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Opportunities and challenges faced with emerging technologies in the Australian vegetable industry.

(Technology Platform 3: Emerging Technologies for Quality & Safety)

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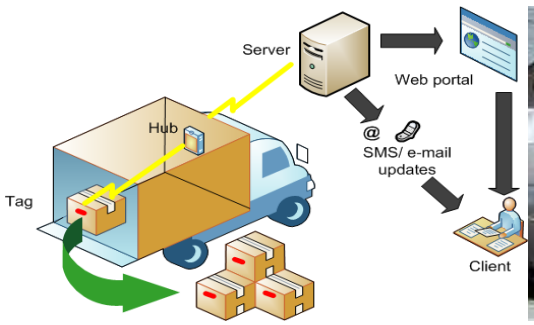

Opportunities and challenges faced with emerging technologies in the Australian vegetable industry.

(Technology Platform 3: Emerging Technologies for Quality & Safety)

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Purpose of Project:

This report was prepared as an outcome of Milestone 104 of project VG08087,"Opportunities and challenges faced with emerging technologies in the Australian vegetable industry". The project aims to provide a broad review of technologies that are influencing the competitiveness of the industry. This is the third of five reports to be developed during 2009-2010 and reviews emerging technologies for managing / improving vegetable quality & safety.

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Disclaimers:

Know-how for Horticulture™

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Media summary

The objective of the project "Opportunities and challenges faced with emerging technologies in the Australian vegetable industry" is to provide a broad review of technologies that are influencing the competitiveness of the Australian vegetable industry.

This report is the third of five analyses to be developed in 2009-2010 and reviews emerging technologies for product quality and safety.

Some key findings of this analysis were:

- An estimate of the economic loss due to spoilage was developed, assuming that the rates of annual waste in the Australian vegetable supply chain range from 2 to 23% (as per information published by Kader, 2005). The vegetable industry loses half a billion dollars per year in product wasted throughout the chain, which represent about 15% of the yearly national gross value from vegetable production[1]. Therefore, R&D investments to improve quality could definitely contribute to the profitability of the industry.
- This report investigated sixteen emerging technologies to evaluate quality, including computer imaging, multispectral and hyperspectral imaging, acoustic impulse response, electronic nose and biosensors. Only computer imaging can be classified as a mature technology. The rest of the technologies investigated are still in development and even in experimental phases, with few of those adapted to be used in commercial grading lines.
- Similarly, fourteen emerging technologies to extend the quality of fresh vegetables were reviewed. Functional genomics, electrolysed water, cold plasma, 1-MCP and modified atmosphere (MA) technologies were included. Only chlorine dioxide and MA can be classified as mature technologies.

Potential strategies to address innovation in quality and safety technologies include:

- Fresh produce supply chains can enter a virtuous cycle of innovation when the positive effects of consumers satisfied with product quality are fed right back through the chain, encouraging all participants to support innovations that will deliver superior product (Banks et al., 2009).
- Centralization of funding in a postharvest vegetable quality platform. This approach would allow larger, more powerful projects than smaller scale projects, which is the current approach followed at HAL in many areas.
- Centralization of data on product wastage due to quality issues. The analysis of data could help in directing R&D investments to specific links that contribute more than others in supply chain quality losses. Further, R&D programs targeting technologies and methods that reduce these losses could be established with a sound cost-benefit case.

[1] Gross value is the value placed on recorded production at the wholesale prices realised in the market place. Market place is the metropolitan market in each state. In cases where commodities are consumed locally, or where they become raw material for a secondary industry, these points are presumed to be the market place.

Executive summary

The objective of the project "Opportunities and challenges faced with emerging technologies in the Australian vegetable industry" is to provide a broad review of technologies that are influencing the competitiveness of the Australian vegetable industry.

This report is the third of five analyses to be developed in 2009-2010 and reviews emerging technologies for quality and safety evaluation and quality extension.

Quality and safety

Quality is defined as the combination of desirable sensory, nutritional and microbiological attributes existent in a wholesome, attractive and safe horticultural product. A holistic concept of quality should include the concept of safety. In some cases, pathogens can be present even when the packaged contents do not present obvious signs of spoilage. Therefore, although the product may appear as wholesome and attractive, it is a low quality (and dangerous) product. For example modified atmosphere packaging of fresh cuts is able to support growth of *Listeria monocytogenes* under certain conditions.

Recently, a study investigated the risk rating of fresh fruit and vegetables in Australia, based on characteristics such as the number of outbreaks and recalls registered and the ranking of organisations such as DAFF FAO/WHO. The top high-risk products are (in descending order): sprouts, lettuce, unpasteurized orange juice, melons and mushrooms. This table could be helpful in setting R&D priorities for research on the development of methods to assess food safety in fresh fruit and vegetables.

The business case for quality evaluation and extension

The economic impacts of quality losses include: loss of potential sales and disposal costs arising from product spoilage; costly product recalls if the product safety has been compromised; and indirect costs associated to quality losses, such as environmental impacts (i.e. food waste) and community health (e.g. foodborne illnesses, lack of nutritional value in low quality products).

An estimate of the economic loss due to spoilage assuming that the rates of annual waste in the Australian vegetable supply chain range from 2 to 23% (Kader, 2005) was developed. An estimated annual average waste of 11% means that the vegetable industry loses half a billion dollars per year in product wasted through the chain. These losses represent about 15% of the yearly national gross value from vegetable production[2]. Therefore, R&D investments to improve quality could definitely contribute to the profitability of the industry.

Quality evaluation and extension technologies

Modern commercial methods to measure quality go back to the 70s, when FMC Corporation (USA) patented an electronic system to sort fruit according to colour. According to our

[2] Gross value is the value placed on recorded production at the wholesale prices realised in the market place. Market place is the metropolitan market in each state. In cases where commodities are consumed locally, or where they become raw material for a secondary industry, these points are presumed to be the market place.

analysis, R&D maturity in quality evaluation technologies was reached in 1999 and the peak number of patents is expected to occur in 2017.

One aspect of particular interest is the time gap between the discovery of a principle for quality evaluation and its commercialisation. For example, a 10-year gap between the publication of the first paper on artificial olfaction (Dodd and Persaud, 1982) and the commercial development of electronic nose technology in the early 1990s was detected in this report.

This report investigated sixteen emerging technologies to evaluate external and internal appearance, aroma, flavour, firmness, food safety and shelf-life. Some technologies included were computer imaging, multispectral and hyperspectral imaging, acoustic impulse response, electronic nose and biosensors. Only computer imaging can be classified as a mature technology. The rest of the technologies investigated are still in development and even in experimental phases, with few of those adapted to be used in commercial grading lines.

Similarly, fourteen emerging technologies to extend the quality of fresh vegetables were reviewed. Functional genomics, electrolysed water, cold plasma, 1-MCP and modified atmosphere (MA) technologies were included. Chlorine dioxide and MA can be classified as mature. The other technologies are still in developmental or experimental phases.

HAL projects on quality evaluation and extension

To detect the major focus of investment in HAL projects, a list of the titles of all vegetable funded projects in quality evaluation and extension was analysed to extract the frequency distribution of keywords within the title. This search led to a sub-sample of 151 projects funded between 1998 and 2009. An analysis of the technology growth curve indicates that the peak number of HAL projects in these areas is expected to occur in 2010, if no factors influence current investment policies and strategies in this platform. The number of projects in this area is lower than the technologies reviewed in other platforms (i.e. supply chain and environmental technologies).

This trend is of concern, given that the Australian Horticulture Plan "Future Focus" highlighted the importance of quality programs as key factors to achieve potential cumulative payoffs representing $1.48 billion by 2020 (Horticulture Australia Limited, 2008). This is unlikely to be achieved if the investment of HAL, as represented by the completed number of projects, peaks in 2010 and then declines.

Challenges and obstacles for the uptake of innovation

Some significant obstacles to develop quality and safety R&D and innovation include:

- Data on quality-related wastage throughout the chain is often not available or goes unmeasured by supply chain participants. Following the principle of "What you can measure you can manage", measurement of quality & safety parameters and the factors that are detrimental to both should be measured. The information should be made available to HAL and the data should be analysed to develop objective performance indicators to evaluate the impact of quality programs and innovations.

- Some growers may be concerned about strengthening the quality evaluation of products if that means that more products will be rejected in the grading line. This thinking undermines the introduction of innovative systems that produce better tasting and longer lasting produce, because quality goes unmeasured.
- A recent hurdle that has affected the uptake of new and mature technologies in postharvest quality evaluation and extension is the reduction of R&D funding dedicated to address production and marketing of horticultural products. CSIRO, DPI and universities carried out research on innovative technologies such as acoustic and impulse measurements for firmness, packaging films for fresh horticultural produce, mathematical modelling, modified atmosphere storage, HarvestWatch and 1-MCP, among other technologies. Now CSIRO and DPI have decreased its research on postharvest and little funding is dedicated to postharvest quality.

Potential strategies for HAL R&D in quality evaluation

- The application of the "virtuous circle" concept. Fresh produce supply chains can enter a virtuous cycle of innovation when the positive effects of consumers satisfied with product quality are fed right back through the chain, encouraging all participants to support innovations 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 et al., 2009).
- Centralization of funding in a postharvest vegetable quality platform. This approach would allow larger, more powerful projects than smaller scale projects, which is the current approach followed at HAL in many areas. Centralised funding would also decrease the frequency of overlapping projects, while the likelihood of achieving critical mass increases.
- Centralization of data on product wastage due to quality issues. The analysis of data could help in directing R&D investments to specific links that contribute more than others in supply chain quality losses. Further, R&D programs targeting technologies and methods that reduce these losses could be established with a sound cost-benefit case.
- HAL and vegetable grower organisation can support universities in reversing the loss of students in postharvest areas, which are the lifeblood of innovation. Support can be provided through meetings and forums that address the challenges for postharvest education in Australia. Further, a study that analyses the opportunities and issues for postharvest education and compiles aspects such as the education programs in postharvest quality existent in Australia and overseas, the R&D programs undertaken in these institutions and the potential synergies among R&D providers, would be helpful. Such analyses can be used to design strategies to overcome the current loss of human resources in education and research.

Project Background

The vegetable industry is a truly multi-disciplinary business, particularly in the context of modern global supply chains. The industry draws knowledge from a variety of fields such as plant breeding and production, greenhouse technologies, irrigation, climate control, information technologies, product processing, packaging, logistics and consumer science, among others. Therefore, the growth of the vegetable sector is intertwined with the development and application of innovative solutions. The use of molecular biology to produce new enhanced (but still non-genetically modified organisms) cultivars, the introduction of pre-packed fresh vegetables and the development of track-and-trace systems that can improve transparency in food supply chains are examples of how emerging technologies can influence the Australian vegetable industry.

The project "Opportunities and challenges faced with emerging technologies in the Australian vegetable industry" provides a broad review of current and emerging technologies that are influencing the competitiveness of the Australian vegetable industry. This review, carried out through the use of competitive intelligence (CI) analyses, provides a technology roadmap that shows: (a) where the Australian vegetable industry lies in the use of technology that benefits the competitiveness of the sector; and (b) what specific technological trends can affect the industry's competitiveness in the years ahead.

The application of CI techniques in this report was based on a two-staged approach:

I) An analysis of the technological state-of-the-art in the Australian vegetable sector, *i.e.* what technologies are been applied commercially (as distinct from pilot trials) during the production, harvesting, processing and distribution of vegetables in Australia. This analysis includes hurdles faced by 'first-movers' in the implementation of new technologies and the benefits reaped from the uptake of new technologies.

II) An analysis of emerging and potentially disruptive technologies with potential impact on the vegetables industry. The analysis included potential impediments for commercial implementation in Australia and potential benefits arising from the uptake of such technologies.

This project delivers competitive intelligence analyses in five key technological platforms relevant to horticultural industries:

(1) Supply chain and logistics systems.
(2) Technology for mitigation and adaption to environmental changes.
(3) Technology for food safety and quality assurance.
(4) Value addition processes (*e.g.* functional genomics, novel manufacturing processes).
(5) Technology for production and harvesting (including glasshouse production, robotics, mechanization and precision agriculture).

The present report specifically delivers to the third technical platform: technologies for extension and evaluation of quality and safety in vegetables.

Introduction and Definitions

Product quality is a highly elusive concept that depends on factors such as the type of product and its physiology, the preference of the buyer (e.g. retailer, consumer, manufacturer) and the market characteristics of each country (Tijskens, 1996).

In this report, ***quality*** is used to describe the combination of desirable sensory, nutritional and microbiological attributes existent in a wholesome, attractive and safe horticultural product. For consumers, quality is a multi-faceted concept, where social trends, quality attributes and quality cues represent their perception of "quality". While quality cues such as appearance, colour, shape, size or structure are easy to define and measure, extrinsic cues such as attitudes to price, brand, nutritional information, production information, country of origin are more difficult to measure. 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 of quality attributes can only be formed from experiences, information or judgment done by others (Wismer, 2009).

In this report, we include the concept of food safety as part of the 'quality' concept. This is relevant because in some cases, pathogens can be present even when the packaged contents do not present obvious signs of spoilage (IFT, 2001). Therefore, although the product may appear as wholesome and attractive, it is a low quality (and dangerous) product. For example modified atmosphere packaging of fresh cuts is able to support growth of *Listeria monocytogenes* under certain conditions (Carlin and Nguyen-The, 1993, Scifo et al., 2008).

Quality assurance (QA) comprises all planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality. Therefore, QA is a system whose function is to ensure that the overall QC job is being done effectively (Kader, 2001, Opara, 2009). In the past, QA was viewed as a reactive system dedicated to the measurement of quality and the application of post-manufacturing (or postharvest) sampling and rejection procedures. Modern QA systems focus on the maintenance of quality standards and the detection of issues that may contribute to quality losses through proactive actions. These actions include the selection of adequate genotypes, scheduling of time to harvest, in-field quality assessments, training, monitoring and controlling critical parameters such as temperatures and times throughout the chain and ensuring that food safety measures and records are being implemented.

While preharvest quality depends on the selection of cultivar, nutrition and handling of the crop (Figure 1), postharvest quality (Figure 2) is better understood as a dynamic parameter that inexorably decreases with time (Hertog, 2004). It could be argued that some postharvest processes such as ripening improve the eating characteristics of bananas or avocado. However, ripening also triggers a decrease in the product's shelf-life.

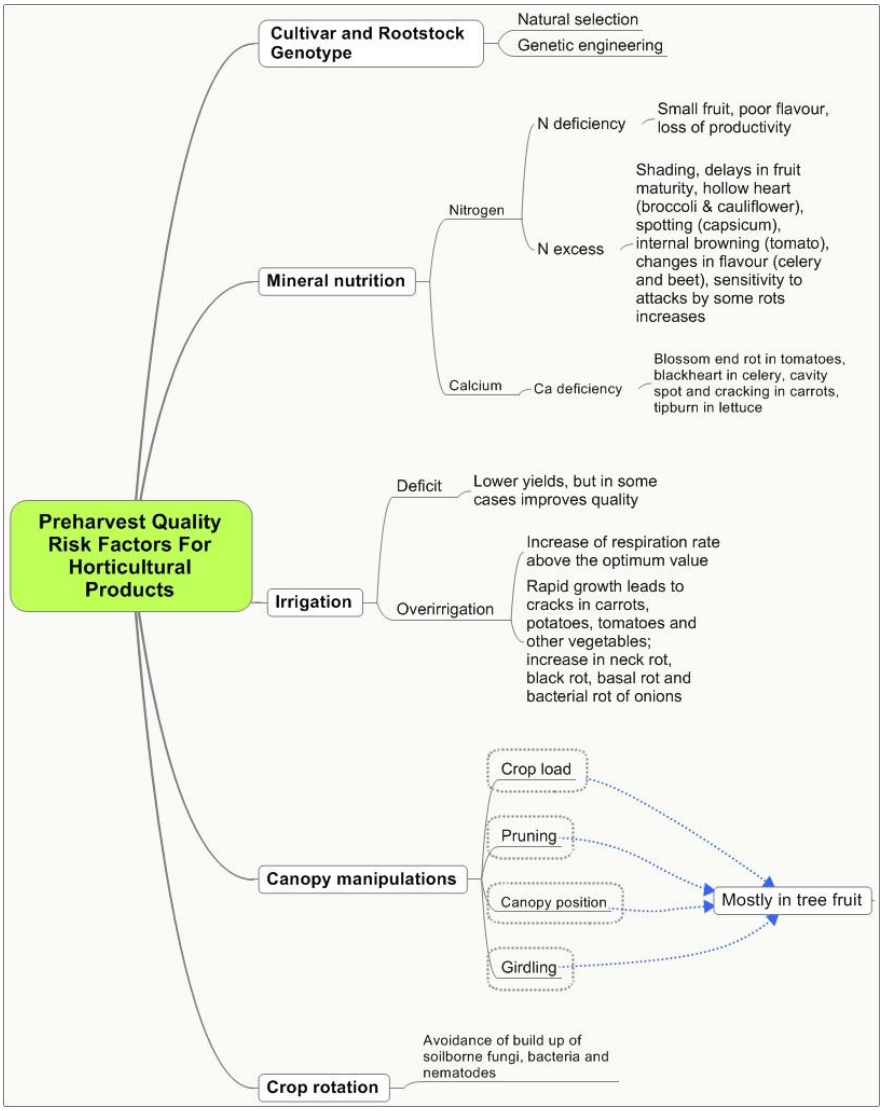

Figure 1. Factors that affect the quality of horticultural goods preharvest. Adapted from: (Crisosto and Mitchell, 2002).

