An overview of preharvest factors influencing postharvest quality of horticultural products

Errol W. Hewett

Institute of Food, Nutrition and Human Health
Massey University, Private Bag 102 904
North Shore Mail Centre, Auckland, New Zealand
E-mail: E.W.Hewett@massey.ac.nz

Abstract: Postharvest product quality develops during growing of the product and is maintained, not improved by postharvest technologies. Available genetic material allows discrimination of external and internal quality attributes that must satisfy consumer requirements and indulgences. Farmers face challenges in utilising technologies for producing high quality crops; meaningful manipulation of light, nutrients, water and plants is possible only when plant responses to environmental conditions are understood. Genetic engineering can produce plants with desirable characteristics, but society is not yet convinced that benefits gained outweigh risks. Protected cropping enables growers to produce consistent crops in environments where production is often variable, and production of high value crops 'out of season'. Farmers, scientists, extension specialists and market personnel must work together to provide knowledge, best practices and enabling tools for growers to ensure preharvest conditions are optimised for production of high quality horticultural crops that titillate, satisfy and reward discerning consumers.

Keywords: satisfaction; dry matter; taste and flavour; consumers; microclimate; mineral nutrition; calcium; harvest maturity; ethylene; transgenic plants; supply chain management.

Reference to this paper should be made as follows: Hewett, E.W. (2006) 'An overview of preharvest factors influencing postharvest quality of horticultural products', *Int. J. Postharvest Technology and Innovation*, Vol. 1, No. 1, pp.4–15.

Biographical notes: Professor Hewett (Emeritus) has been Professor of Horticultural Science at Massey University since 1986. He is an Honorary Fellow of the New Zealand Society for Horticultural Science and a member of the American Society of Horticultural Science. Since 1998 he has been Chair of the Quality and Postharvest Commission of the International Society for Horticultural Science. He is a member of the Management Committee of the International Tropical and Subtropical Fruit Network. He has supervised many graduate students in postharvest physiology, he has been involved in the publication of more than 80 papers, and made presentations at many international conferences.

1 Introduction

Sustained commercial horticultural success depends on satisfying consumer demands no matter where the market is located. Appropriate product quality for a particular end use must be attained if continued repeat purchases are to be made and if producing enterprises are to remain profitable. Global expansion of major supermarket chains has a dramatic effect on the businesses of horticultural producers in many countries. This effect is brought about by the struggle of businesses to comply with quality and food safety requirements imposed on them. The need to operate within consolidated and integrated supply chains may be an imperative for sustained growth and profitability.

It is axiomatic that the eating quality of fresh horticultural products is already determined at harvest. Because the harvested product has been removed from its source of carbohydrates, water and nutrient supply by the very act of harvesting, there is no possibility for further improvement in the components that contribute to the unique quality attributes of any particular horticultural crop. In fact, with the very best of postharvest knowledge and technologies available, the best that can be achieved is a reduction in the rate at which products deteriorate as they progress through their normal developmental pattern of maturation, ripening and senescence. Therefore, it is very important to understand what preharvest factors influence the many important harvest quality attributes that affect the rate of postharvest deterioration and, subsequently, the consumers' decision to purchase the product in the marketplace.

2 What is quality?

Quality is a difficult term to define. This difficulty stems from people being different and individuals having expectations of what they expect and what they like about any particular product. Quality is 'fitness for purpose'. It is the product state that meets the expectations of the customer/consumer. This state will encompass concepts such as the position of a person in the supply chain from farm to consumer. It will be a function of the financial position as well as the cultural background of the individual purchaser. Whatever happens, the customer is always right. If producers do not recognise these needs and desires, then a decline in consumption of fresh fruits and vegetables could occur. Customers will then rely on more convenient 'pill diets' comprising an increasing range of purportedly health containing properties (Shewfelt, 1999; Shewfelt and Henderson, 2003).

