroxide
HACCP: hazard analysis critical control points
HCS: hue, chroma, saturation
HFMS: headspace fingerprint mass spectrometry
HHSS: harvest, handling, shipping and storage
HOCl: hypochlorous acid
HPLC: high pressure liquid chromatography
HUT: home use test
ICT: information and communication technologies
IFS: international food standard
IIP: Investors in People
IQA: International Quality Association
IRCA: Immigration Reform and Control Act
IS: International Standards Organization
JAR: just-about-right questions
JAS: Japan Agricultural Standard
LCTF: liquid crystal tunable filters
LIFO: last in, first out

MA: modified atmosphere
MAP: modified atmosphere packaging
MCP: 1-methylcyclopropene
MRI: magnetic resonance imaging
NASAA: National Association for Sustainable Agriculture, Australia
NFC: not-from-concentrate (orange juice)
NFT: nutrient film technique
NGO: non-government organization
NIR: near-infrared radiation
NMR: nuclear magnetic resonance
O_2^-: superoxide
OECD: Organisation for Economic Co-operation and Development
OH^-: hydroxyl radical
PAA: peroxyacetic acid
PAL: phenylalanine ammonia lyase
PDO: protected designations of origin
PG: peptidoglycan polymer
PGI: protected geographical indications
PLUs: price look-up codes or product look-up numbers
PMA: Produce Marketing Association
PODs: peroxidases
Ppm: parts per million
PPOs: polyphenol oxidases
PRP: prerequisite program
QA: quality assurance
QC: quality control
QDPI: Queensland Department of Primary Industries
QI: quality improvement
QMS: quality management system
QS: anti-quorum sensing
RFID: radio frequency identification
RH: relative humidity
RMSEP: root mean squared error of prediction
ROS: reactive oxygen species
RPC: reusable product container
SCAR: Standing Committee for Agricultural Research
SEP: standard error of prediction
SMS: short message service
SPC: standard plate count
SPC: statistical process control
SPME: solid phase micro-extraction
SQF 2000: safe quality food scheme
SQF: safe quality food
SSC: soluble solids content
TA: total acidity

Tis: temperature indicators
TPC: total plate count
TQM: total quality management
TSS: total soluble solids
TTIs: time–temperature indicators
UCL: upper control limits
ULO: ultra low oxygen (storage)
UNECE: United Nations Economic Commission for Europe
U-pick: you pick
UV: ultraviolet
UV-B: ultraviolet-B
UV-C: ultraviolet-C
WASD: weighted average source distance
WHO: World Health Organization
WIC: special supplemental nutrition program for women, infants, and children
WRKY proteins: DNA-binding proteins that recognize elements in the promoters of a large number of plant defense-related genes
WTO: World Trade Organization
WTP: willingness-to-pay
X-ray CT: X-ray computed tomography

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