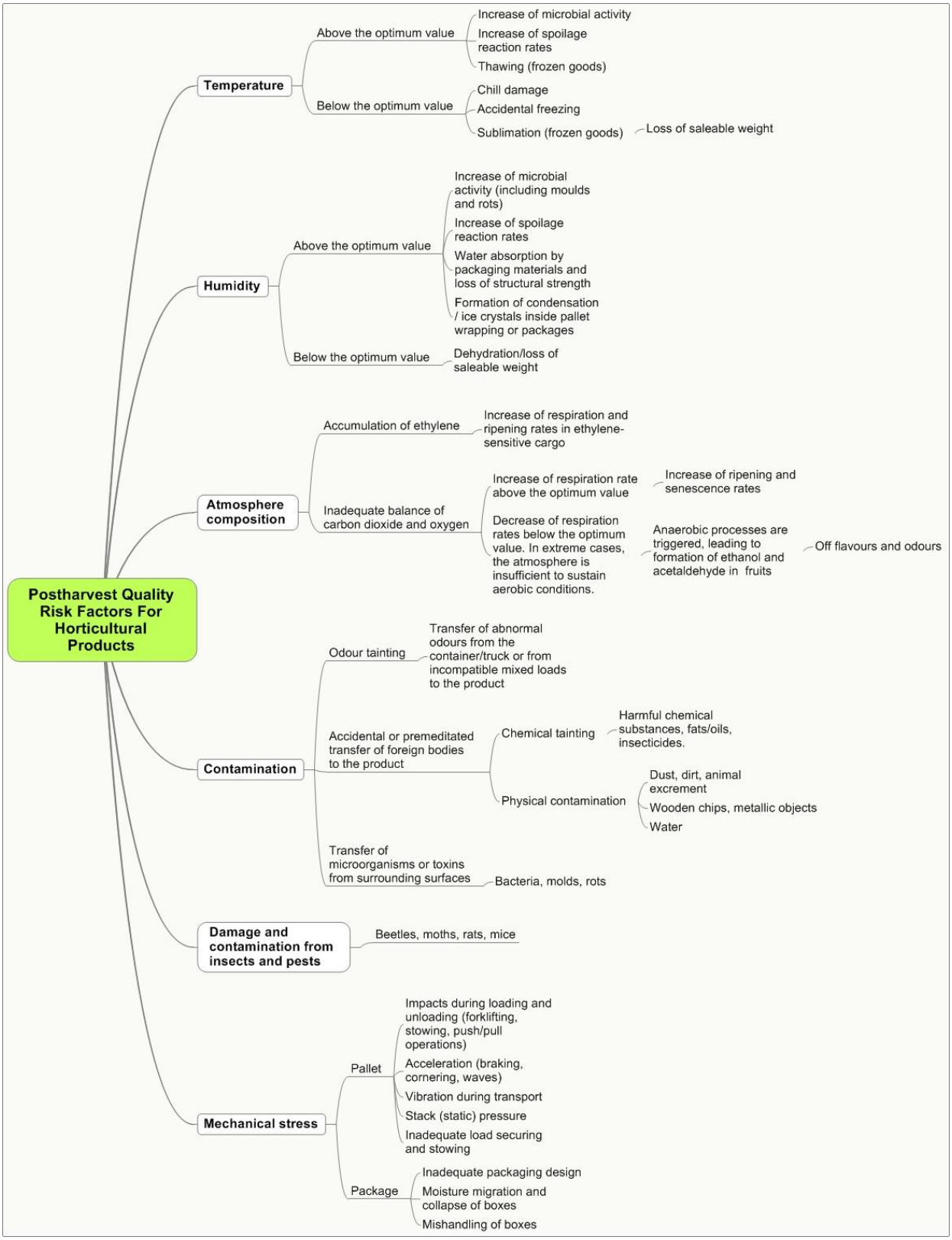

Figure 2. Factors that affect the quality of horticultural goods during postharvest. Adapted from: (Wild et al., 2008).

Critical factors for keeping quality

Spoilage can be regarded as the series of mechanisms that trigger quality loss. In horticultural products, spoilage is caused by a combination of physiological/biochemical and microbial activities that occur in pre-harvest and postharvest, as illustrated in Figures 1 and 2.

From a biochemical point of view, temperatures above the optimum value for any given product induce an acceleration of metabolic and physical processes, leading to colour changes, dehydration, and conversion of starches to sugars, breakdown of proteins and cell wall components and changes in aroma compounds, between many other effects. Likewise, temperatures below the optimum level can lead to rapid deterioration, particularly in fruits and vegetables that are susceptible to chilling damage.

From a microbiological point of view, the rate of growth of spoilage microorganisms depends on the history of the product before arriving to the consumer (e.g. type of product, processing, transport and storage, packaging) and the domestic storage conditions. The sum of these actions are reflected in the appearance, texture, flavour, aroma, colour and nutritional value of food, just before its consumption (Paull, 1999) .

From the above, it follows that the enhancement of shelf-life can be achieved by minimising the growth of spoilage microorganisms and by controlling the factors that contribute to biochemical changes in foods.

The factors that are traditionally addressed in horticultural supply chains to maintain quality are:

(a) *Temperature.* Low temperature slows down the growth of microorganisms, but does not eliminate bacteria. It is widely recognised that optimum temperatures for chilled products are below 4.4 °C, but some horticultural products such as lettuce may require temperatures close to 1 °C. The limiting factor of temperature reduction, particularly in tropical and subtropical fruits, is the physiological disorder known as "chilling injury". The causes of this disorder are not totally clear, but a strong theory is that it is caused by changes in membrane lipids and structural changes in enzymes and other proteins. For products that are not susceptible to chilling injury, the lower temperature limit is of -2 to 0 °C, before freezing of plan tissue appears. Ice crystal formation may lead to cellular dehydration and structural damage.

FRUITS AND VEGETABLES: The respiration rate is directly related to the shelf life of fresh produce. Research suggests that for every 10 °C increase above the optimum temperature, the respiration rate is doubled or even trebled and shelf-life decreases in about the same proportion. In strawberries, a 10 °C increase can lead to a 4-fold increase in the respiration rate.

(b) Time before consumption ('use-by' dates): Providing a means of knowing how long the product has been maintained circulating in a supply chain is part of a good traceability system. For example, packaged fresh-cuts have a unique

product code that contains information such as the manufacturing plant code, the date of production, the shift, the packaging line and a "Best if Used By" (BIUB) date. Arguably, the most important rule in industrial storage is "first in, first out" and significant management tools are put in place to ensure that this rule is followed. Approaches such as time-temperature indicators have been implemented are useful for links in the chain where temperature control is difficult to implement (e.g. loading and unloading, transport, retail). Some examples of time-temperature indicators include biosensors (which base their response on the behaviour of a biological material, such as enzymes), electronic sensors (which based their response on an electric signal) and electromagnetic sensors (which use x-rays or high frequency waves as a response), among others. Networking technologies (e.g. RFID enabled chains) have also been applied to solve the uncertainties of the links mentioned above.

(c) *Humidity.* Humidity control during storage is important with respect to the management of moisture loss and microbial spoilage. Dehydration of non-packaged fruit and vegetables during refrigerated storage will lead to a loss of weight and possibly wilting or shrivelling and loss of texture (Ben-Yehoshua, 1987). Dehydration (or evaporation) occurs when the vapour pressure of water at the surface of the product is greater than the partial pressure of water in the ambient air. If a high relative humidity is used during storage (e.g. more than 99.5%), the vapour pressure at the evaporating surface and the partial pressure of water in the air will be close or at equilibrium and no moisture loss from the product would occur. However, reaching these humidity levels during storage may be counterproductive if condensation occurs, increasing the risks of microbial spoilage. The effect of temperature and relative humidity (RH) is intertwined: for example, a storage using a 95% RH and a temperature set-point of 0 ^{o}C with just a ±0.5 ^{o}C oscillation around the set-point can result in condensation in the surface of products or other surfaces that have reached the dewpoint temperature. Larger temperature oscillations lead to higher probabilities of condensation.

(d) *Airflow composition, distribution and air velocity.* Airflow plays the following relevant roles in the storage of refrigerated products:

- As a means to achieve rapid cooling/freezing of products.
- Alongside temperature and relative humidity, as a factor determining the rate of humidity loss in unwrapped products.
- As a means of transport for gases existent inside the refrigerator (e.g. ethylene produced by certain fruits, oxygen, carbon dioxide, odours, moisture).

To date, no comprehensive studies that provide air velocity guidelines to minimise moisture loss from products under refrigerated storage conditions have been published.

Notwithstanding the importance of temperature, time, humidity and airflow, emerging technologies for extension are evolving in other areas, such as:

(a) Cleaning/sanitation.
(b) Physical removal (e.g. selection, washing, trimming).
(c) High temperature treatments.
(d) Reduction of water activity.
(e) Application of organic acids (low pH).
(f) Modified atmospheres.
(g) Use of antimicrobial substances.
(h) Novel process-related technologies:

- → radio-frequency/microwave processing
- → pulsed electric fields
- → pulsed light technology (including UV radiation)
- → ultrasound
- → pulsed x-rays
- → irradiation
- → hurdle technologies
- → ohmic and inductive heating
- → high-pressure technology
- → oscillating magnetic fields
- → high voltage arch discharge
- → electron beam (also known as negative ions)

Food safety as a quality factor

Food spoilage is not a food safety risk itself. In fact, food spoilage can be a useful indicator for the consumer, signalling when a product has undergone conditions that allow the growth of bacteria (potentially pathogenic). Nevertheless, some treatments can eliminate spoilage microorganisms and promote the growth of pathogens. For example, spoilage bacteria that would normally grow in produce under standard storage conditions will slow its reproduction in MAP conditions. The decrease in oxygen concentration and the increase in carbon dioxide concentration will favour microbes that can grow in a low oxygen environment (e.g. lactic acid bacteria, yeasts). In a microenvironment where oxygen is completely lacking, anaerobic populations will prevail (Sela et al., 2009). Some harmful microbes, such as *Clostridium botulinum* could grow under these conditions. The case of *Listeria monocytogenes* was discussed previously.

Outbreaks and cases of diseases associated to the consumption of fresh fruit and vegetables and unpasteurized juices have been documented with increasing frequency in many countries in recent years (Beuchat, 2006). In a survey conducted in the USA, fresh produce accounted for the largest proportion (45%) of the foodborne illnesses cases[3] registered from 1998 to 2006 (including sprouts) (Zagory, 2008). In terms of outbreaks, fresh produce was the third vector, behind eggs (48%) and seafood (25%). In England and Wales, 4% of all

[3] A case defines a person, time and place of illness. An outbreak is an occurrence encompassing two or more cases linked by a common source, propagation, behavioural aspects or zoonotic causes. The average of cases per fresh produce outbreak in Australia is 34.

infectious intestinal disease outbreaks between 1992 and 2006 were associated with the consumption of prepared salads. A total of 3,434 people were affected, with 66 hospitalizations and one death reported (Little and Gillespie, 2008).

Australia is no exception. A summary of produce-related outbreaks and produce recalls are presented in Appendices 1 and 2.

External influences that may be contributing to the increasing frequency of outbreaks attributed to fresh produce in the past three decades are:

1. Modification in agronomic practices, processing and packaging technologies.
2. Modifications in supply chain practices and the evolution of global supply chains, which aim to provide horticultural products sourced from many regions, all year round.
3. Changes in population demographics (e.g. an increase of the elderly population segment worldwide).
4. Emerging medical conditions that compromise the human immune system (e.g. HIV).
5. Changes in food consumption patterns and preferences; recognition of nutritional benefits of plant-derived 'nutraceuticals'.
6. Improved surveillance systems and an increase on publicly available information about food-related diseases.

Fresh horticultural products cannot be 100% sterile. In fact, most of the microorganisms that are naturally present on the surface of fresh produce are non-pathogenic and these can act as a barrier to prevent the growth of pathogens, should they be present (Rediers et al., 2009).

Nevertheless, raw fruit and vegetables can become contaminated with human pathogens or spoilage bacteria at any point in the supply chain. Fresh produce that is eaten raw is not subjected to processes that retard microbial growth such as cooking, freezing, or treatments with additives or preservatives. Hence, the maintenance of safety in fresh horticultural products depends significantly on: (a) avoiding pathogen contamination; and (b) applying recommended food safety practices throughout the supply chain (e.g. GAPs, GMPs, GTPs) (Estrada-Flores, 2003b).

A recent report (Estrada-Flores, 2009) rated the risk of fresh fruit and vegetables in Australia based on the following parameters:

A. Number of outbreaks (sorted from largest to smallest).
B. Number of recalls (sorted from largest to smallest).
C. DAFF risk category (sorted from highest risk =1 to lowest risk = 3.5).
D. FAO/WHO risk category (sorted from highest risk = 1 to lowest risk = 3).
E. 2005-06 production in Australia (sorted in descending order).

The results of this ranking are shown in Table 1. The top five high-risk products are (in descending order): sprouts, lettuce, unpasteurized orange juice, melons and mushrooms. This table could be helpful in setting R&D priorities for research on the development of methods to assess food safety in fresh fruit and vegetables.

Table 1. Categorization of fresh horticultural products according to its level of food safety risk, using criteria A to E above as sorting factors.

Product	Production in Australia (05-06), kt	Can it be consumed in raw state?	Is it grown in or close to the ground?	Is the skin typically peeled off before eating?	Risk category (DAFF)	Risk category (FAO)	Outbreaks in Australia	Recalls in Australia
Sprouts (mung/alfalfa) and shoots	?	Yes	Yes	No	1	2	4	4
Lettuce	163	Yes	Yes	No	1	1	4	2
Oranges(unpasteurised juice)	507	Yes	No	Yes	3.5	0	4	0
Melons	219	Yes	No	Yes	1.5	2	2	0
Mushrooms	44	Yes	Yes	No	1	0	1	0
Berries	30	Yes	Yes	No	1.5	2	1	0
Onions	222	Yes	Yes	Yes	1.5	3	1	0
Cucumber	?	Yes	Yes	Yes	1.5	3	1	0
Paw paw	?	Yes	No	Yes	3.5	3	1	0
Carrots	265	Yes	Yes	No	1	3	0	0
Beans	38	Yes	No	No	1.5	0	0	0
Capsicum/ chillies	61	Yes	Yes	No	1.5	0	0	0
Cauliflower	77	No	Yes	No	1.5	0	0	0
Broccoli	48	No	Yes	No	1.5	0	0	0
Cherries	10	Yes	No	No	1.5	0	0	0
Tomatoes	450	Yes	Yes	No	1.5	2	0	0
Chestnuts	1	No	No	Yes	2	0	0	0
Potatoes	1,250	No	Yes	Yes	2	0	0	0
Asparagus	10	No	Yes	No	2	0	0	0
Cabbage	79	No	Yes	No	2	1	0	0
Pears	139	Yes	No	No	3	0	0	0
Nashi	3	Yes	No	No	3	0	0	0
Apples	276	Yes	No	No	3	0	0	0
Nectarines	49	Yes	No	No	3	0	0	0
Plums	26	Yes	No	No	3	0	0	0
Peaches	91	Yes	No	No	3	0	0	0
Apricots	17	Yes	No	No	3	0	0	0
Kiwifruit	0	Yes	No	Yes	3.5	0	0	0
Bananas	187	Yes	No	Yes	3.5	0	0	0
Pineapples	153	Yes	No	Yes	3.5	0	0	0
Mandarins	92	Yes	No	Yes	3.5	0	0	0
Avocado	34	Yes	No	Yes	3.5	0	0	0
Lemons/limes/ grapefruit	46	Yes	No	Yes	3.5	0	0	0
Mangoes	36	Yes	No	Yes	3.5	3	0	0

The case to decrease quality losses in the Australian supply chain of vegetables

Even in cases where products have been handled in optimum conditions from farm to retail, quality in perishables inevitably decreases to a point where the product becomes unacceptable for consumption. If this point is reached before the product provides the desired value to the ultimate buyer (i.e. consumers), the purchased product translates directly into a loss of value for the entire chain. This loss can take the form of future sales, disposal costs or even costly product recalls if the product safety has been compromised. There are also indirect costs associated to quality losses, such as environmental impacts (i.e.

food waste) and community health (e.g. foodborne illnesses, lack of nutritional value in low quality products).

Figure 3 shows some of the reasons and consequences (i.e. loss of value) of quality losses in a typical supply chain for vegetables. In a previous HAL report (Estrada-Flores, 2009b), a financial loss of $160.7 million per year at retail level was calculated, assuming that 5.5% of vegetables (or 170 kilotonnes) are spoilt or damaged between farm and retail. However, losses of 2% to 23% between farm and retail and 5% to 30% at consumer level have been reported for developed countries (Kader, 2005). It is expected that the wastage rates will vary depending on several factors such as seasonal changes, differences among farms and other conditions.

An estimate of the economic loss assuming that the rates of annual waste in the Australian vegetable supply chain range from 2 to 23% was developed. Three hundred and sixty five random factors ranging from 2 and 23% (representative of waste per each day of the year) were generated through the use of ModelRisk ®, a Risk Analysis software. A Weibull distribution was used to generate the wastage random factors, given that other quality parameters have been shown to follow this distribution (Smale, 2005). The following assumptions were used:

- The value of vegetable production during 2007-08 was used[4].
- The tonnage of vegetable production during 2007-08 was used[5].

Table 2 shows the results of this simulation. An estimated annual average waste of 11% means that the vegetable supply chain loses half a billion dollars per year in product wasted through the chain. These losses represent about 15% of the yearly national gross value from vegetable production[6]. Therefore, R&D investments to improve quality could definitely contribute to the profitability of the industry. The reader should note that these costs do not include the costs of recall or disposal procedures.

The analysis of historical wastage patterns due to quality losses is an important performance indicator for perishable supply chains. This information can be translated into forecasting models that provide insights on how to reduce wastage based on past experiences. However, data on quality-related wastage is either not available or goes unmeasured by growers and other chain participants. Table 2 indicates that waste avoidance in vegetable chains is an important factor of profitability and sustainability for the vegetable industry and it should be measured and analysed in the same way that other farm costs are.