Quality is made up of many attributes, both intrinsic and extrinsic (Jongen, 2000). These attributes will vary depending on the expectations and memory of the consumer. Intrinsic features of the product include key external attributes such as colour, shape, size and freedom from defects. In addition, internal attributes include texture, sweetness, acidity, aroma, flavour, shelf life and nutritional value. These are important components of the subjective approach used by the consumer in deciding what to purchase. Extrinsic factors refer to production and distribution systems. These factors include chemicals used during production, package types and their recycling capability, sustainability of production and distribution in relation to energy utilisation. These extrinsic factors are likely to influence consumer's decision to purchase rather than to reflect on the actual quality of a product.

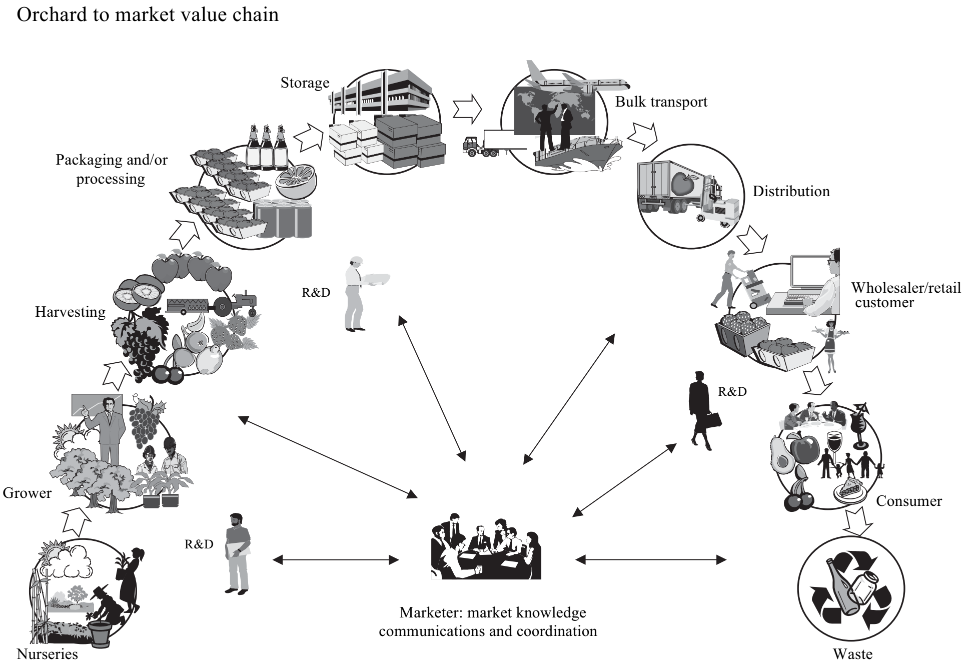
Consumer markets in the western world are changing rapidly. Supermarkets continue their relentless global march in opening new hypermarkets in South East Asia, Central America and China, having almost reached saturation in Europe and the USA. This growth, generally at the expense of small traders, will provide both opportunities and threats for small- to medium-sized farmers in many countries. Most multinational supermarket chains insist on a single set of product quality and safety standards that are the same as those in their home base country. Achieving these will be difficult if not impossible for small farmers who will need to make considerable infrastructural investment in items such as irrigation, greenhouses or protective plastic structures, trucks, cooling sheds, packhouses and packaging equipment. Small farmers must also meet tight delivery schedules and document farming practices to comply with EUREPGAP (European Retailers Produce Working Group for Good Agricultural Practice; this is a global partnership for safe and sustainable agriculture that includes retailers, producers/farmers and associated members from the input and service side of agriculture) or whatever is required by the supermarket (Fritschel, 2003). Medium- to large-scale farmers are likely to have better access to investment capital. They are more likely to be accustomed to meeting compliance requirements for larger customers. Nonetheless major changes occurring in food retailing will have far reaching implications for sustainability and profitability of small- to medium-sized farmers in many developing countries.

3 The supply chain

Success in any horticultural enterprise depends on the ability to satisfy the needs, aspirations and indulgences of consumers (whether they buy at the local wet market or at Harrods in London). Producers must keep the consumer in mind at all times. Also, they must provide high quality products that will make the consumer come back, repurchase and tell all their friends and family about the wonderful fruit, vegetables or flowers that they have bought.