Further, data of product wastage due to quality issues could also help in directing R&D investments to specific links that contribute more than others in quality losses in the chain. For example, if data reveals that 80% of the quality losses occur during supermarket handling, then R&D programs targeting technologies and methods that reduce these losses could be established with a sound cost-benefit case.

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[4] ABS. Value of Principal Agricultural Commodities Produced, Australia, Preliminary, 2007-08

[5] ABS. Agricultural Commodities, Australia, 2007-08.

[6] Gross value is the value placed on recorded production at the wholesale prices realised in the market place. Market place is the metropolitan market in each state. In cases where commodities are consumed locally, or where they become raw material for a secondary industry, these points are presumed to be the market place.

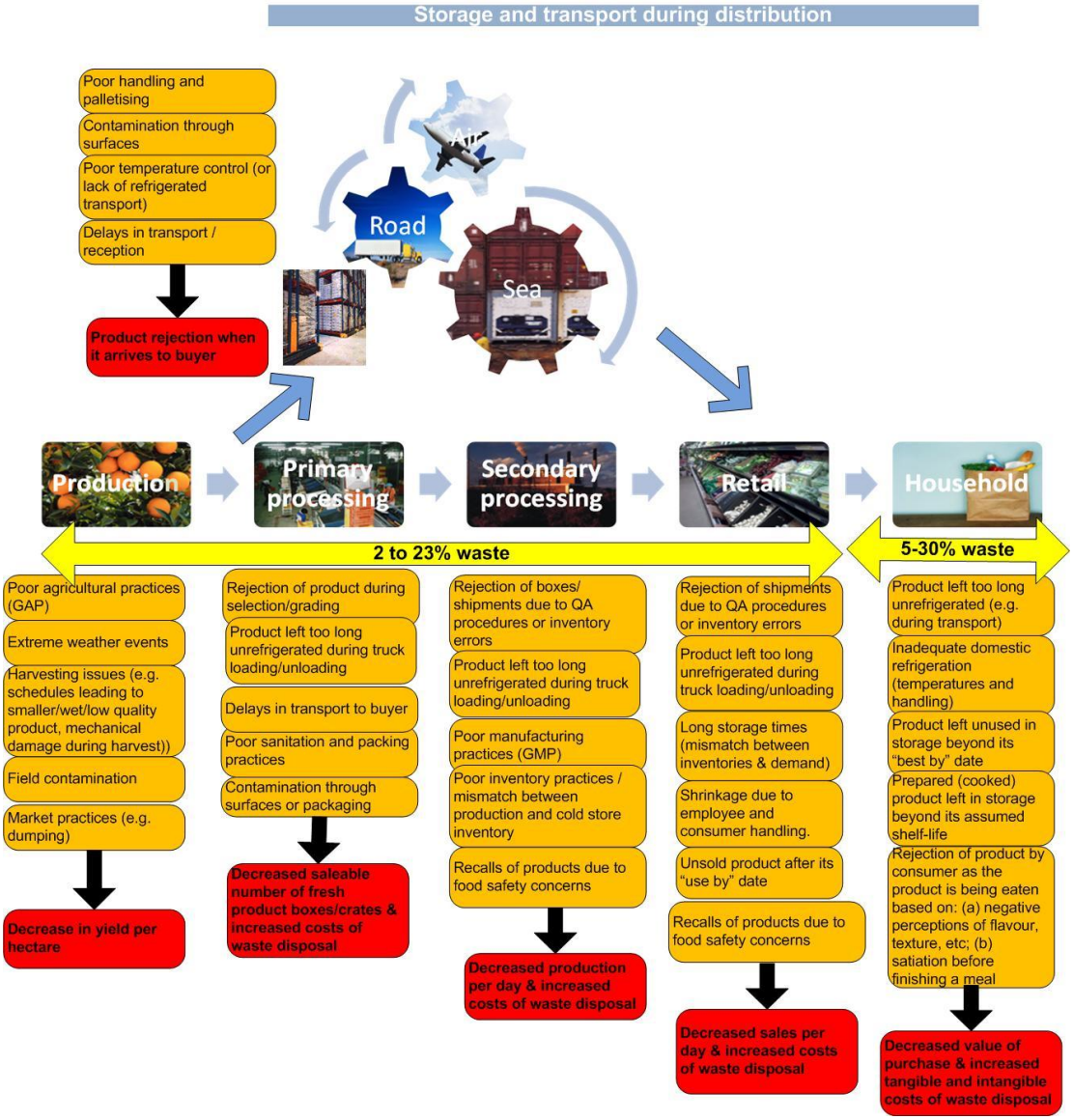


Figure 3. Some factors of quality losses (orange boxes) and their impact on lost value (red boxes) in a typical supply chain for vegetables.

Table 2. Estimated national economic losses in vegetables supply chains from product losses from farm to retail.

Month	Loss factor	Wasted production- farm to retail (t)	Economic loss- farm to retail ($m)
1	0.108173	29,743.8	$ 38.75
2	0.120244	33,062.8	$ 43.95
3	0.098785	27,462.2	$ 45.18
4	0.120107	31,198.2	$ 48.21
5	0.109874	31,397.6	$ 44.64
6	0.107919	27,745.7	$ 37.19
7	0.121504	32,388.0	$ 38.03
8	0.122244	31,467.6	$ 40.33
9	0.121134	32,541.3	$ 39.37
10	0.097655	26,351.6	$ 43.70
11	0.120811	32,875.1	$ 41.56
12	0.117779	30,972.7	$ 40.07
TOTAL/YEAR		**367,206.6**	**$ 500.96**

Scope of this report

Technology and instrumental techniques cannot yet substitute consumer testing. Attempts to draw correlations between sensory panels and instrumental techniques have delivered mixed results (Saftner et al., 2008, François et al., 2008). Further, the combination of the experiences and social cues that define quality is not likely to be simulated by technological means in the near future. Yet vegetable producers still require a measure of acceptability based on colour, aroma, sugar content and similar parameters that is relatively easy to apply during grading and relatively inexpensive. This report presents some emerging technologies for quality evaluation that can be used alone or in combination with sensory techniques to improve the market acceptance of vegetable products and therefore, their sales.

Technology also has an active role in avoiding quality losses introduced from farm to retail (i.e. quality extension). The investigation of technologies to improve yields in the pre-harvest phase will be provided in the report 5 "Technologies for production". In the present report we focus on postharvest emerging technologies. The technologies reviewed in this and previous reports of this project are presented in Figure 4.

Novel technologies for quality extension may have a positive effect on the preservation of horticultural products in more than one way. For example, ultraviolet irradiation decreases bacterial loads (thus aiding microbiological quality) and has also been shown to decrease breakdown and chilling injury of peaches during cold storage (thus protecting quality attributes) (Gonzalez-Aguilar et al., 2004). Similarly, new quality evaluation technologies may be useful to evaluate more than one parameter. For example, gas spectrometry can be used to evaluate product taste and aroma. To avoid repetition we mention each technology under only one category, highlighting the potential applications in either evaluating or benefiting quality in other categories whenever possible.

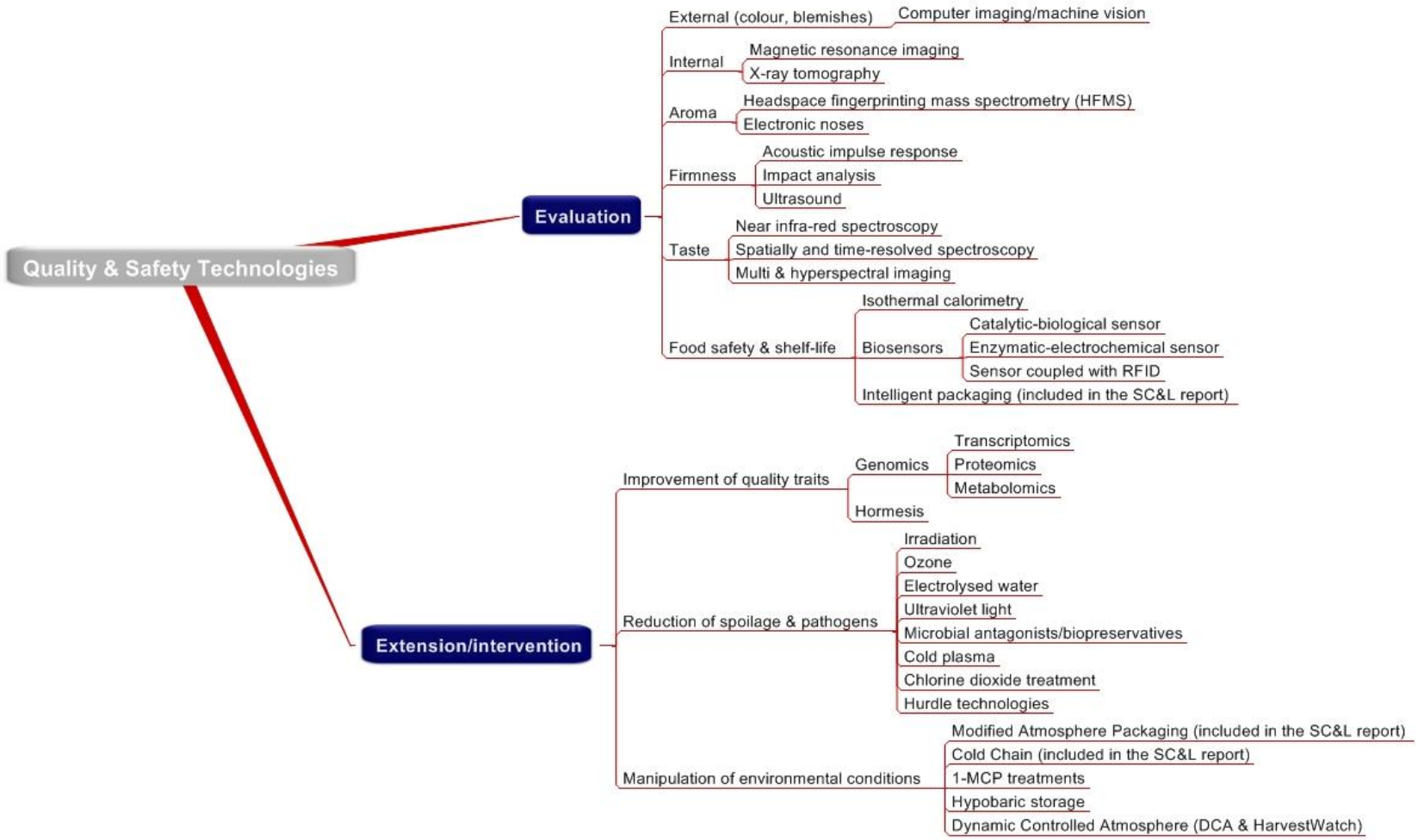


Figure 4. Technologies for quality evaluation and extension investigated in this project.

Technologies for Quality Evaluation

Although methods to measure quality and quality-related attributes have been developed over centuries, instrumentation appeared only in the past 80 years (Abbott, 1999). Modern commercial methods go back to 1973, when FMC Corporation (USA) patented an electronic system to sort fruit according to colour (Figure 5).

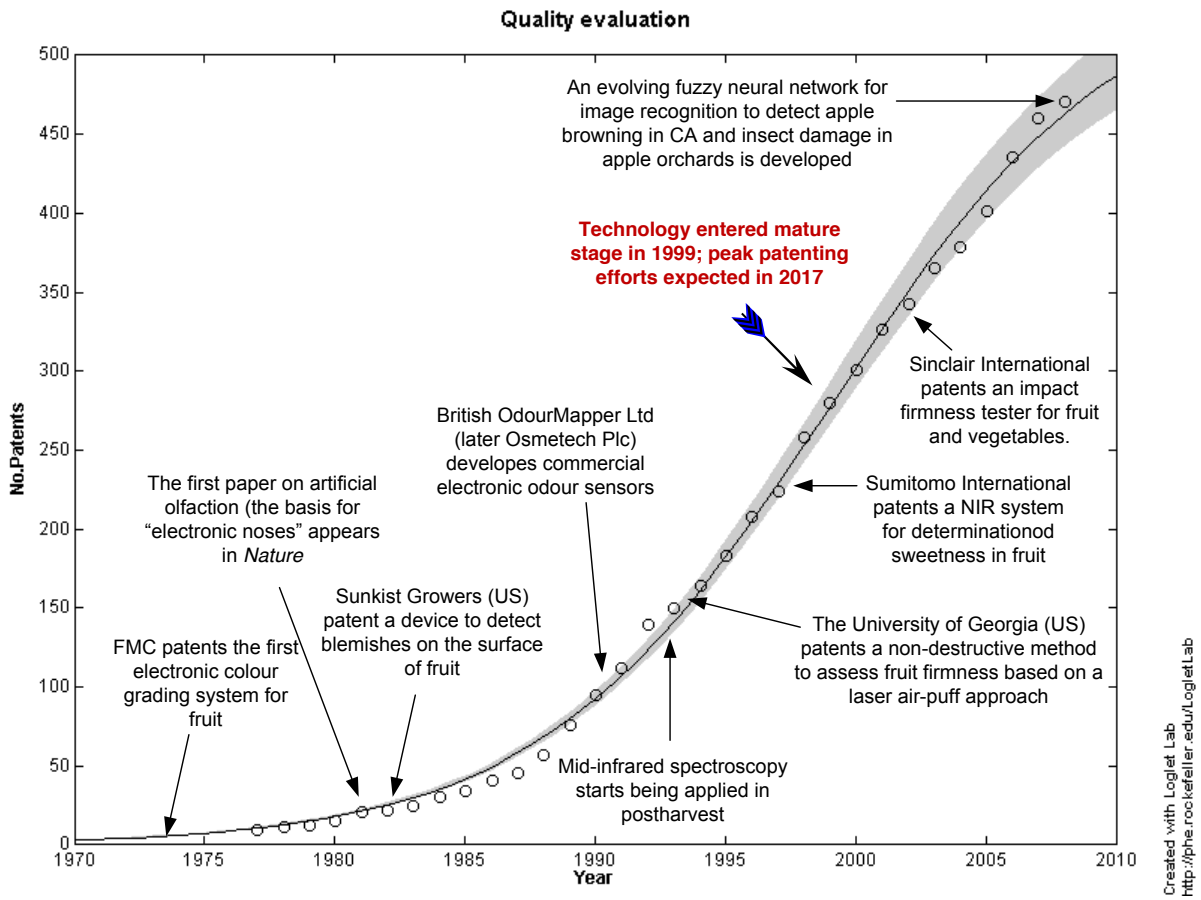


Figure 5. Growth curve of international patents in the area of quality evaluation (1973-2008). Some milestones in the development of modern technologies for postharvest quality evaluation are shown.

Figure 5 indicates that R&D maturity was reached in 1999. The peak number of patents in the area of quality evaluation is expected to occur in 2017.

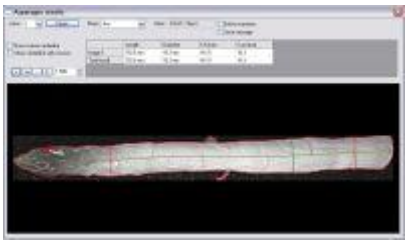
One aspect of particular interest is the time gap between the discovery of a principle for quality evaluation and its commercialisation. For example, Figure 5 shows a 10-year gap between the publication of the first paper on artificial olfaction (Dodd and Persaud, 1982) and the commercial development of electronic nose technology in the early 1990s.

As indicated in Figure 4, in this section we will focus on technologies to evaluate external and internal appearance, aroma, flavour, firmness, food safety and shelf-life.

External appearance

External appearance parameters include colour, blemishes, gloss, shape, size and weight. External quality aspects are the most immediate way to attract potential consumers.

Food producers and manufacturers are moving out of human inspection and investing in objective and automated visual quality instruments (Nicolai et al., 2009). Benefits of quantitative instrumental techniques to measure quality include speed, accuracy, repeatability and the ability to store quality parameters as continuous variables, which can then be used in sophisticated statistical quality assurance systems and records.

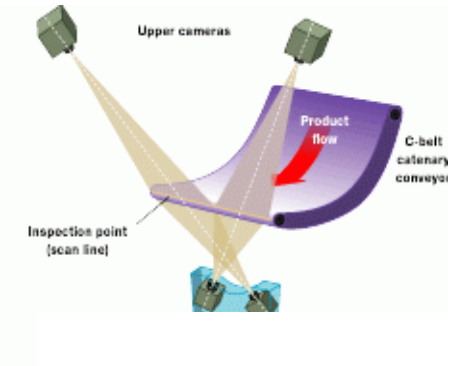


Computer vision for asparagus grading

In fresh produce operations, sorting and grading are the most significant applications for evaluation technology. ***Sorting*** is the segregation of edible or marketable product into distinct quality categories. ***Grading*** is an inspection that determinates whether or not the packed lot complies with requirements of a grade standard for a predetermined grade classification. Inspection for grading is generally more precise than, and differs from, the inspection of product for sorting (Bollen et al., 2009).

Sorting and grading have a major influence on the price paid by produce buyers. However, the natural variability of horticultural products contradicts the buyer demand for batches of homogeneous quality. Quality varies widely, from vegetable to vegetable, from one field to another and from one moment to the next. Considering this, data collection of external appearance parameters and analysis is an important step to achieve homogeneous product. High speed processing is also indispensable, particularly in vegetable processing environments where times between sorting and freezing or chilling can be as short as 15 minutes.

Quality evaluation systems based on machine (or computer) vision can provide high speed of data collection and processing. Modern systems inspect the colour of each product on the grading line and can measure its three-dimensional profile [7], thus triggering actuators to sort each fruit according to whether any bruising or damage had occurred. Product that does not meet the standards set is then sorted and sent to waste bins or used for juices, rather than being sent to buters (e.g. supermarkets, importers). Machine vision can also detect defects and foreign material in products such as leafy greens (e.g. baby spinach, lettuce mixes and others). Table 3 summarises the principles, cost/benefit aspects and other relevant information for these systems.



Vision inspection system

[7] http://www.vision-systems.com/display_article/281373/19/none/none/Depar/Food,-glorious-food!