Getting the produce to any market means involving different people and organisations who inevitably ‘add value’ as the produce passes through the chain. However, all of these people have a different view of what quality means to them. Still, it is critically important that producers are fully aware of all the steps in the supply chain at which quality could be compromised (Figure 1). Producers have to ensure that they deliver only the highest quality fruits and vegetables into the supply chain. Quality is only maintained by postharvest technologies, not improved. The implementation of modern supply chain management concepts (Bowersox *et al*., 2003; Collins, 2003) in the horticultural sector has the potential to increase efficiency of supply and distribution and marketing and brings about improved profitability to all chain participants (Hewett, 2003).

Figure 1 Example of components in a typical horticultural supply chain



Source: Kerr *et al*. (1998)

4 Genetic material

Growers have the choice of selecting preferred cultivars prior to planting crops. This choice may be limited by availability of planting material depending on the crop. They should keep in mind, however, the eating needs and desires of the ultimate customer. In some crops, a great deal of plant breeding has been done to provide a wide range of varieties with different quality attributes. This can be seen in the wide range of commercial fruit and vegetable varieties available to growers for planting. Shapes, sizes, colours, productivity levels, dry matter and taste attributes vary, as well as the ripening times and rates and postharvest longevity.

For example, tomatoes vary in size, shape, sugar content, acidity, dry matter, resistance to pests and diseases, susceptibility to handling damage and rate of postharvest ripening both on and off the vine. During the 1990s, so-called ‘long life’ tomato varieties became available. These varieties became better due to naturally occurring single gene mutation (known as the *rin*, or ripening inhibitor mutation based on ethylene response). A number of such single-gene ripening mutants of tomato that affect the ripening process, including *Nr* (never ripe), *rin* (ripening inhibitor) and *nor* (non ripening), have been studied. While commercial varieties derived from such material express very long shelf life, they are generally characterised by, or associated with, decreased fruit quality. There is real potential for combining these qualities and shelf life attributes using genetic engineering. Commercialisation, however, will have to wait until society is ready to accept such crops.

Environmental conditions (such as light intensity and duration, temperature, water availability, nutrition) modify fruit quality. Different varieties, however, respond relatively similarly to changes in these conditions. Providing optimum conditions for cropping, timing of harvest, storage conditions postharvest and marketing methods are also important in determining final product quality at the consumer level.

5 Site and microclimate

Plants are adapted to grow in many climates throughout the world. They can be classified according to the zones where maximum productivity is achieved. It is no coincidence that scientists tend to specialise research efforts on tropical, subtropical, warm temperate and/or cool temperate crops. Most crops have a temperature optimum in which they attain maximum yields and quality limited growth occurs. Only if these crops are planted outside fairly specific temperature and day length criteria. Tropical or subtropical crops suffer from chilling or freeze injury if grown in temperate climates. Also, temperate crops will not flower successfully and may sustain heat injury if grown in tropical zones.

Protected cultivation is often used as a means of ameliorating unfavourable growing conditions to produce crops that are generally destined for specific markets ‘off season’. This refers to the time when the same crops grown in open fields are not available. A diverse range of horticultural crops are grown under glass or plastic covers. These horticultural crops include tomatoes, capsicums, cucumbers, beans, several types of gourds, strawberries, lettuce, many types of flowers and, occasionally, fruit trees. In general, the physiology of all these crops is the same as that of similar crops grown outdoors – final quality is influenced by preharvest conditions, quality deterioration begins at harvest and is markedly influenced by postharvest temperature, relative humidity, ethylene and atmosphere. These crops are grown in a sheltered environment and not exposed to variable wind, rain and often temperature conditions. The produce is often more susceptible to physical damage in the handling chain than those grown in the open (Hewett, 2004).