Table 3. Key aspects of technologies used for evaluation of external quality in horticultural products.

Technology	Working principles	Cost/Benefit aspects	Applications	Some companies offering this technology
Computer imaging for external defects	Computer vision systems normally encompass: (a) an illumination system for the sample; (b) a camera that acquires an image of the sample; (c) a frame-grabber, to digitize the picture; (d) a computer or microprocessor to store and process the images; and (e) a high-resolution colour monitor to visualize and analyse images (Abdullah and Da-Wen, 2008).	Costs vary depending on capacity and technology. Investment can go from $100,000[8] to over $1 million. Positive points are high speed of grading, based on shape, colour, surface defects, calyx and stalk.	Figs, capsicums, apples, avocado, olives, broccoli, cucumber, citrus, onions, potatoes (whole, chips), stone fruit, tomatoes, lettuce.	• Colour Vision Systems Pty Ltd. 11 Park Street, Bacchus Marsh, VIC, 3340, Australia Telephone: +613 5367 3155. Email: cvs@cvs.com.au • Key Technology Australia Pty Ltd. One Fir Street Dingley 3172 VIC, Australia • Ellips, B.V. 5641 KA Eindhoven, The Netherlands. Telephone: +31-40-2456540. Email: info@ellips.nl • Sunkist Research and Technical Services. 10509 Business Dr. Unit B,Fontana, California 92337 U.S.A. Telephone: (909) 933-5823 • Compact Sorting Equipment Ltd. PO Box 13 516 Onehunga Auckland 1643 NEW ZEALAND Tel: +61 418 269 233 Email: ussales@compacsort.com

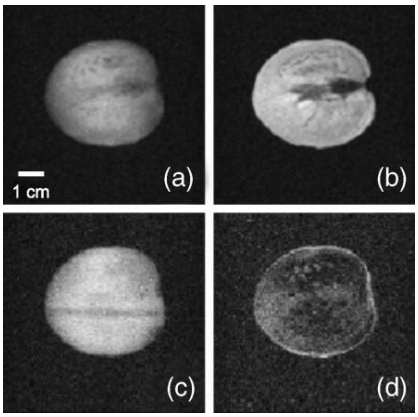
[8] http://www.cvs.com.au/index.php?page=items/uni1

Internal structure

Internal disorders in horticultural products include bruises, water core, worm damage, mealiness and some chilling injuries. Specific common internal disorders in vegetables include:

- "Hollow heart", internal bruising and hardening in potatoes.
- Chilling injuries in zucchini, eggplant and cucumber.
- Internal cracking in cucumbers and cell rupture in tomatoes due to rough handling.
- Rots in several varieties.

These defects are normally not revealed by external visual symptoms. Conventional colour or black-and-white imaging techniques cannot measure chemical constituents or internal quality attributes of fresh fruit because they only record the spatial distribution of light intensities over a broadband spectrum. Many chemical constituents are only sensitive to specific wavelengths or narrow wavebands (Lu, 2008).



Magnetic resonance images of a potato with damaged pericarp.

Two non-destructive tomography 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). The former technology allows capturing very high resolution images of the plant material's cellular and sub cellular structure. MRI has only been recently shown to be applicable for online detection of internal defects (Nicolai et al., 2009).

Spectral imaging or spectral analysis has also been used for detection of internal defects in produce. Spectral sensors collect information as a set of 'images'. Each image represents a range of the electromagnetic spectrum and is also known as a spectral band. These 'images' are then combined and form a three dimensional hyperspectral cube for processing and analysis. While hyperspectral imaging normally captures a set of contiguous bands (usually by one sensor), multispectral imaging is a set of optimally chosen spectral bands that are typically not contiguous and can be collected from multiple sensors.

Delayed light emission (DLE) and chlorophyll fluorescence are techniques that detect changes on plant tissues containing chlorophyll, due to physiological stresses that affect the chloroplast. Among these stresses are chilling, high temperatures, ozone, SO_2, and nutrient deficiencies and toxicities (Abbott et al., 1994). From all the methods investigated, these are the methods that most relate to fundamental physiological changes in tissues and thus they need an understanding of plant physiology to interpret the results. This is perhaps the reason why these methods have been used only in research and not in commercial settings. However, they provide valuable insights and in the future, they may develop into commercial testing units.

Table 4. Key aspects of technologies used for evaluation of internal quality in horticultural products.

Technology	Working principles	Cost/Benefit Aspects	Applications	Some companies offering this technology
X-ray imaging	Wavelengths used to measure produce quality range from X-rays (i.e. short wavelengths down to 0.01 nanometre or nm) that measure variations in water density within tissue, to radio waves (i.e. long wavelengths reaching as long a 100 km) that are used for magnetic resonance imaging. These waves are transmitted, reflected, absorbed, and scattered by produce tissues and can provide useful information about the quality of the product as a whole [9].	A recent case study found that the cost of x-ray inspection per grading line per day for sweet onion packing is about US$1,040.00; estimated costs per 18.14 kg box of X-ray inspected onions ranged from US $9.00 to US $15.00 (estimated selling price per box of onions= US $11.35 - US $25.34), depending on farm yield, the quality of incoming crop and the gross profit margin goals (Mosqueda et al., 2010)	• Woolliness in nectarines. • Hollow heart in potato. • Water core in apples. Spongy tissue in mango. • Core breakdown disorder in Conference pears (Nicolai et al., 2009). • Botrytis neck rot in sweet onion.	See companies in Table 3.
Multispectral (MS) and hyperspectral (HS) imaging systems	These combine measurements taken at different wavelengths (e.g. NIR and visible light) to measure attributes and discriminate between specific types of blemishes. This is useful to distinguish a lesion from a specific disease of quarantine significance from other ordinary surface grade defects.	Spectral imaging is a powerful platform technology for food process monitoring. However, there are three major barriers to its widespread adoption: (a) The high purchase cost; (b) since this technology is still evolving as a tool for quality evaluation, there are few commercial suppliers. It is anticipated that future technological developments in HSI systems for the	• Freeze damage in white mushrooms (Gowen et al., 2009). • Bruises in pickling cucumbers (Ariana et al., 2006). • Soluble solid contents distribution in kiwifruit, apples and peaches. • Firmness in apples (Lu, 2008). • Chilling injury in apples (ElMasry et al., 2009). • Moisture content, total	The best way to design these systems is to consult companies that can integrate the HS unit with the data processing software and hardware. See Table 3 for suggestions.

[9] http://www.growingproduce.com/americanvegetablegrower/?storyid=1272

		pharmaceutical industry will promote the manufacture of low cost systems suitable for food industry applications. (c) The relatively lengthy times necessary for image acquisition, processing and classification. Improved cameras, faster hardware, more accurate and efficient algorithms, will shorten processing and acquisition time, enabling real-time HSI quality monitoring systems.	soluble solids and acidity in strawberry (ElMasry et al., 2007). • Citrus canker (Qin et al., 2009).	
Magnetic resonance imaging	Based on the fact that certain nuclei align along a strong static magnetic field. Images (MRI) are created by applying a magnetic gradient in one direction (phase encoding) and a radio frequency gradient in the other direction (frequency encoding); gradients permit the reconstruction of spatial information (Abbott, 1999).	The technology has been used on fresh vegetables to evaluate maturity and ripening and to measure internal quality. These include measurements of soluble solids, total solids, firmness, core breakdown, bruising, insect damage, and chilling and freezing injury in different products[5]. However, the system is currently too expensive and difficult to operate for routine quality testing (Gowen et al., 2007).	• Detection of core breakdown in Bartlett pears. • Detection of void spaces, worm damage and bruises in fruit. • Quantitative NMR imaging of kiwifruit during growth and ripening. • Water core and internal browning in Braeburn, Fuji and Red Delicious apples. • Woolly breakdown in nectarines. • Browning and core breakdown • in pear (Nicolai et al., 2009).	• Aspect AI Ltd Telephone: +972-9-8923107 Ha'Melacha 8 PO Box 8875, Netanya, Israel. E-mail: m_j_mccarthy@sbcglobal.net
Fluorescence (Delayed Light Emission) imaging	A horticultural product's chlorophyll emits visible light when short-wave light is applied to the surface. This fluorescence can help distinguishing maturity	While the technique can detect injury before becoming visible, some chlorophyll fluorescence measurement techniques may be difficult to	Tomato, papaya, orange, banana, lemon, stone fruit, capsicum, olive, onion, pomegranate (Gunasekaran and Panigrahi, 2001).	A fluorescence or reflectance imaging system consists of the following components: (i) irradiation/excitation

	in fruits and vegetables that lose chlorophyll as they ripen or mature. Because temperature, salinity, moisture, atmospheric pollutants and mechanical damage can also affect fluorescence, this technique should enable visualization of the spatial distribution of stress responses before visible damage develops (Abbott, 1999).	use commercially because the equipment to measure fluorescence is expensive and the tissue must be kept in darkness for some time before taking a measurement.		light source(s); (ii) detector(s); (iii) image acquisition and data handling routines; and (iv) image processing. To our knowledge, no commercial grading lines or bench versions that have all these elements exist. Commercial chlorophyll fluorescence sensors can be obtained from: • HansaTech Instruments. Narborough Road, Pentney, King's Lynn, Norfolk, England PE32 1JL. Tel: +44 (0)1760 338877. Email: info@hansatech-instruments.com • Technologica Ltd, FOURWAYS. Bromley Road, Frating, Colchester, Essex, CO7 7DP, UK. Phone & Fax: +44 (0)1206 251696

Aroma

The Cyranose 320, developed by Cyrano Sciences, USA.

The aroma or odour of a product is detected when its volatiles enter the nasal passages at the back of the throat and are perceived by receptors of the olfactory system (Meilgaard et al., 1991).

Instrumental analytical methods such as gas chromatography (GC), gas chromatography with mass spectrometry (GC-MS), sniffing GC-MS, and/or high performance liquid chromatography (HPLC), combined with appropriate sample preparation techniques, are routinely employed for quality evaluation in laboratories. In particular, GC-MS is based on the sampling of the product's headspace, either using a gas syringe or via a concentration technique, such as purge and trap or solid-phase micro extraction. After injection in the GC, the headspace is separated into its different volatile components. Every eluting component is transferred to a mass spectrometer where it is fragmented into a mass spectrum for identification. The component can then be identified through a mass spectrum library search (Nicolai et al., 2009).

However, the analytical techniques mentioned above are time-consuming and expensive, and they require skilled personnel to operate the equipment and interpret the results. These methods are also not compatible with applications such as grading lines, which require fast screening

Electronic nose (E-nose) instruments may provide an alternative to the slower testing systems mentioned above. Unlike analytical techniques, the E-nose does not detect and identify single volatiles, but differentiates smell patterns of vapour mixtures. E-noses comprise an array of chemical sensors based on conducting polymers, metal oxides, surface acoustic wave devices, quartz crystal microbalances, or combination of these devices (Berna et al., 2004). The sensors capture a signal pattern characteristic of the mixture of volatiles in the product's headspace. This pattern is then evaluated using pattern recognition techniques such as neural networks and multivariate statistical techniques (Dittmann et al., 2000).

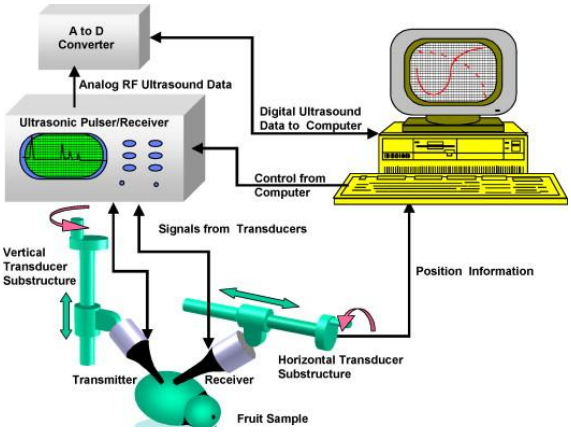
Research performed on relating aroma sensory attributes as measured by a trained panel, an electronic nose and headspace fingerprint mass spectrometry (HFMS) showed a high correlations between these techniques (Berna et al., 2005).

Interestingly, electronic noses could be also used for for early diagnose of microbial contamination (Concina et al., 2009). This option can provide faster results than any traditional microbiological procedures that require several hours or days for plate cultures. However, the technique is still no better than other analytical methods such as GC–MS, although the use of an E-nose would be much simpler.

Table 5. Key aspects of technologies used for evaluation of olfactory quality in horticultural products.

Technology	Working principles	Cost Benefit Aspects	Applications	Some companies offering this technology
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. The spectrum resulting from simultaneous ionization and fragmentation of the mixture of molecules introduced can be considered as a fingerprint of the actual aroma.	The implementation of the technique in grading lines can be expensive but it is more affordable as a bench instrument for a QA laboratory. HFMS is unable to take into account variable odour thresholds. This is particularly problematic when the headspace contains thiols or amines, which have a very low odour threshold.	• Ripeness of apples • Aroma profile of tomato cultivars. • Aroma production in strawberries during super-atmospheric oxygen storage (Nicolai et al., 2009). • Rapid screening of organophosphorus insecticide residues in strawberries and cherries (Lambropoulou and Albanis, 2003). • Evaluation of banana ripening (Vermeir et al., 2009).	• InProcess Instruments. Gesellschaft für Prozessanalytik mbH. Otto-Lilienthal-Straße 16. 28199 Bremen, Germany. Phone: +49 (0)421 52593 0. Email: mail@in-process.com • MOCON Inc. 7500 Boone Ave. N. Minneapolis. MN 55428 USA. Phone: +1-763-493-6370.
Electronic nose	These devices aim to simulate the functioning of the olfactory system. They are made of an array of chemical and electronic sensors with partial specificity and of a system of pattern recognition, able to recognize simple and complex odours. Each sensor reacts to a different set of volatile compounds; the pattern of the combined responses of all the sensors gives a "fingerprint" of a compound or a mixture (Zerbini, 2006).	In 2006 the retail price of a Cyranose (from Smiths Group) was US$8,000. However, other systems can cost more (i.e. over $60,000) (van Deventer and Mallikarjunan, 2006). While these methods are promising, the technology is expensive and sometimes difficult to adapt. Prices need to come down and the technology needs to be adapted to harsher commercial environments to be used commercially in detecting internal vegetable quality.	Electronic noses can differentiate ripeness states of fruit and vegetables. Examples include grapes, peaches, apples, tomato, mandarin, pear, truffle, and mango. Potentially useful to detect contaminated lettuce (with pathogens or chemicals).	• Scensive Technologies Limited. Metic House. Ripley Drive, Normanton. West Yorkshire. WF6 1QT,UK. Telephone: +44(0) 1924 227 231.Email: info@scensive.com • Smiths Group plc. 2nd Floor, Cardinal Place. 80 Victoria Street. London, SW1E 5JL, UK. T: +44 (0) 20 7808 5500. • CSIRO Cybernose. Food Futures Flagship. Phone: 61 2 6246 4126 Email: Stephen.Trowell@csiro.au

Firmness



An ultrasound system to measure fruit firmness

The term 'firmness' is used to describe the sensory experience when the mechanical strength of a product is assessed. The latter is defined in mathematical terms such as yield stress, rupture stress, elastic modulus, viscous behaviour and others (Estrada-Flores, 2003a) . In most horticultural products, firmness decreases after harvest. There are several elements that contribute to the tissue strength, such as the cell structures and the biological changes that occur following harvest. The specific physiological factors that determine the rate of softening of the product's tissues have not been fully established, but there is evidence linking cellulase (an enzyme that destroys cellulose present in the cell wall structure) activity with the softening process (Hofman et al., 2002). It has also been suggested that other hydrolytic enzymes participate in the process.

Traditional puncture methods to assess avocado firmness are based on the original Magness-Taylor pressure tester (penetrometer), which is of a destructive nature. Disadvantages of destructive testing include the inability of performing follow-up measurements on a same fruit and the strong dependence of the Magness-Taylor results on the operator's technique during testing (Muramatsu et al., 1997).

Alternative non-destructive firmness methods have been developed in recent years. One of the many properties that have been used to develop such methods is the vibrational response of the fruit when they are tapped with another object. For example, the acoustic measurement of firmness is based on the analysis of the resonance frequencies produced when the product surface is tapped.

The acoustic response of the product can be collected through a microphone as the main sensing element. Vibration can also be measured using a piezoelectric sensor, which produces an electrostatic charge that changes proportionally to the external force applied. When the product is thumped lightly, the resulting vibration is received in the sensor and the electrostatic charge is transmitted to a voltage amplifier. The signal is later mathematically analysed to extract the resonant frequencies of the fruit. This method correlates better with products of spherical or ellipsoidal shape.

Both acoustic and impact sensors are commercially available and their ability to sense firmness and firmness changes of fruit with very different properties. Not so with the ultrasound sensor. Non-destructive techniques are likely to become the new standards for 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., 2006b).

Table 6. Key aspects of technologies used for evaluation of firmness in horticultural products.