6 Light, temperature and water

Taste and flavour of horticultural crops are influenced by the environment, agrichemicals, nutrition and management systems that can impact on flavour through effects on plant development (Mattheis and Fellman, 1999). Appropriate light (intensity and quality) and temperature do influence postharvest eating quality (Kays, 1999). Both are required for optimal plant productivity and harvest index (the edible dry weight – dry matter or DM – of the crop harvested as a proportion of the total dry weight of the plant). In perennial crops, light utilisation is a key determinant of productivity and quality (Snelgar *et al*., 1998; Tustin *et al*., 2001) as the leaf area exposed to sun during the day must be adequate to provide the carbon needed for both fruit and vegetative growth.

For some tree crops, there is a good understanding of the carbohydrate assimilation, distribution and accumulation within the plant (apples and grapes). However, for others (such as kiwifruit and apricots) there remain gaps in understanding of the factors that influence partitioning of carbon into the different plant parts. Seasonal variations do occur in dry matter accumulation. The best possible example of this is with wine grapes.

The best vintages (in terms of wine quality) are those where vine yields are relatively low. However, the radiation, temperature and possibly rainfall conditions during the growing season are such that maximal partitioning of sugars (and other components that contribute to the important quality attributes of wine) are accumulated in the fruit, instead of the shoots, prior to harvest. There is a real need to develop more robust physiological models of carbon assimilation, distribution and accumulation on different plant organs of commercially important crops. This should provide growers with management tools to minimise the proportion of low dry matter fruit that have the potential to provide a bad taste experience for consumers and generate a ‘no return purchase’ mentality that will lead to falling sales.

Tree form will influence the amount of light perceived and captured by fruit trees. Traditional horticultural technologies, using size controlling rootstocks and adaptive pruning and thinning techniques, are good examples of enabling technologies to optimise productivity (crop load) and quality of fruit. These technologies do so by influencing size and form of the tree and hence the volume occupied in an orchard. Conceptual advances in understanding the genetic plasticity of trees, or the extent to which the external or internal environment can influence tree architecture, should provide further insights in factors that control carbon assimilation and distribution within fruit trees (Seleznyova *et al*., 2003).

In general, growers adopt water management strategies to minimise moisture stress so as to allow optimal photosynthesis, plant growth and harvestable yield. Irrigation systems vary. However, they apply water on a regular basis (determined by evapotranspiration demand) well before serious stress conditions occur. However, maximum yields are not always a prerequisite for optimal quality. In some situations with some crops, careful manipulation of water supply may well decrease water usage and improve crop quality without compromising sustainable plant growth. Having very high yields can compromise wine quality. The best wine quality vintages come from those years where environmental conditions often impose stress on the vines (high temperatures, low rainfall). High crop loads can reduce dry matter in some fruit, such as kiwifruit, and thus may affect the taste and flavour as experienced by the consumer. The use of Regulated Deficit Irrigation (RDI) to minimise water applied without affecting plant performance, and sometimes increasing fruit quality, is a system that has been used successfully for a range of fruit crops (Behboudian and Mills, 1997).

7 Mineral nutrition

Optimum plant performance depends on a balanced and timely availability of mineral nutrients that may be limiting in many soils around the world. Inorganic mineral nutrients can influence the quality of horticultural crops in many ways but particularly in physiological fruit disorders (Ferguson and Boyd, 2002). Much effort has been expended to develop protocols for estimating critical threshold levels of both macro- and microelements for many crops. Management practices have been developed to apply appropriate fertilisers to the crop at times when benefits of yield or quality can be achieved. This may be done with soil or foliar applications, or through irrigation systems (trickle) in the field. It may also be done in Nutrient Film Techniques (NFT) in protected cultivation where very precise formulations can be added at particular stages in the crop phenology to obtain greatest benefits. For broad scale cropping, care has to be taken to avoid over application. Nitrate contamination of ground water supplies can create environment risks and may lead to introduction of government regulation of fertiliser use to minimise risks to public health (Hartz, 1997).