Technology	Working principles	Cost Benefit Aspects	Applications	Some companies offering this technology
Acoustic impulse response	This method evaluates product firmness based on the analysis of the resonance frequencies produced when the fruit surface is tapped. The resulting sound is recorded and analysed, applying mathematical techniques on the signal.	The bench version is below $2,000. It has been reported that the acoustic technique may be more sensitive for firm samples, whereas the impact technique is more sensitive for soft specimens (De Ketelaere et al., 2006a).	Apples, avocados, peaches, kiwifruit, nectarines, citrus, melons, tomatoes, pears, mango, potato, onion.	• AWETA G&P. Burgemeester Winkellaan 3. 2631 HG Nootdorp. The Netherlands Tel: +31 15 310 9961.E-mail: sales@aweta.nl
Impact analysis	This method evaluates firmness. A sensing element placed inside a bellow expander measures the impact response of the fruit when its surface is tapped. Systems include a data acquisition system and a program that analyses the resulting signals.	The bench version is below $2,000. See note above.	Apples, pears, avocados, peaches, nectarines, citrus, kiwifruit.	• J-Tech Systems Pty. Ltd. P.O. Box 5047, Lavington DC. NSW 2708. Phone +61 2 6049 5000. Email: s.abbott@jenkinsgroup.co.nz
Ultrasound	The method is based on local measurements of ultrasonic wave velocity and attenuation, by means of two inclined ultrasonic probes. The probes are placed in different positions to obtain an average reading. The ultrasound signal emerging from the product is sensed by a piezoelectric element (receiver) that converts it back to electrical energy (Mizrach, 2008).	The ultrasound technique has not progressed as fast in the fresh fruit sector as in the food industry, mainly due to the lack of appropriate equipment that provides the right waves to to avoid tissue damage. Efforts from the inventors to fully commercialise the technology have not been successful.	Avocado, tomato, apple, mango, plume, melon, potato, sweet potato, carrot, orange, pear.	Only available as an experimental tool through The Institute of Agricultural Engineering, The Volcani Center, Israel.

Taste

Taste is the sum of sensory attributes arising from the stimulation of the gustatory receptors on the tongue. Lack of characteristic flavour is a recurrent complaint of consumers when purchasing products such as tomatoes in supermarkets (Berna et al., 2004).

Receptors have been identified for at least five taste attributes: sweet, acid, salt, bitter and umami. The latter attribute represents "savouriness" and 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 (Nicolai et al., 2009).

The combination of responses from traditional instrumental analytical techniques such as high pressure liquid chromatography, gas chromatography, soluble solids content (Brix %), titratable acidity and pH can provide a "taste" profile of products. However, they are often laborious and time-consuming. Other drawbacks are the high cost and the need for skilled people to operate the equipment (Beullens et al., 2006).

Infrared techniques have been used to predict sugar contents in agricultural and food products in either solid or liquid form. For example, attenuated total reflectance infrared has been successfully used to measure sucrose in beetroot (Garrigues et al., 2000) and organic acids and sugars in apple juices. Flow injection analyses have been used for the determination of sucrose and glucose and the discrimination of red wines, edible oils and beer (Haberkorn et al., 2002).

In time-resolved or time-domain reflectance spectroscopy, a series of very short NIR light pulses are pumped into the product. A detector measures the absorption and scattering coefficient as a function of wavelength, which are parameters that depend on the tissue characteristics of the product. These measurements can then be correlated to internal quality attributes, such as soluble solids content.

So far, the results from this technique are not encouraging: the obtained correlations between absorption and scattering spectra and quality attributes such as SSC or firmness have been low to non-existent, most probably due to instrument drift or the limited wavelength range considered in the experiments (Nicolai et al., 2009).

Electronic tongues have proven to be a good alternative for traditional chromatographic techniques in the analysis of food. Similarly to the e-nose concept, e-tongues consist on an array of non-specific chemical sensors with a wide selectivity towards several components in a sample. Different e-tongues have proven to be successful in discrimination and classification, quality evaluation and control, process monitoring and quantitative analysis of foodstuff and beverages. The main advantages of e-tongues are the low cost, easy-to-handle measurement set-up and speed of measurement (Gallardo et al., 2005).

The most well known e-tongue sensor that is also commercially available is the ASTREE e-tongue developed by Alpha-Mos in France.

Table 7. Key aspects of technologies used for evaluation of flavour quality in horticultural products.

Technology	Working principles	Cost/Benefit Aspects	Applications	Some companies offering this technology
Infra-red spectroscopy (FTIR, near-NIR and mid-MIR)	A typical NIR instrument consists of a radiation source, a wavelength selection device such as a monochromator, a sample holder, a photoelectric detector that measures the intensity of detected light and converts it to electrical signals, and a computer system that acquires and processes spectral data. Traditional dispersive grating MIR spectrometers had similar optical systems. The IR light emitted from an IR source passes through a sample and then through a monochromator that contains optical devices such as a prism or grating. The light is guided through the prism or grating and separated into a spectrum of different wavelengths. An exit slit is employed to allow light at specific wavelengths to be segmented into readily measurable components and pass through to reach the detector.	These systems have been used for estimating soluble solids content, but also other properties: dry matter, firmness, acidity. Generally the estimation for soluble solids is satisfactory and consistent, while for firmness and acidity the results are more variable. The systems can be used as a bench instrument (e.g. in a QA laboratory), a handheld device to test product on the field or integrated in a grading line. In grading lines, the cost of the NIR depends on the number of lanes with NIR on and the fruit or produce sorted.	Tomato, sugar beet, carrot brassica, cucumber, potato, cassava, onion, several fruit. NIR has also been used to predict optimum harvest date of apples from the changes in soluble solids, after correction for seasonal effects (Zerbini, 2006). In Australia, the Cooperative Research Centre for Viticulture (CRCV) has developed NIR and MIR applications for the analysis of grape and wines [10].	• Portable Analytical Solutions Pty Ltd, PO Box 4185. Copacabana NSW 2251. Telephone: +61 2 43 812844 • NewSpec Pty. Ltd. 134 Gilbert Street. Adelaide, South Australia, 5000. Tel: +61 8 8463 1967. • NIR Technology Systems. Suite 103, 56 Kitchener Pde, Bankstown, NSW 2200. Tel: +61 (0) 2 9708 5068. (03) 5820 5337. 33 – 37 O'Brien Street, Mooroopna, VIC 3629. email: sales@edp.com.au • Taste Tech. 64 - 72 Victoria Street, Onehunga, Auckland 1061, New Zealand. Phone: +64-9-622-4434. Email: info@taste-technologies.com

[10] http://www.crcv.com.au/viticare/

Spatially and time-resolved spectroscopy	A short laser light pulse is projected into the product. Photon absorption and scattering lead to an attenuation of the reflected pulse. Two parameters (i.e. the absorption coefficient and the transport scattering coefficient) are estimated and its values correlated to product's characteristics. Absorption is determined by pigments (chlorophyll, anthocyanins) or key constituents (water, sugars), while scattering is related to the cellular structure (Zerbini, 2006).	Still in experimental stages. Not recommended for commercial purposes yet.	Mainly apples, nectarines and pears.	See cost/benefit aspects.
Electronic tongue	An array of cross-sensitive (or partially selective) chemical sensors and pattern recognition and multivariate calibration methods for output processing.	There are considerable differences in use protocols depending on the type of instrument, thus some systems are easier/faster to implement than others. The specific cost of commercial e-tongues is unknown.	Apples, tomatoes, juices.	Alpha MOS France - Headquarters 20, avenue Didier Daurat 31400 Toulouse - France Ph: + 33 5 62 47 53 80 - Fax: + 33 5 61 54 56 15 info@alpha-mos.com Note that CSIRO's Future Manufacturing Flagship is also developing e-tongues for a variety of applications

Microbial spoilage and pathogen contamination

Although the expiration of shelf-life in horticultural products can be easily identified by external signs of quality decay, internal decay is less obvious. Further, the contamination of products by pathogens is not always evident.

Routine detection methods for microorganisms are based on colony forming unit (CFU) counts, which require selective culture or biochemical and serological characterizations. Although, bacterial detection by these methods is highly sensitive and selective, the turnover of results can be a matter of hours or days (Ercole et al., 2003).

The aspects mentioned above are key drivers for the development of freshness and pathogen indicators. The most common indicators are based on chemical changes when a temperature/ time threshold is exceeded. These sensors are normally lumped with other "intelligent packaging" technologies and have been analysed previously (Estrada-Flores, 2009a). In this section we focus on sensors based on a biological response to environmental conditions, specifically biosensors.

A biosensor is an analytical device which converts a biological response into an electrical, chemical or physical signal [11]. Biosensors used in the detection of spoilage or pathogenic bacteria involve a biological recognition component such as nucleic acids, antibodies or receptors that are in contact with transducers. The signal transduction can be electrochemical, optical, piezoelectric, thermal or magnetic (Volpe et al., 2003).

For example, a foodborne pathogen can be detected through a dye-activated antibody tag, which is designed to allow bacteria to pass through a porous membrane toward an antibody attached to a dye complex. Once it binds to this layer, it further binds to another layer of antibodies, with the dye complex attached, and creates a pattern in any shape desired. The antibodies are bacteria-specific. For example, if the tags have an antibody that can only distinguish *E. Coli* O157:H7, they will not offer any indication if there is *Salmonella* present.

A similar principle is used in the so-called nano barcodes. These contain nanoparticles (which can be biological) that detect the presence of spoilage or pathogenic bacteria and that have recognisable chemical fingerprints. These can be read through the use of a computer scanner, an ultraviolet lamp or an optical microscope (Mongillo, 2007).

The majority of available biosensors are still in development. At present, two biosensors are commercially available: (a) ToxinGuarde, developed by Toxin Alert (Ontario, Canada) is a visual diagnostic system that incorporates antibodies in a polyethylene-based plastic packaging and is capable of detecting *Salmonella sp., Campylobacter sp., E. coli 0517* and *Listeria sp;* (b) The Food Sentinel System ™ (SIRA Technologies, California, USA), a biosensor system capable of continuous detection of contamination through immunological reactions occurring in part of a barcode (Kerry et al., 2006).

Biosensors have also been used in the detection of organophosphates and carbamate pesticides in horticultural products (Pogacnik and Franko, 2003).

[11] http://www1.lsbu.ac.uk/biology/enztech/biosensors.html#fig6_1

Table 8. Key aspects of technologies used for evaluation of shelf-life in horticultural products.

Technology	Working principles	Cost/Benefit Aspects	Applications	Some companies offering this technology
Piezoelectric biosensor	Specific antibodies that bind to the microorganism of interest are immobilised on the surface of the transducer (e.g. a quartz crystal). The microorganism binds to the crystal when present, increasing the mass load and decreasing the frequency of oscillation. These changes are measured and correlated to the concentration of the microorganism.	• The total market potential for detection of pathogens in the USA is about $563 million/year with an annual growth rate of 4.5% (Luong et al., 2008). • Biosensors allow rapid "real-time" and multiple analyses that are essential for the detection of bacteria in horticultural products. • However, biosensor technology for detection of food spoilage and pathogens is still in development. Many of these have been tested under laboratory conditions but several issues (e.g. sensor drifting) can be encountered in real supply chain scenarios. • Although plants that perform fruit and vegetables processing carry out fewer microbiological tests than their dairy and meat counterparts, the number of tests per year is still considerable. For example, One Harvest performs over 500 tests per year for pathogens in finished product, washing water and product stored to the end of its shelf-life. • Selection of the appropriate sensor is a crucial decision. Whether a sensor is suitable to monitor a certain product depends on both its temperature dependence and on the underlying kinetic mechanism.	Detection of *S. Typhimurium, E.Coli, L. monocytogenes, Vibrio cholerae* and *P. Aeruginosa* (Kim et al., 2003, Kim et al., 2004, Sun et al., 2009).	Neogen Corporation. Food Safety Division. 620 Lesher Place, Lansing, MI 48912 USA. 800/234-5333 (USA) foodsafety@neogen.com
Enzymatic-electrochemical sensor	An enzymatic sensor shows a dependency on a property, for example, colour change due to the enzymatic hydrolysis of a lipid substrate. The sensor consists of a circular plastic pouch with two sealed compartments. One compartment combines an aqueous solution of a lipolytic enzyme and a pH indicating dye compound while the other compartment contains the lipid substrate. The sensor is activated by applying pressure to the plastic, disrupting the barrier between the two compartments and inducing the mixing of enzyme and substrate. The subsequent reaction will decrease the pH,		• Mushrooms. • Salad mixes (fruit and vegetables). • Sprouts. • Hydroponic leafy greens. • Floral/foliage.	Vitsab International. Malmo, Sweden. sales@vitsab.com Phone: + 46 40 55 54 70

	which causes a colour change of the pH indicator from deep green to bright yellow (Bobelyn et al., 2006).			
Biosensor coupled with RFID	An RFID-enabled biosensor comprises a label with a substrate and an enzyme. When enzyme and substrate are placed in contact with each other, the conductivity of the substrate changes as a function of time and temperature. This makes it possible to track the accumulated exposure of product temperatures on a continuous basis and across longer periods of time. This accumulated temperature response can be carried by an RFID label in a similar fashion to other RFID-based time-temperature indicators. The label is read with a handheld scanner at various points of the chain.		All perishables.	Only one company based in Sweden developed RFID biosensors during 2004-2007 (Bioett AB). The company left the market in 2008. It is unknown if the technology was transferred to other RFID companies and whether the commercialisation efforts were successful.

Technologies for Quality Improvement and Extension

Quality is an aspect that determines the market and price of horticultural products. In the submission of the Chamber of Fruit and Vegetable Industries in Western Australia Inc. (CFVIWA) to the ACCC Inquiry Into the Competitiveness of Retail Prices for Standard Groceries:

> *"High quality producers are highly sort after by wholesalers. Wholesalers are prepared to pay quality producers a premium for their produce as they know they can readily find a buyer [...] and that the buyer is unlikely to subsequently return or reject the produce and leave the wholesaler with the difficult task of finding another buyer [...]. Poor quality producers are paid a lower price because their produce is more difficult to sell and it is often the case that oversupply of poor quality fruit can lead to significant marketing problems for all concerned." (CFVIWA, 2008).*

In figures 1 and 2 we discussed the preharvest and postharvest factors that influence the quality of horticultural products. Improvements on quality are typically obtained through manipulation of preharvest factors (although not always, as we discuss in the next section), while quality extension is based on postharvest treatments.

Due to the varied nature of methods for quality extension and improvement, it is not possible to analyse patent trends for each technology. We have selected five technologies to build Figure 6: hypobaric, modified atmosphere, ozone, ultraviolet irradiation and1-Methylcyclopropene (1-MCP).

Figure 6 indicates that the development of patents in the areas above reached its maturity in 2000. Logistic theory indicates that the decline in the number of patents should occur in 2032.

As in the case of quality evaluation, there seems to be a 5 to 10-year gap between the first patent related to the use of 1-MCP (*i.e.* early 90's) as a senescence retardation agent and its full development as a commercial technology in the late 90's. 1-MCP is registered for use on a number of horticultural products in several countries, although commercial information remains limited, except for apple fruit and ornamental products.

As many other postharvest technologies, the commercial development of 1-MCP has been affected by factors such as the product response in relation to quality (as perceived by the consumer), the implementation of 1-MCP treatments in the supply chain (*i.e.* handling, storage and transport systems), the scale of the application, and competition with other technologies in the marketplace (*i.e.* whether 1-MCP provides access to markets that are otherwise unavailable using current technologies) (Watkins, 2006a).

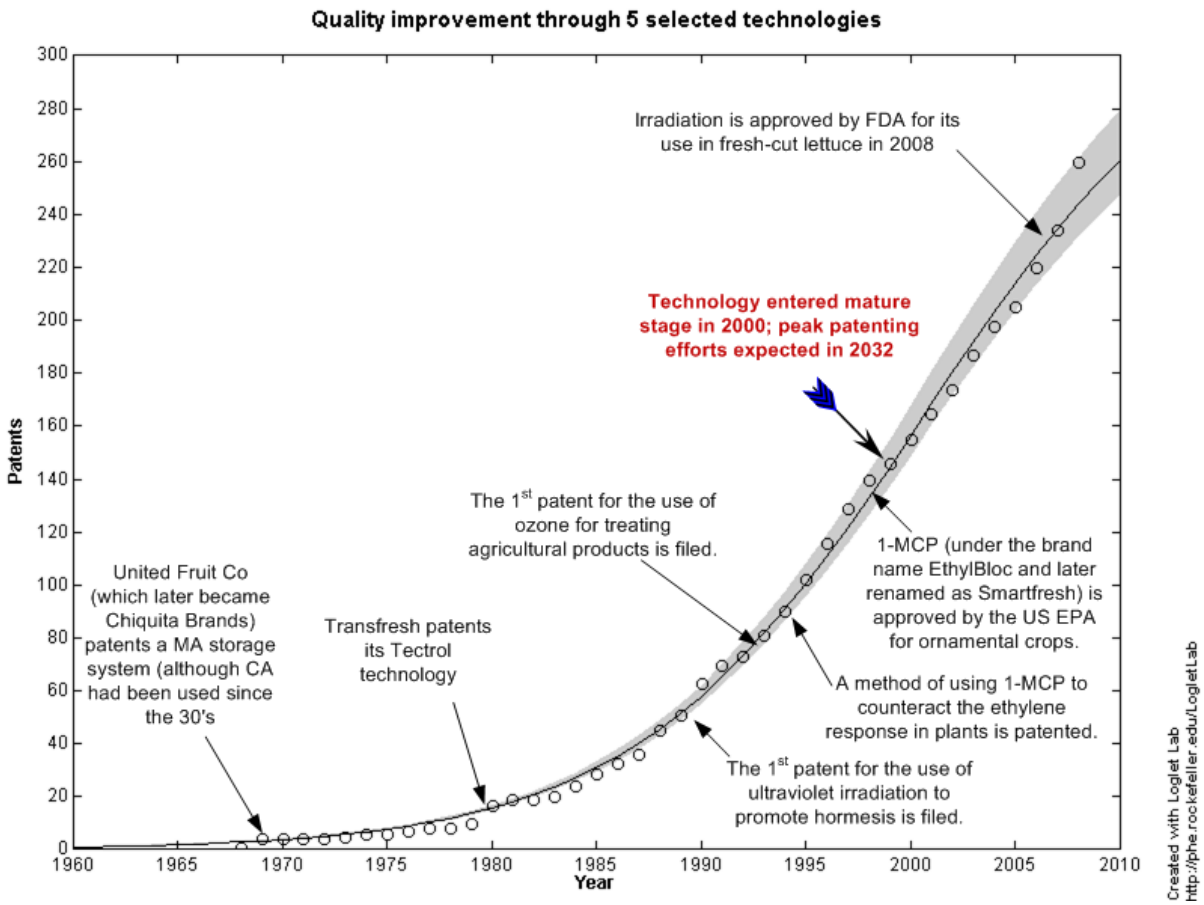


Figure 6. Growth curve of international patents in the areas of: hypobaric, modified atmosphere, ozone, ultraviolet irradiation and1-Methylcyclopropene (1-MCP) (1968-2008). Some milestones in the development of modern technologies for postharvest quality extension are shown.