Some specific postharvest quality disorders of fruit and fruit vegetables result from nutritional imbalances (deficiency or excess) of certain minerals elements (Kays, 1999). Excess nitrogen may result in reduced firmness and enhanced susceptibility to postharvest decay. Of particular importance is calcium, a deficiency of which may induce a range of postharvest disorders in many fruits and vegetables (Shear, 1975). Some of these are bitter pit in apples and blossom end rot in tomatoes and capsicums (Table 1). One reason for the development of calcium deficiency symptoms in harvested products is because of the way that calcium is transported around the plant (in the xylem only and not the phloem) and the time at which it is available to be imported into fruit (only early in the development and not during maturation) (Ferguson, 1980; Ferguson and Watkins, 1989; Ferguson *et al*., 1999; Hewett, 1997). Calcium deficiency is normally overcome by spraying with calcium salts during fruit development or by postharvest calcium dip/drench treatments of the fruit (Hewett and Watkins, 1991).

Table 1 Physiological disorders related to calcium deficiency in some horticultural crops

Crop	*Disorder*
Apple	Bitter pit, cork spot, cracking, internal browning, Jonathan spot, lenticel blotch/breakdown, low temperature breakdown, senescent breakdown, water core
Avocado	End spot, malformation
Beans	Hypocotyl necrosis
Brussels sprouts	Internal browning
Cabbage	Internal tip burn
Carrots	Cavity spot, cracking
Celery	Blackheart
Cherries	Cracking
Lettuce	Tipburn
Mango	Softnose
Parsnip	Cavity spot
Pears	Cork spot, Alfalfa greening
Peppers	Blossom end rot
Strawberry	Tip burn
Tomatoes	Blossom end rot

Source: Shear (1975)

8 Maturity at harvest

Deciding when to harvest a crop is often one of the most difficult decisions that a grower has to make. Often, this decision is made by pickers who are not always familiar with crop development. Maturity at harvest has a very important influence on subsequent storage life and eating quality. Horticultural maturity is that stage of development at which a plant or plant part is ready for use by consumers for a particular purpose. This use can occur at any stage of development depending on the commodity (Watada *et al.*, 1984).

There are many different ways for determining maturity. Different maturity or harvest indices have been devised (see Reid, 2002 for examples). For these indices to be useful, they must objective, easy to use and interpret, be unambiguous and have generality so that data obtained can be compared between farms, regions and years. Also, they should measure what is important. The kiwifruit industry in New Zealand has used 6.2% soluble solids as a minimum harvest index for many years. However, to obtain optimal flavour when the fruit is eaten ripe, cognisance needs to be taken of the dry matter in the fruit. If the dry matter (DM) is less than 14.5% at harvest, then it is unlikely that the fruit soluble solids at eating will exceed 12.5%, which is the minimum threshold for consumer acceptability (Crisosto and Crisosto, 2001). Fruit acid content at eating ripe can influence perception of taste and flavour and thus acceptability.

Unfortunately, DM is not a good harvest index as there is no change in the rate of carbon accumulation (in contrast with soluble solids at about 6.2% when starch commences its conversion to soluble sugars) that can be used by growers to indicate a critical minimum stage of development resulting in fruit of an acceptable eating quality. This apparent relationship between DM and eventual eating quality probably occurs with many fruits as does the interaction with acid concentration. Thus, it is likely that a combination of components need to be utilised to decide the optimum time of harvest to allow long storage and shelf life while maintaining excellent eating quality.

9 Growth regulators

There are numerous examples of growth regulators being used commercially to influence some quality attribute of a product. However, with few exceptions, these growth regulators are not used in a widespread manner, often because the concentration range between obtaining sub-optimal and super-optimal effects is quite narrow. Some compounds such as Naphthalene Acetic Acid (NAA) are used for thinning blossoms in apples or applied as a gel to prevent regrowth from pruning stubs. Others such as gibberellic acid are used to increase fruit size in grapes and to maintain rind integrity in citrus. Ethephon (Ethrel) is used as a preharvest spray to induce ripening in some crops such as tomato to get uniform maturity at harvest.