A technological area that is difficult to evaluate through the number of patents is mathematical modelling and its role on the development of new technologies to extend quality and shelf-life. Mathematical models predict quality as a function of temperature, storage time, gas concentrations and other parameters (Tijskens, 1996). These models can provide valuable information about the effect of new technologies, product handling and storage conditions on horticultural products (Lukasse and Polderdijk, 2003), which can the be used to optimise these processes.

Integration of models to simulate pre and postharvest quality development is ongoing (Mebatsion et al., 2008). These models would allow more accurate representations of changes of plants at cellular level as a response to environmental factors (e.g. handling, temperature, atmosphere, etc) in all supply chain phases.

Another development in this area is the use of mathematical models to estimate the biological variation in horticultural products and how this parameter affects the outcomes of postharvest treatments (Hertog et al., 2007). Natural variability of fruit and vegetables is often overlooked in postharvest modelling, yet product variability is an important commercial driver.

Improvement of quality traits and nutritional content

Historically, breeding research has been directed towards improving yield, uniformity, pest resistance and storage qualities. While breeders may want to introduce quality and nutritional traits without altering the agronomic properties of the crop (Bernadac et al., 2003), the combination of acceptable agronomic traits with sensory and nutritional quality via traditional genetics often requires a long and complex breeding program.

Genetic engineering can offer an alternative to restoring desirable consumer traits to cultivars while maintaining their agronomic properties. However, biotechnology-based innovations to improve nutritional content, ripening control or processing characteristics, have not been exploited to nearly the same extent than pest-resistance traits have (Graff et al., 2009). In some cases, improvements in yield and shelf-life have led to a loss of quality (e.g. flavour in tomato).

A recent study that analysed 558 quality-improving innovations in agricultural biotechnology (Graff et al., 2009) found that only 25% of these reached early regulatory stages and only five were fully commercialised. Only two remain on the market (a carnation commercialized in Australia and Asia and a reduced nicotine cigarette in the United States). These results illustrate the difficulty in achieving a successful commercialisation of genetic engineering innovations for quality improvement and extension.

Genetic engineering is not the only alternative for horticultural quality improvement. Nutritional enhancement can also be achieved through a process called hormesis. Hormesis is a stimulation of a beneficial plant response by low or sub lethal doses of an agent such as a chemical inducer or a physical stressor (Stevens et al., 1996). Examples include the application of UV-C (254 nm) light at low hermetic doses reduced postharvest decay of onions (Lu et al., 1987), sweet potatoes (Stevens et al., 1990), carrots (Mercier and Arul, 1993), and tomatoes (Liu et al., 1993). Hormesis can be triggered either in preharvest or postharvest stages.

In regards to postharvest treatments, there is at least one patent for harvested grapes to increase the content of stilbene resveratrol, a phytochemical with cardio protective and anticancer properties (Cantos et al., 2003), through the use of UV pulses. Given that many fruit and vegetables are phytochemical-rich foods (e.g. berries, red cabbage, red onion, apple, apricot, parsley, celery, chilli peppers, citrus, broccoli and leek), there is potential for extending the use of UV treatments to enrich other products.

Similarly, a patented treatment is said to enhance vitamins C and D as well as increasing chlorophyll contents of fruit and vegetables. The technology uses a lamp that irradiates light at 590 nanometres. After three days of treatment under refrigeration, Vitamin C contents are said to rise by 10% in broccoli sprouts, compared with a 25% drop in conventional refrigerators. In cabbage, the increase is claimed to range between 14% and 16%[12].

[12] Appliance Design, 1st June 2005. Note: Refrigeration creation. From the website: http://www.appliancedesign.com/CDA/Archives/bef1a3405ca38010VgnVCM100000f932a8c0____

Table 9. Key aspects of technologies used for improvement of quality traits in horticultural products.

Technology	Working principles	Cost/Benefit Aspects	Applications	Some companies offering this technology
Functional genomics	A technique to represent all the genes expressed in a plant, which in turn 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. **Transcriptomics** is based on the analysis of RNA, while **proteomics** and **metabolomics** are based on the analysis of proteins and metabolites. As the productivity 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, 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 quality (Tonutti et al., 2009).	Because the genetic engineering of agricultural quality attributes was clearly in its infancy in the late 80s, it is reasonable to assume that the field entered its growth phase sometime in the early 90s. Innovation would have continued to increase for some time and the number of innovations entering the market would have increased. Instead, innovation levelled off around 1998. Factors for this behaviour include: • As more complex nutritional and quality traits involving greater complexities in gene expression were pursued, these likely were more difficult or costly to develop. • Legally, the difficulty and cost of navigating access to essential 'enabling' intellectual property probably increased as more technologies came under patent. • Expected economic returns from transgenic quality innovations may have declined due to competition from reasonably close non-transgenic substitutes, such as bred varieties of fresh tomatoes. • Expected demand for transgenic products may have been tempered by growing consumer	See Appendix 4. Other aplications include: • Increase of starch content (420%) in potatoes, less accumulation of reducing sugars, and less browning due to the Maillard reaction during cooking. • Increased sweetness of fruit and vegetables • Increasing lycopene production in tomato. • Increasing vit C contents in strawberry. • Production of seedless fruit of marketable size with good sensory quality.	• Monsanto Australia. 12/600 St Kilda Road. Melbourne VIC 3004. Phone: 03 9522 7122 • Bayer Crop Science. 391-393 Tooronga Road. East Hawthorn Vic 3123. Phone: 03 9248 6888 03 9248 6888 • Syngenta Crop Protection Pty Ltd. Level 1, 2-4 Lyonpark Road. Macquarie Park, NSW 2113. Ph: +61 2 8876 8444 +61 2 8876 8444 • Dow AgroSciences Australia Ltd. Locked Bag 502. Frenchs Forest, NSW 1640 Phone: 1800 700 096 1800 700 096 • Pioneer Hi-Bred Australia Pty Ltd. Locked Bag 9001 - 204 Wyreema Road. Toowoomba Queensland 4350.

		uncertainties over food uses of biotech • Key public decisions against GM from major institutional buyers (e.g. McDonald's) and suppliers (e.g. Zespri, Dole Europe). • The halting of regulatory approvals in Europe in 1998 and its repercussions with regulators in other countries.		Phone (61) 07 4637 2966 (61) 07 4637 2966
Hormesis via UV treatment	A stimulation of a beneficial plant response by low or sub lethal doses of an agent such as a chemical inducer or a physical stressor.	Any process for irradiating produce must fulfil the following essential requirements: (1) Produce should not be subjected to any form of mechanical handling during irradiation that might cause it to become damaged. (2) There should be provision for both varying the UV dose delivered and controlling the dose. (3) UV-C treatment should not unduly increase processing costs. (4) The design of equipment should enable high throughputs to be treated. (5) Ideally, a wide variety of different types of fruit and vegetables should be treatable. UV-C as a control treatment for postharvest disease has been more successful on preventing decay on roots (e.g. carrots, sweet potatoes, potatoes) than on fruits. To this author's knowledge, no cost-benefit studies for the various ways of UV application (e.g. greenhouse films, UV lamps) have been	Application of UV treatments (Jansen et al., 2008): • Broad bean (leaves) —4-fold increase in dehydroascorbate level • Pea plants —4.0-and 1.4-fold increase in total glutathione level • Spinach plants —2.7-, 1.9-and 0.9-fold increase in ascorbic acid level • Spinach (thylakoids) —30% decrease in a-tocopherol levels • Cucumber (cotyledons) —50% decrease in a-tocopherol level • Lettuce and spinach plants —8.2- and 7.8-fold increase in a-tocopherol levels, respectively (Tsormpatsidis et al., 2008): Lollo Rosso lettuce grown under films varying in their ability to transmit UV radiation— the quality of Lollo Rosso (in terms of phenolic compounds) can be enhanced under a highly UV transparent film (UV280) compared to the standard horticultural UVI/EVA film	Measurements and development of films for UV control need to be discussed with greenhouse film suppliers. Examples include: • David Gill Greenhouses, PO Box 20, Huntly, Victoria 3551 . Ph:+61 (03) 5448-8846. Email: dgill_greenhouses@bigpond.com.au • Glen Reidy, Redpath Greenhouses, Rohs Rd RSD4, Bendigo East, Victoria, 3539. Ph:1800 024-680. Email: redpath@netcon.net.au • LS Climate Control Pty Ltd, 2/43 Leighton Place, Hornsby NSW 2077. Ph:(02) 9477-6955. Email: info@livingshade.com.au

		developed. Although there is a wealth of laboratory-obtained data attesting to the positive benefits of applying low doses of UV to a variety of produce, to date there is little evidence of its application on a commercial scale. This is partly due to the difficulty in obtaining the correct processing conditions for each produce: UV-C can, at sufficiently high dose, cause a number of harmful effects that would render the produce as unmarketable (Shama, 2007).	(UV320). • Control of mould in several fruit. • Resistance to pathogens in sliced carrots. (Shama and Alderson, 2005): • Capsicum—UV doses prevented infections by *Botrytis cinerea*	

Technologies for reduction of pathogens and spoilage

While not perceived as critical in the marketing of whole products, disinfection is one of the most critical processing steps in fresh-cut vegetable production, affecting the quality, safety and shelf-life of the end product (Gil et al., 2009).

The fresh-cut industry has traditionally used chlorine as a sanitizer. However, there are growing concerns about the efficacy of chlorine on the produce, the high water usage and the environmental and health risks associated with the formation of carcinogenic halogenated disinfection by-products (Ölmez and Kretzschmar, 2009). Alternative sanitizing methods have been sought to address these concerns.

Some chemical alternatives such as chlorine dioxide, ozone, organic acids, peracetic (peroxyacetic) acid and hydrogen peroxide have gained interest in recent years. Physical methods such as aeration 'jacuzzi' washers can reduce the bacterial loads on vegetables by between 1 and 2 log units. Other methods include ultrasound, high pressure, high-intensity electric field pulses, ultraviolet radiation, radio frequency, ultrasound and ionizing radiation. All of these methods have been shown to be capable of killing or inhibiting bacterial growth, but the conditions of application lead to variable efficacy. An approach to account for the variability of end results could be addressed by the hurdle concept, which combines novel technologies with other methods such as aqueous chlorine dioxide.

Biopreservation is a new concept that consists on using bacteriocins, a heterogeneous group of antibacterial peptides and proteins with different molecular weight and composition. The most investigated bacteriocins are produced by lactic acid bacteria, natural ingredients found in all fermented foods and dairy products (Randazzo et al., 2009).

Studies on the effect of bacteriocins against *L. monocytogenes* in ready-to-eat Caesar salad, fresh alfalfa sprouts, soybean sprouts and green asparagus have shown promising results (Cai et al., 1997, Molinos et al., 2005). A recent study showed the effect of nisin on fresh-cut lettuce (Allende et al.). Further, other studies have shown the synergistic effect of bacteriocins in combination with other food additives against *L. monocytogenes* in various types of minimally processed fruits and vegetables. Examples include nisin, pediocin, sodium lactate, citric acid, phytic acid, potassium sorbate and EDTA on fresh-cut cabbage, broccoli and mungbean sprout (Bari et al., 2005), nisin in combination with H_2O_2, sodium lactate and citric acid on whole melon surfaces and on fresh-cut pieces (Ukuku et al., 2005), and nisin together with lytic bacteriophages on fresh-cut melons and apples (Leverentz et al., 2003). Bacteriocins may provide a novel, safe alternative and effective hurdle which, combined with other control measures, such as pH and temperature, can maximize protection from food-borne pathogens on processed vegetables.

Table 10. Key aspects of technologies used for reduction of spoilage and pathogenic microorganisms in horticultural products.

Technology	Working principles	Cost/Benefit Aspects	Applications	Some companies offering this technology
Irradiation	A non-thermal treatment that has the ability to effectively eliminate internalized bacteria from different products. Low-dose gamma irradiation is very effective reducing bacterial, parasitic, and protozoan pathogens in raw foods (Rico et al., 2007). When microbes present in the product are irradiated, the energy from the rays is transferred to the water and other molecules in the microbe. The energy creates transient reactive chemicals that damage the microbial DNA, causing defects in the genetic instructions. Unless it can repair this damage, the microbe will die when it grows and tries to duplicate itself. Disease-causing organisms differ in their sensitivity to irradiation, depending on the size of their DNA, the rate at which they can repair damaged DNA, and other factors. It takes a higher dose to kill microbes in frozen foods.	Irradiation is only approved in Australia for herbs and spices, herbal teas and some tropical fruits. Irradiation is a capital-intensive technology. In 1996 the initial investments ranged from $1 million to $5 million. In the case of large research or contract irradiation facilities, major capital costs include a radiation source (cobalt-60), hardware (irradiator, totes and conveyors, control systems, and other auxiliary equipment), land (1 to 1.5 acres), radiation shield, and warehouse. Operating costs include salaries (for fixed and variable labour), utilities, maintenance, taxes/insurance, cobalt-60 replenishment, general utilities, and miscellaneous operating costs. Treatment costs vary as a function of dose and facility usage. Low dose applications range between US$0.01/lbs and US$0.08/lbs while higher	• A low-dose irradiation (0.51 kGy) with subsequent refrigerated storage (4°C) can effectively reduce or eliminate Listeria monocytogenes on chopped romaine lettuce. In minimally processed lettuce, doses of up to 0.5 kGy have been proved not to affect quality. • 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. • 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) also had acceptable sensory quality.	• SADEX Corporation. 2650 Murray St. Sioux City, IA 51111. hclemmons@sadexsc.com. Phone: 888-44SADEX • FTSI. 502 Prairie Mine Road. Mulberry, Florida 33860. Phone: 863-425-0039.

		dose applications can cost as much as US$0.20 / lbs.		
Ozone	O_3 is commercially generated by passing O_2 through an electrical charge. Thus, molecular O_2 is split into two $O^{\cdot}$ which are highly reactive moieties. When a free $O^{\cdot}$ encounters O_2, it combines to form the O_3 molecule which rapidly degrades back to O_2 with the released $O^{\cdot}$ combining with another $O^{\cdot}$ to form O_2, or combining with other chemical moieties to cause oxidation. Upon release of $O^{\cdot}$, O_3 acts as a strong oxidizing agent being very effective in destroying microorganisms. The main systems for O_3 application include the gaseous phase storage (for cyclic or continuous exposure) or as ozonated dips.	Although ozonation has no chemical costs involved, there are high initial capital cost for generator, usually needs filtration system when water re-used some are complex, modest maintenance and energy costs.	• The bactericidal effects of O_3 have been shown on a wide variety of Gram+ and Gram− bacteria as well as spores and vegetative cells. • The effect of a flow of 4±0.5ppm O_3 enriched air applied cyclically (30 min every 3 h) on whole and sliced tomatoes prevented fructose, glucose, ascorbic and fumaric acid losses. In addition, O_3 maintained good overall quality of tomato slices and reduced bacterial and fungal counts. • The efficacy of ozonated water on pure cell suspensions or on the food surface and treating these surfaces with O_3 under conditions that simulate normal processing. Decrease in pathogens including *S. aureus, S. typhimurium, Y. enterocolitica, L. monocytogenes* and *E. Coli* O157:H7 has been demonstrated. Other products that benefit from O3 application are: • Avocados • Bananas • Berries • Citrus • Cucumbers	• Purfresh, Inc. 47211 Bayside Parkway. Fremont, CA 94538. Phone: 510.580.0700 • Ozone Industries Pty Ltd.18 Dividend Street. Mansfield Qld 4122. Phone: (07) 3219 2233. E-mail: sales @ozoneindustries.com.au

			• Grapes • Kiwifruit • Onions • Peppers • Pome Fruit • Potatoes • Stone Fruit • Tomatoes	
Electrolysed water	EW is formed by adding a very small amount of NaCl (usually about 0.1%) to pure water, and conducting a current across an anode and cathode. The cathode area produces alkaline reducing water while the anode area produces acidic oxidizing water. EW has a strong bactericidal effect against pathogens and spoilage microorganisms due to its high redox potential (Ongeng et al., 2006).	Advantages of using EW at neutral pH are that it does not affect pH, surface colour or general appearance of fresh-cut vegetables. EW involves on-site production of the disinfectant, which means there are no chemicals to store or handling costs. Disadvantages include short shelf-life (about two weeks), and only companies with access to an electrolysis machine can benefit from it.	• EW containing 15–50ppm available chlorine was effective as a disinfectant for fresh-cut carrots, spinach, bell pepper, potato and cucumber, without discoloration and lowering microbial counts from 0.6 to 2.6 log units. • EW containing 60mgL−1 free chlorine (pH 6.5) is as effective as chlorine in washing lettuce samples, showing good quality retention. Acetic EW has also been shown to effectively inactivate *E. coli O157:H7, S. enteritidis* and *L. monocytogenes* on lettuce. • EW water can also reduce germination of many fungal species, such as *Alternaria spp., Bortrytis spp., Cladosporium spp., Colletotrichum spp., Curvularia lunata, Didymella bryonaie, Epicoccum nigrum*, and *Fusarium spp*. among others.	• Amano USA Holdings, Inc. 140 Harrison Avenue Roseland, New Jersey. 07068-1239 U.S.A. TEL :+1-973-403-1900. • EOwater Ltd. 16 Hillside Business Park, Kempson Way, Bury St Edmunds, Suffolk IP32 7AR. Tel: 0800 977 5687. • NIPPON INTEK AQUA-CHEMICAL CO.,LTD. 2779-1, NAKADAI, IMAFUKU. Japan. Tel: 492410104
Microbial antagonists/	Biopreservation refers to the extension of the shelf-life and	Specific costs of application of biopreservatives are not	• Chlorine and nisin–EDTA treatments led to a reduction	• Danisco Australia Pty. Ltd. 45-47 Green Street

biopreservatives	improvement of the safety of foods using microorganisms and/or their metabolites. Lactic acid bacteria (LAB) allows the development of desirable flora in fermented foods. They also prevent the development of spoilage and pathogenic bacteria in both fermented and non-fermented foods by using broad- and narrow-host-range bacteriocins, respectively.	known.	of native microflora in whole melons and fresh-cut pieces. • Combinations of nisin, EDTA, sodium lactate and potassium sorbate led to a reduction of Salmonella on fresh-cut cantaloupe. • Mixtures of nisin, pediocin, sodium lactate, citric acid, phytic acid, potassium sorbate and EDTA are effective in the reduction of *L. monocytogenes* on fresh-cut cabbage, broccoli and mungbean sprouts (Settanni and Corsetti, 2008).	NSW 2019. Botany. Phone: +612 9384 5000 +612 9384 5000 . E-mail:info@danisco.com Danisco manufactures Nisaplin® and Novasin™, which are natural bacteriocins produced by fermentation of *Lactococcus lactis* .These commercially available substances are effective against Gram-positive bacteria, including *Listeria, Clostridium, Bacillus* and lactic bacteria. This results in either a killing or growth inhibitory activity against vegetative cells by targeting the cytoplasmic membrane, or prevention of the outgrowth of heat-resistant spores.
Pulsed light/ultraviolet (UV) light	Involves the use of intense and short duration pulses of broad-spectrum "white light". The spectrum of light for includes wavelengths in the ultraviolet to the near infrared region. The product is exposed to 1 to 20 pulses of light per second, with each pulse having an energy density in the range of about 0.01 to 50 J/cm^2 at the surface. At least 70% of the electromagnetic energy is within the range of 170	Specific costs of application of biopreservatives are not known.	• Surface disinfection of fresh-cut fruit and vegetables. • In zucchini squash slices UV–C exposure (between 10 and 20 min) reduced microbial activity and deterioration during subsequent storage at 5 or 10 ◦C. Similar results were found for tomato, strawberry, carrot, table grape and sweet potato. • 4–14 kJm−2 UV–C applied to broccoli heads delayed yellowing and chlorophyll	• Fluidquip Australia Pty. 12 Carl Court, Hallam. Victoria, 3803. Australia • Atlantium Technologies Ltd. Har Tuv Industrial Park,POB 11071,Israel 99100. Tel: +972 2 992 5001. Email: sales@atlantium.com

	to 2600 nm. In the UV variation, microorganisms are susceptible to UV light between 200 and 280 nm. This power does not allow penetration to foods, thus only inactivating microorganisms in the surfaces of foods as well as in air and package. These technologies damage the microbial DNA; also, fruit is stressed and its response is the production of protective chemical components (e.g. antifungal components, UV protective components).		degradation at 20 ◦C, displayed lower respiration rate, and increased total phenols and flavonoids, along with higher antioxidant capacity. • In whole bell peppers harvested from integrated pest management production and treated with 2.27 kJm−2 UV–C, decay caused by Botrytis cinerea was reduced after 21 d at 5 ◦C. The inhibitory effect remained after a further 5 d period at 15 ◦C.	
Cold plasma	A process that uses high voltage electricity to ionize a gas (such as air) in order to generate a plasma field. In its most basic form, the gas is air and it is exposed to electricity coming from electrodes. Bacteria, viruses and spores that are exposed to this non-thermal gaseous energy in the form of reactive chemical species are eliminated on contact, and the plasma dissipates immediately when the electrode is turned off (Bricher and Keener, 2007).	There is no equipment commercially available that could treat produce on the packing line. The treatment remains experimental.	Cold plasma is currently used to sanitize surfaces. US researchers are testing cold plasma to decontaminate the surface of produce without destroying organoleptic attributes. Most of this research has focused on the sanitation of apples to determine cold plasma's antimicrobial efficacy and the efficiency of bacteria inactivation on the fruit's surface. In initial studies, cold plasma was applied to apples that had been inoculated with *L. innocua* (a surrogate for *L. monocytogenes*). The application of the technology led to a 90% reduction on the apple surface without altering the appearance of the treated apples during subsequent storage.	Companies performing R&D in this field are: • Applied Plasma Physics AS. Bedriftsveien 25, 4313 Sandnes, Norway. P.O. Box 584, N - 4305 Sandnes, Norway. Telephone: + 47 5160 2200. E-mail: app@app.no • AirInSpace, BV. Prins Bernhardplein 200, 1097 JB Amsterdam, The Netherlands. Phone: +31 15 2600 930;Fax: +31 15 2600 931. • CSIRO Food & Nutritional Sciences. 671 Sneydes Road. Werribee VIC 3030
Chlorine dioxide	ClO_2 is a strong bactericide and	ClO_2 is about 5 to 10 times	There are very few reports about	• TwinOxide Australia Pty

treatment	virucide at levels as low as 0.1 ppm. It attacks planktonic and sessile bacteria, fungi and viruses, disinfects surfaces, and prevents and rapidly removes biofilms, avoiding bacterial re-growth. With minimal contact time, it is highly effective against pathogenic organisms such as Legionella, amoebal cysts, Giardia cysts, E. coli, and Cryptosporidium.	more expensive than chlorine.ClO_2 is usually made on site. The costs of ClO_2 depend upon the price of the chemicals that are used to produce it (e.g. sodium chlorate and sodium chlorite). ClO_2 is less expensive than other disinfection methods, such as ozone.	the use of ClO_2 in horticultural products. Some of them have shown that for apple, lettuce, strawberry and cantaloupe a solution of 5ppm was effective for inhibiting inoculated *E. coli* and *L. monocytogenes*.	Ltd. 8 Cocos Court. Patterson Lakes, VIC 3197, Australia. Ph: +61 3 9772 5025.E-mail: info@twinoxide.com.au • Lenntech BV. Rotterdamseweg 402 M. 2629 HH Delft, The Netherlands.Tel: (+31)(0)15 2610900. e-mail: info@lenntech.com
Hurdle concept	The combination of two or more preserving technologies increases the possibilities of microorganism destruction and/or growth inhibition. The most important hurdles used in food preservation are based on controlling temperature, water activity, acidity, redox potential and the use of preservatives, modified atmosphere and competitive microorganisms (e.g., lactic acid bacteria). By combining hurdles, the intensity of the individual preservation techniques can be kept comparatively low, minimising the loss of quality, while the overall impact on microbial growth may remain high. Some patented hurdle technologies include: ozone + electron beaming and UV + antimicrobial substances.	A number of issues have to be addressed to apply hurdle technology successfully. These include: application of the hurdles, distribution in the food matrices, influence on flavour and colour and long-term effects of the preservatives especially regarding the possibility that microorganisms may become resistant to the new hurdles. For the emerging additives to have large-scale commercial success, they must have consumer and regulatory acceptance. Manufacturers need access to the hurdles in bulk amounts at reasonable costs.	Organic acids, chitin/chitosan, enzymes, lactoferrin, nisin, reuterin, plant-derived antimicrobials, ozone and electrolysed oxidizing water are all antimicrobial hurdles. Among the organic acids, benzoic, lactic, acetic and fumaric acids and parabens show the greatest and most well documented effects against microorganisms. A number of plant-derived antimicrobials have demonstrated good antimicrobial effects and are also widely accepted by consumers as being 'more natural' than organic acids. Among the newest antimicrobials, reuterin seems very promising (Søltoft-Jensen et al., 2005).	Hurdle systems require the combination of several technologies. The design is best left to the companies mentioned above or to a consultant.

Technologies for control of environmental conditions

Produce respiration and shelf-life are interdependent factors during storage of fresh fruit and vegetables. In this stage, the decrease of respiration rates through controlled atmosphere (CA) technologies is a commercially effective means of extending the shelf-life. CA can also decrease product softening, colour changes, ethylene production and ethylene sensitivity.

The application of CA varies depending on the product type and maturity, storage temperature and the stage of the supply chain where the technology is applied. In regards to the latter aspect, farmers apply CA storage technologies as the most common way of controlling gas atmospheres. At retail and even during domestic refrigeration, atmosphere modification within wholesale or retail packages is a common extension of this technology (Shewfelt et al., 2009). Modification of the atmosphere can also be achieved by an initial application of gas mixtures to packages or containers and after that through the use of absorbent compounds to limit carbon dioxide (CO2) and ethylene (C2H4) concentrations (Kader et al., 1989).

The discovery and commercialisation of 1-methylcyclopropene (1-MCP) as an inhibitor of ethylene perception represented an exciting new strategy for controlling ethylene production and thus ripening and senescence of fruit, especially climacteric ones, as well as senescence of vegetative tissues (Watkins, 2006b). The application of 1-methylcylclopropene (1-MCP) can delay ripening by slowing respiration and volatile compound generation (Golding et al., 1999). Appendix 5 shows some generalisations on the effects of 1-MCP on the metabolism of fruit and vegetables.

Modified atmosphere packaging (MAP) is another technique used for prolonging the shelf-life period of fresh or minimally processed foods. This technology was reviewed in a previous report (Estrada-Flores, 2009a). Successful applications of MAP in vegetables include lettuce broccoli florets, cauliflower florets, carrots, mushrooms, coleslaw, stir fry mixes, mixed leaf salad, baby carrots, baby spinach and peeled garlic, among others (Sandhya, 2010). Some commercially available MAP systems for small and large quantities of produce are presented in Appendix 6.

Table 11. Key aspects of technologies used for control of environmental condition during postharvest.

Technology	Working principles	Cost/Benefit Aspects	Applications	Some companies offering this technology
Modified atmospheres (MA)	The gaseous environment of the atmosphere surrounding a product is changed. The most common methods are: (a) MAP: the product is enclosed in a gas-barrier material; the air is removed from the enclosure and replaced by a particular combination of gases (normally rich in CO_2 and low in O_2). The enclosure is then sealed hermetically; (b) MA storage: same principle as MAP but the new atmosphere is applied to entire sections (pallets) in a cold storage; (c) MA pallets: a film is sealed around each pallet unit just before loading on refrigerated trucks (d) Scavengers: selected gases are extracted from the cold store or package, by means of filters with scavenging properties or selective gas membranes. Apart of slowing down the respiration rate and the metabolic processes of ripening, MA has an antimicrobial action produced by changes in the oxidation-reduction (REDOX) potential and the increase of CO_2 concentration, which affects aerobic bacteria.	The strongest growth segment for MAP from the 1990s through 2003 was fresh-cut products. In 2003, two-thirds of the volume of fresh-cuts served through the foodservice sector was lettuce, valued at $2.4 US billion, with up to 15% of the produce in some form of MAP (Brody and Jung, 2005).	Successful applications in vegetables include broccoli florets, cauliflower florets, carrots, baby carrots, peeled garlic. Other applications include: • Artichoke • Beans, snap • Brussels sprouts • Cabbage • Chilli peppers • Corn, sweet • Cucumber • Lettuce (leaf) • Mushrooms • Spinach • Tomatoes • Onion	The best manner to develop MA storage solutions is to combine the expertise of cold storage engineering and postharvest knowledge. **Cold storage solutions:** • Starfrost (UK) Ltd, Starfrost House, Newcombe Road, Lowestoft, Suffolk, NR32 1XA. Tel: +44 (0) 1502 562206. Email: davepearson@starfrost.co.uk • SKM Consulting. 100 Christie Street, PO Box 164, St Leonards, Sydney. NSW 2065.Phone: +61 2 9928 2100;Fax: +61 2 9928 2500. • Partridge Partners Pty Ltd. Level 4, 1 Chandos Street, St. Leonards NSW 2065. Phone us: +61 2 9460 9000. Fax us: +61 2 9460 9090. Email: partridge@partridge.com.au

				Postharvest knowledge providers: • Food Chain Intelligence. PO Box 1789, North Sydney 2059, NSW, Australia. Tel 0404 353 571.E-mail: Silvia@food-chain.com.au • Postharvest and Market Access Group. NSW DPI. Gosford Primary Industries Institute. Centre of Excellence for Market Access and Greenhouse Horticulture. Locked Bag 26, Gosford NSW 2250, Australia. Tel: +61 (02) 4348 1900 • Postharvest Fresh. Faculty Agriculture, Food and Natural Resources . Woolley Building, Sydney University, NSW 2006 Phone: +61-2/(02)-9945-1730. E-mail: pf@postharvest.com.au **MAP** • Transfresh USA. Teresa Scattini - Vice President International Services. Ph:(831) 772-6084;e-mail: tscattini@transfresh.com • Coregas Pty Lts. 66 Loftus Rd, Yennora NSW

				2161. E-mail: Chandresh.wadhwana@coregas.com • RMCG (at'n: Dr Doris Blaesing). 135 Mollison Street, Bendigo 3550. Ph: (03) 5441 4821. dorisb@rmcg.com.au • Cryovac (Sealed Air Australia). Regents Park NSW, Tel: +61-2-97218900.
Dynamic Controlled Atmosphere (DCA)	DCA storage uses technology that involves monitoring the responses of fruit to low oxygen. Fruit responses can be detected by measuring metabolic processes, such as ethanol production, fruit respiration, or chlorophyll fluorescence (See pages 21 and 23 in this report for an explanation on chlorophyll monitoring). The CA is then controlled dynamically, according to the fruit responses. HarvestWatch™ is a fluorescence-based DCA technology and the results obtained in the US for this system (as applied in apples) are used in the next boxes[13].	British Columbia has extensively tested HarvestWatch™ in commercial conditions, using 0.5-0.7% or 1-1.2% oxygen (O_2) on various apple cultivars since 1989 without any CA-induced fruit injury. After substantial testing, it was concluded that inclusion of the system to commercial CA rooms was not justified due to the equipment cost and no additional low- O_2 benefit. Any fruit loss under a commercial setting was to be the sole responsibility of the end-user and not the distributor of HarvestWatch. Hence, the packinghouse management / CA operators were not willing to risk their fruit pushing the low limit of O_2 for little added benefit. The use of HarvestWatch is limited to storage operations that	• Various apples varieties. • New Zealand 'Hass' avocado (Yearsley et al., 2003)	HarvestWatch™ has been marketed by Satlantic Inc. (Nova Scotia) for several years. Recently, however, the South African company Gas At Site Inc. became the license holder for this technology in North America. With this, there seems to be a resurgence of interest and questions about the HarvestWatch technology.

[13] http://www.omafra.gov.on.ca/english/crops/hort/news/orchnews/2008/on-0408a8.htm

		have high quality CA rooms with adequate air-tightness, as well as accurate gas control systems to maintain O_2 levels below 1%. These are also the same commercial factors that limit the use of known safe low O_2 regimes (0.7-1.5%) for certain apple cultivars. Each HarvestWatch sensor monitors only six apples, so the variability in fruit behaviour within that storage room must be considered. It is well known that there are major differences in the minimal acceptable O_2 level among apple cultivars, growing seasons, and orchard blocks. Watkins (2008) concluded that there has been insufficient work in New York to show whether the variability among orchard blocks typical of our growing region will permit the safe adoption of HarvestWatch technology. HarvestWatch is not the only way to utilize lower O_2 levels or programmable CA storage. The use of low O_2 by measuring the alcohol content of apples and adjusting the O_2 level accordingly is being promoted by an Italian company. Others are simply using combinations of ultra-low O_2 (<1%) storage and initial low O_2 stress (~0.5%) to eliminate the use of postharvest chemicals.		

		Research in Ontario and Québec has shown that programmed CA regimes with sequential reductions in O_2 and/or temperature can increase firmness retention (+3.6 lb) and reduce incidence of storage disorders (0 vs. 25-32%) in apples.		
1-MCP	1-MCP is thought to interact with ethylene receptors and thereby prevent ethylene-dependent responses. A commercial breakthrough in 1-MCP application technology resulted from the formulation of 1-MCP as a stable powder in which it forms a complex with γ-cyclodextrin, so that 1-MCP is easily released as a gas when the powder is dissolved in water.	1-MCP has a non-toxic mode of action, negligible residue and is active at very low concentrations. By 2005 food use registration for the chemical had been obtained in Argentina, Australia, Austria, Brazil, Canada, Chile, Costa Rica, France, Guatemala and Honduras, Israel, Mexico, the Netherlands, New Zealand, South Africa, Switzerland, Turkey, UK, and the US (Watkins, 2006b). A drawback caused by 1-MCP application is loss of aromatic flavour. Influence of 1-MCP on microbial growth and decay has not been consistent; it may negatively influence plant defence systems to increase decay, on the other hand, may decrease decay by slowing ripening [14].	• Apple • Melon • Avocado • Banana • Mango • Melon • Nectarine • Papaya • Tomato • Kiwifruit • Peach • Pear • Pepper • Pineapple • Plantain • Squash • Plum • Persimmon[15] Registration for use on various fruit and vegetables is expected to increase.	AgroFresh, Inc, a subsidiary of Rohm and Haas (Springhouse, PA), developed 1-MCP under the trade name SmartFresh™ and have global use rights for edible horticultural products. They also market a similar technology (EthylBloc™) for the floral industry to maintain the freshness of fresh-cut flowers and potted and bedding plants. Contact through webpage: http://www.agrofresh.com/contactus.html
Hypobaric	It consists on the reduction of	Commercial application of this	• Tomato	See MA storage. The

[14] http://www.ars.usda.gov/research/publications/Publications.htm?seq_no_115=226584
[15] http://www.agrofresh.com/smartfresh_faqs.html

storage	pressure below atmospheric pressure (i.e. less than 1 atm) inside a food containment system (*e.g.* package, coldstore, shipping container, dedicated storage compartment). Gases created by metabolic processes (e.g. ethylene, carbon dioxide, aromas) are constantly being flushed out of the containment system. A decrease of pressure will lead to a decrease in oxygen, thus leading to low respiration rates and retarded ripening of fruit and vegetables. Further, oxygen concentrations below 1% lead to the inhibition of growth of aerobic bacteria and most fungi varieties This technology is also known as *low pressure (LP), sub-atmospheric, moderate vacuum* or *partial vacuum* storage.	technology in shipping containers has been surrounded by controversy and lawsuits, which may have handicapped the application in this area permanently. Opportunities can be opened in new areas of application e.g. retail and domestic refrigeration, although significant technical challenges remain.	• Parsley • Asparagus (Li and Zhang, 2006)	technology remains experimental.