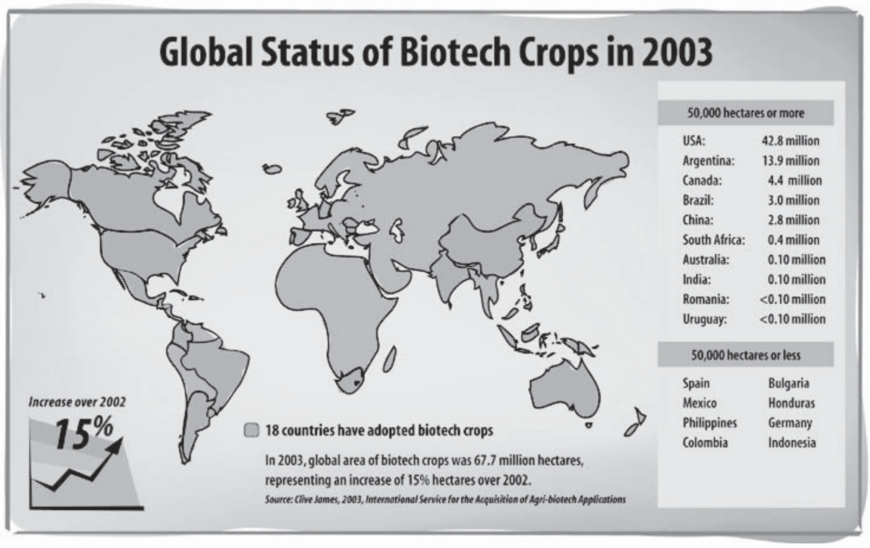
ReTain™ is a plant growth regulator that inhibits the endogenous synthesis of the naturally occurring ripening gas, ethylene, providing a useful harvest management tool for apple and pear growers. It is sprayed onto trees about four weeks before normal harvest and reduces preharvest fruit drop. It delays fruit maturation and ripening, allowing enhancement in fruit colour and size. Also, it maintains firmness during postharvest storage.

Interest is being expressed in the potential of developing a process for applying the ethylene inhibitor 'SmartFresh®' as a preharvest treatment to manipulate postharvest quality. 'SmartFresh®', the commercial formulation of 1-methylcyclo propene (MCP), is a remarkably effective inhibitor of ethylene action. It is approved for use on an increasingly wide range of crops (Watkins and Miller, 2003; 2005). Currently, MCP can only be applied in a gaseous form postharvest. However, there could be significant advantages for growers to apply 1-MCP, or its analogues, as a spray prior to harvest in order to manipulate fruit ripening and subsequent postharvest quality decline.

10 Genetic modification of plants

Modern science has the ability to dramatically change the performance and quality of food crops through utilisation of genetic technology. Despite the widespread use of transgenic crop plants (Figure 2), only four horticultural transgenic crops are available in the USA. These are papaya from Hawaii, sweet corn, squash and a carnation (Clark *et al*., 2004). This lack of adoption of transgenic plants is not due to lack of potential products, but rather to lack of acceptance by consumers in many countries.

Figure 2 Global status of plantings of transgenic crops 2003



Source: James (2004)

Possible traits that can be introduced into horticultural crops include the following: increased resistance to pests and diseases which may be forced as the number of 'approved' chemicals for their control diminish (the Hawaiian papaya industry now exports transgenic fruit resistant to the devastating papaya ringspot virus); improved productivity and quality traits such as modified metabolism and ripening in apples; increased content of vitamins, nutrients or nutraceuticals; manipulation of ethylene biosynthesis and sensitivity to slow down ripening and senescence both pre- and postharvest. The potential for improving both the productivity and quality of major fruit, vegetable and flower crops is great. However, increased plantings will not occur until the market is ready to accept and promote such products that must have compelling benefits for growers, marketers and consumers (Clark *et al*., 2004).

11 Conclusion

In today's world, consumers are becoming more discerning in their purchasing behaviour. Supermarkets have a major impact on producers in many countries as they extend their global reach and impose food safety and quality standards on the produce they purchase. If growers wish to take advantage of the market opportunities created by these global initiatives, then they need to confront the challenge of consistently providing high quality products that comply with supermarket requirements as well as meet the taste and flavour expectations of the consumers. Having many satisfied consumers returning to repurchase tasty and nutritious fruits and vegetables will ensure marketing success and profitability for all members in the supply chain, from paddock to plate. To achieve success, it is important to understand the nature of the supply chain and to implement supply chain management systems. These systems must ensure that movement of the product from the farm to consumer is done efficiently, economically and without loss of quality. However product quality is determined in the field. Postharvest technologies can only maintain quality, not improve it. Thus, it is critically important that producers understand how a multitude of preharvest factors can interact to influence quality during and after harvest.

Management tools exist for growers to minimise the effects of extreme environmental events and to manipulate timing of harvest (protected cultivation). A number of enabling technologies are available for optimising product quality through manipulation of nutrition, water and light (plant architecture) to minimise postharvest disorders and quality deterioration as well as to optimise carbon assimilation, distribution and accumulation in harvested organs. Achieving high dry matter within many harvested products seems to be a prerequisite to enhanced sugar and flavour components, especially in perennial tree crops. This is important in satisfying consumer expectations and indulgences and, more importantly, in increasing demand through repurchasing. Genetic engineering has the potential to improve quality in a number of different ways in many crops. However, this potential will only be realised commercially when society as a whole is convinced that the benefits associated with this technology far outweigh the risks.

References

Behboudian, M.H. and Mills, T.M. (1997) 'Deficit irrigation in deciduous orchards', *Horticultural Reviews*, Vol. 21, pp.105–131.

Bowersox, D.J., Closs, D.J. and Cooper, M.B. (2003) *Supply Chain Logistics Management*, New York: McGraw Hill Higher Education.

Clark, D., Klee, H. and Dandekar, A. (2004) 'Despite benefits, commercialization of transgenic horticultural crops lags', *Californian Agriculture*, Vol. 58, No. 2, pp.89–98.

Collins, R. (2003) 'Supply chains in new and emerging fruit industries: the management of quality as a strategic tool', *Acta Horticulturae*, Vol. 604, pp.75–84.

Crisosto, C.H. and Crisosto, G.M. (2001) 'Understanding consumer acceptance of early harvested "Hayward" kiwifruit', *Postharvest Biology and Technology*, Vol. 22, pp.205–213.

Ferguson, I.B. (1980) 'Movement of mineral nutrients into the developing fruit of the kiwifruit *Actinidia chinensis* Planch', *New Zealand Journal of Agricultural Research*, Vol. 23, pp.349–353.

Ferguson, I.B. and Boyd, L.M. (2002) 'Inorganic nutrients and fruit quality', in M. Knee (Ed.) *Fruit Quality and its Biological Basis*, England: Sheffield Academic Press, pp.15–45.

Ferguson, I.B. and Watkins, C.B. (1989) 'Bitter pit in apple fruit' *Horticultural Reviews*, Vol. 11, pp.289–355.

Ferguson, I., Volz, R. and Woolf, A. (1999) 'Preharvest factors affecting physiological disorders of fruit', *Postharvest Biology and Technology*, Vol. 15, pp.255–262.

Fritschel, H. (2003) 'Will supermarkets be super for small farmers?', *IFPRI Forum*, International Food Policy Research Institute, December 2003, pp.1, 11–12, www.ifpri.org/pub/newsletters/ifpriforum/if4.

Hartz, T.K. (1997) 'Efficient fertilizer management in vegetable production', in L.D. Currie and P. Loganathan (Eds.) *Proceedings of Workshop Nutritional Requirements of Horticultural Crops*, Massey University Fertiliser and Lime Research Centre, Occasional Report No. 10, pp.5–16.

Hewett, E.W. (1997) 'Fruit quality and tree nutrition', in L.D. Currie and P. Loganathan (Eds.) *Proceedings of Workshop Nutritional Requirements of Horticultural Crops*, Massey University Fertiliser and Lime Research Centre, Occasional Report No. 10, pp.159–171.

Hewett, E.W. (2003) 'Perceptions of supply chain management for perishable horticultural crops: an introduction', *Acta Horticulturae*, Vol. 604, pp.37–46.

Hewett, E.W. (2004) 'Postharvest challenges for crops grown under protected cultivation', *Proceedings of ISHS International Symposium on Greenhouse Environmental Controls and In-house Mechanization for Crop Production in the Tropics and Sub-Tropics*, Malaysia, 15–17 June 2004.

Hewett, E.W. and Watkins, C.B. (1991) 'Bitter pit control by sprays and vacuum infiltration of calcium in Cox's Orange Pippin apples', *HortScience*, Vol. 26, pp.284–286.

James, C. (2004) *Global Status of Commercialised Transgenic Crops*, http://www.isaaa.org/.

Jongen, W.M.F. (2000) 'Food supply chains: from productivity toward quality', in R.L. Shewfelt and B. Brückner (Eds.) *Fruit and Vegetable Quality: An Integrated View*, Lancaster, USA: Technomic Publishing Co. Inc., pp.3–20.

Kays, S.J. (1999) 'Preharvest factors affecting quality', *Postharvest Biology and Technology*, Vol. 15, pp.233–247.

Kerr, J.P., Stoke, M.J. and Aitken, A.G. (1998) 'The New Zealand Fruit Industry – an investment in the future', *Confidential Report by the Martech Consulting Group to The New Zealand Fruitgrowers Federation*, p.45.

Mattheis, J.P. and Fellman, J.K. (1999) 'Preharvest factors influencing flavor of fresh fruit and vegetables', *Postharvest Biology and Technology*, Vol. 15, pp.227–232.

Reid, M.S. (2002) 'Maturation and maturity indices', in A.A. Kader (Ed.) *Postharvest Technology of Horticultural Crops*, University of California, Davis Agricultural and Natural Resources Publication 3311, pp.55–62.

Seleznyova, A.N., Thorp, T.G., White, M., Tustin, S. and Costes, E. (2003) 'Application of architectural analysis and AMAPmod methodology to study dwarfing phenomenon: the branch structure of "Royal Gala" apple grafted on dwarfing and non-dwarfing rootstock/interstock combinations', *Annals of Botany*, Vol. 91, pp.665–672.

Shear, C.B. (1975) 'Calcium-related disorders of fruits and vegetables', *HortScience*, Vol. 10, pp.361–365.

Shewfelt, R.L. (1999) 'What is quality?', *Postharvest Biology and Technology*, Vol. 15, pp.197–200.

Shewfelt, R.L. and Henderson, J.D. (2003) 'The future of quality', *Acta Horticulturae*, Vol. 604, pp.49–59.

Snelgar, W.P., Hopkirk, G., Seelye, R.J., Martin, P.J. and Manson, P. (1998) 'Relationship between canopy density and fruit quality in kiwifruit', *New Zealand Journal of Crop and Horticultural Science*, Vol. 26, pp.223–232.

Tustin, D.S., Cashmore, W.M. and Bensley, R.B. (2001) 'Pomological and physiological characteristics of Slender Pyramid centre leader apple (*Malus domestica*) planting systems grown on intermediate vigour, semi-dwarfing and dwarfing rootstocks', *New Zealand Journal of Crop and Horticultural Science*, Vol. 29, pp.195–208.

Watada, A.E., Herner, R.C. and Kader, A.A. (1984) 'Terminology for the description of developmental stages for horticultural crops', *HortScience*, Vol. 19, pp.20–21.

Watkins, C.B. and Miller, W.B. (2003) 'Implications of 1-methylcyclopropene registration for use on horticultural products', in M. Vendrell, H. Klee, J.C. Peche and F. Romojaro (Eds.) *Biology and Biotechnology of the Plant Hormone Ethylene III*, Amsterdam: IOS Press, pp.385–390.

Watkins, C.B. and Miller, W.B. (2005) *A Summary of Physiological Processes or Disorders in Fruits, Vegetables and Ornamental Products that are Delayed or Decreased, Increased, or Unaffected by Application of 1-methylcyclopropene (1-MCP)*, http://www.hort.cornell.edu/department/faculty/watkins/ethylene/.