Opportunities and Barriers

Table 12 summarises the social, technological, economic, ecological and political/legal factors affecting the uptake of emerging quality evaluation and extension technologies. This table was compiled from views expressed in a variety of industry reports and forums, which are included in the References section.

Table 12. Environmental (STEEP) analysis showing the opportunities, challenges and threats affecting the diffusion of quality evaluation and extension technologies.

VARIABLE	TREND	OPPORTUNITY	CHALLENGE
Social	Labour shortages in rural Australia.	Development of quality extension and monitoring technologies that decrease manual labour. Use of modern technologies in packing houses can attract young workers that want to work in an innovative company.	Cost-benefit may not be positive for all operations and products. KNOWLEDGE BARRIER
	Rejection of GMs, which are perceived as 'Frankenfoods'.	Address erroneous information about GMs and enhance communication with consumers about benefits of GM crops.	Discussing GMs with consumers is a delicate PR exercise. Public perception may only change if the food safety of GMs is proved beyond any doubt. PR will need to be backed by scientific results that guarantee public and environmental safety.
	Emergence of environmental concerns such as "food miles" and food carbon footprints.	Development of quality extension systems that maintain product quality while decreasing environmental impacts.	Competition and fragmentation may make communication and trust-building difficult. COMPETITIVE POSITIONING BARRIER.
	Consumers need for foods that fit their health and wellness expectations remain strong	Positioning the horticultural industry as a main supplier of healthy and innovative processed and fresh products.	An improvement in nutritional contents of fresh vegetables will have to be achieved against a backdrop of increased climate challenges and decreased land availability. The amounts of water, nutrient, and chemical inputs required for protection and growth will be drastically reduced. Physiology and engineering will be fundamental to precisely deliver inputs via spray, drip, injection, or carried on nanoparticles [16]. ENVIRONMENTAL BARRIER
Technological	Use of biotechnology for developing varieties with improved quality (flavour, colour, size, nutritional content).	When applied successfully, biotechnology can substantially improve product differentiation and reduce costs for growers (see cost-benefit aspects for biotechnology in Environmental report).	Horticulture includes hundreds of distinct plants, the majority of which are grown on small acreages and which individually represent relatively small market values. This makes it difficult to recover R&D costs.

[16] http://www.goodfruit.com/issues.php?article=2664&issue=103

		High costs to gain access to patented genetic-engineering methods and meeting the regulatory requirements for testing and registration of biotech crops. Negative consumer perception and reluctance of food processors and marketers to accept new biotech commodities. Particularly in Australia and New Zealand, where the "clean and green" image is highly regarded by consumers. Due to disappointing past commercial results and current market outlook, many horticultural seed and nursery companies are reducing their investments in genetic engineering research. REGULATORY/COST/COMPETITIVE POSITIONING BARRIERS. **THREAT: Competitors are already using biotechnology. Australian horticulture can be disadvantaged if biotechnology is not developed, particularly in the light of Australian-specific climate change challenges.**
Use of sophisticated technology for grading often requires specialised knowledge. Operators need to be trained in several product types and the learning curve can be slow.	Opportunity to develop systems that are easy to use and with little training required. Easy-to-use factors include the automation of as much of the set-up process as possible, so that the operator can set up on a new product with minimal interaction with the system. Particularly in companies with a large number of product mixes and short batch runs on the same production line. Unskilled operators need to be able to reconfigure the vision system quickly and reliably to inspect a new product type.	Cost of development. Companies generally prefer to invest in "off the shelf", already tested technology. COST/AWARENESS BARRIER.

	The need for profit has led the private sector to defend their investments in crop biotechnology with patents, intellectual property rights, and new protection methods, e.g. 'terminator' technology that inhibits germination of self-pollinated seeds. This technology protection system prevents farmers from saving seeds from their harvest for further utilisation as next season planting propagules (Ortiz, 1998).	There is an opportunity to create IP protection systems (e.g. laws, technology) that effectively balance elemental human rights (e.g. produce, market and eat foods that are GM free) with protection for the companies that have invested in GMs, without resorting to 'terminator' technology.	Developing a global IP protection system for biotechnology is likely to be difficult. Companies will need to be convinced that 'terminator' technologies are a barrier to increase acceptance to GMs. Further, consumers need to be convinced that GM developers are not jeopardising crop production and thus, putting in risk food security. COMMUNICATION BARRIER
	Strong consumer focus on price as a result of the financial crisis, yet quality remains important due to a shift towards home cooking and a decrease in restaurant meals.	Positioning high quality horticultural products on the "good value" bracket, as opposed to the "low price" category.	Premiums expected for high quality product may not justify investment in emerging technologies for quality improvements. COST BARRIER.
Economic	Increased energy / fuel costs.	Improvement of cold chain equipment and protected horticulture technology to decrease energy consumption.	Temptation to cut energy costs by sacrificing temperature control and thus, product quality. AWARENESS AND COST BARRIERS.
	Increasing role of supermarkets as gatekeepers in the supply chain, demanding longer lines of consistent quality fruit.	Opportunity to place supermarkets as innovation leaders in the development of technologies that decrease quality variability and meet retailers' quality expectations. In this role, supermarkets could provide the skills and capabilities, forward contracts, economies specialisation, scale and scope needed for sophisticated domestic market development.	There is a risk of such a structure stifling innovation down to achieving the quality levels for the domestic market (*i.e.* what supermarkets require), but not achieving higher quality levels for export markets. The current environment is not conducive to collaborative innovation between suppliers and retailers. This structure can only work if there is trust and transparency among the co-innovators. COMPETITIVE POSITIONING BARRIER.
	The cost-benefit case for technologies that improve quality and shelf-life is poorly understood. Often, technology providers do not develop specific studies for speciality markets such as horticulture.	Developing cost-benefit studies that clearly show the cost of waste due to decreased shelf-life, food safety recalls and poor quality. With this information, develop the case for emerging technologies that monitor or improve quality.	The development of these cases can be quite complex. It will be different for each type of produce, market and volume. Further, the costs of implementation of emerging technologies are not as predictable as in the case of established technologies. AWARENESS AND INFORMATION BARRIERS.

Ecological	Vulnerability of food distribution systems can increase under climate change.	The vegetable industry can develop new local and regional distribution models that decrease the vulnerability of supply chains. Disruptions in product quality due to natural disasters (*e.g.* bushfires, hurricanes) can be better managed with alternative distribution systems.	No assessments on the consequences of disruptions due to extreme weather events and bush fires on product safety and quality have been undertaken for the vegetable industry. AWARENESS BARRIER. Perishable supply chains are likely to become more dependent on cold chain maintenance. Potential increase in distribution costs and food safety risks. AWARENESS BARRIER **THREAT: Recent experiences from Hurricane Larry and the Victorian bush fires demonstrate that both supply and quality of fresh vegetables is disrupted. This makes the Australian industry more vulnerable to lose market share to imported product.**
Political/ regulatory	Reclaimed water can help polluting industries to comply with EPA standards for outfall discharge (Hamilton et al., 2008).	Opportunity for developing case studies that show the safety of recycled water in produce and the impact on nutrient contents.	Changes in the use of recycled water can lead to increased food safety risks and produce-related outbreaks. This can in turn lead to over-regulation of the horticultural sector. REGULATORY BARRIER.
	FSANZ is currently developing Primary Production and Processing Standards for seafood, dairy, eggs, poultry and seed sprouts. It is likely that fruit and vegetables will be also included in the future.	Better regulations can lead to improved quality.	**THREAT: Decrease of profit margins due to new regulatory burdens around food safety for vegetable processors.**

HAL-Funded Projects in Technologies for Quality Evaluation and Extension

To detect the major focus of investment in HAL projects, a list of the titles of all vegetable funded projects[17] in quality evaluation and shelf-life extension was analysed to extract the frequency distribution of keywords within the title.

Titles of projects and start dates were extracted from the HAL database by performing a keyword search that reflected quality evaluation and extension technologies, *i.e.* project titles with concepts such as:

- Colour
- Flavour
- Aroma
- Taste
- Damage
- Computer imaging
- machine vision
- Magnetic resonance imaging
- X-ray tomography
- Mass spectrometry
- Electronic nose
- Firmness
- Ultrasound
- Near infra-red spectroscopy
- Spatially and time-resolved spectroscopy
- Dips
- biopreservatives
- Ultraviolet
- Cold plasma
- Shelf-life
- Calorimetry
- Biosensors
- Sensors
- Genomics
- Transcriptomics
- Proteomics
- Metabolomics
- spoilage
- pathogens
- Irradiation
- Ozone
- Electrolysed water
- Chlorine dioxide
- 1-MCP
- Hypobaric storage
- HarvestWatch
- Microbial

This search led to a sub-sample of 151 projects funded between 1998 and 2009. The analysis considered both fruit and vegetable types of projects, as it is believed that diffusion of technological developments is common between these areas, particularly in the context of HAL's activities.

Figure 7 shows the frequency of projects related to the concepts above. The results suggest that HAL has placed a strong emphasis on pathogen detection. Further analysis of the projects focused into pathogen investigation indicates that most of these projects investigated soil-borne pathogens, as distinct from contaminations occurring during postharvest.

[17] This list was provided by Karen Symes, HAL, on April 2009.

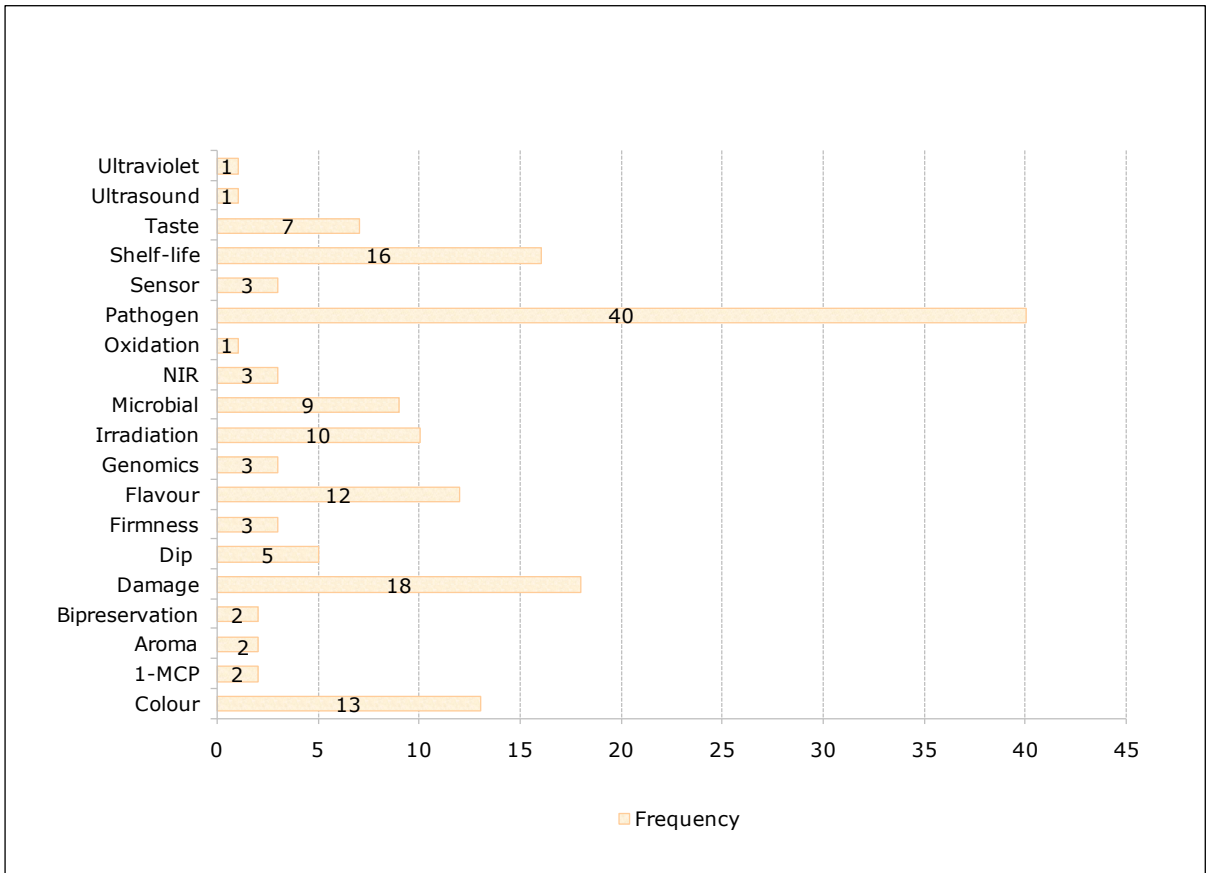


Figure 7. Analysis of keywords found in the titles of HAL-funded projects for the vegetable industry in the area of quality extension and evaluation.

Figure 8 shows the growth curve of HAL projects developed from 1988 to 2009 in the areas of quality evaluation and extension. The technology curve reached maturity in 1999 and the peak number of HAL projects in these areas is expected to occur in 2010, if no factors influence current investment policies and strategies in this platform.

This analysis is based on the number of projects, as distinct to the financial investment made on the area. HAL has an average spend per project of around $72,000 per year (Horticulture Australia Limited, 2008), which is relatively small. If future HAL strategies switch to fund fewer (but larger) projects in this and other areas, future analyses should be performed in terms of investment.

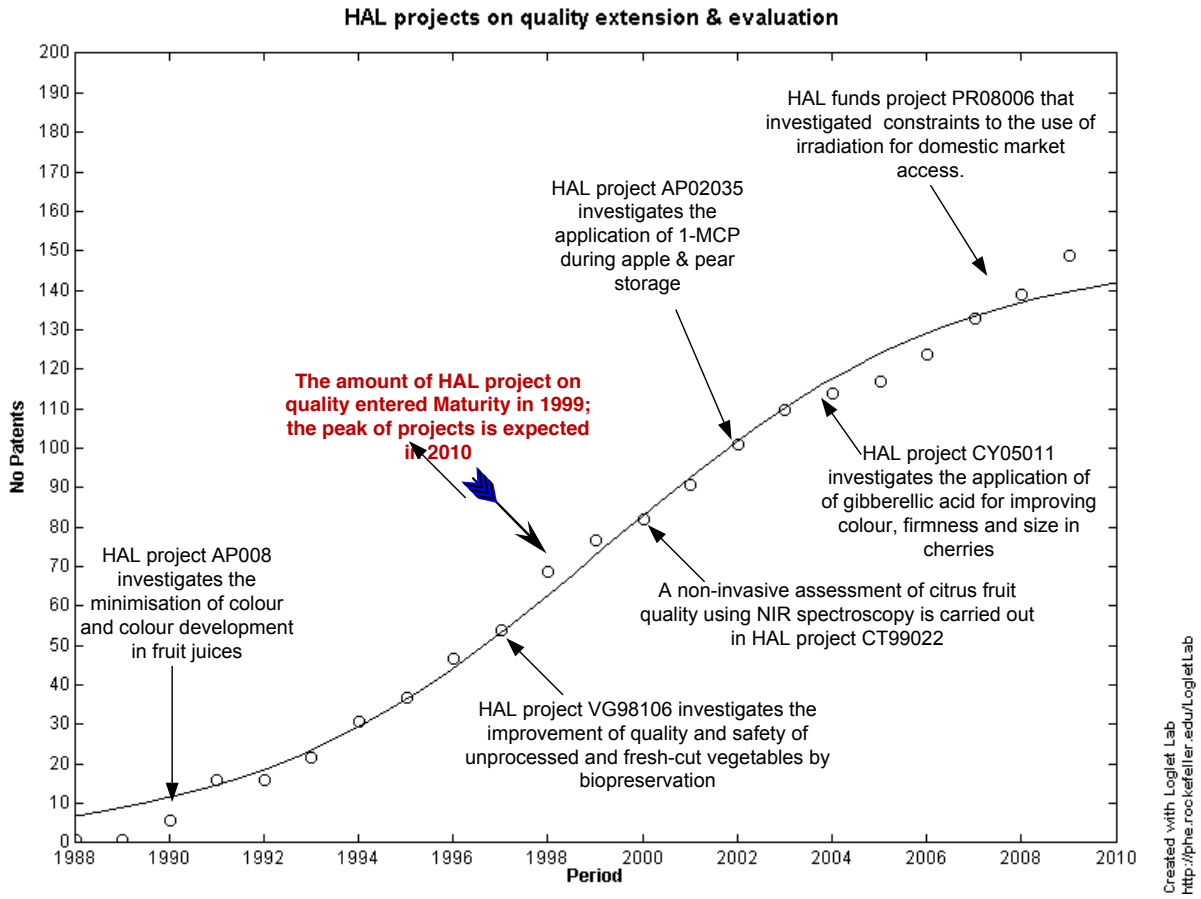


Figure 8. Historical cumulative number of projects developed with HAL funding in quality extension and evaluation technologies.

Implications and Recommendations

The trends of HAL-funded projects in quality and safety technologies suggest that the peak investment in this area will occur in 2010 and that most projects have focused on the management of soil-borne pathogens.

Figure 9 shows that the number of HAL projects related to quality aspects is lower than any of the previous platforms investigated (i.e. emerging environmental technologies and emerging supply Chain and logistics technologies), analysed in the two previous reports (Estrada-Flores, 2009a, Estrada-Flores, 2009b).

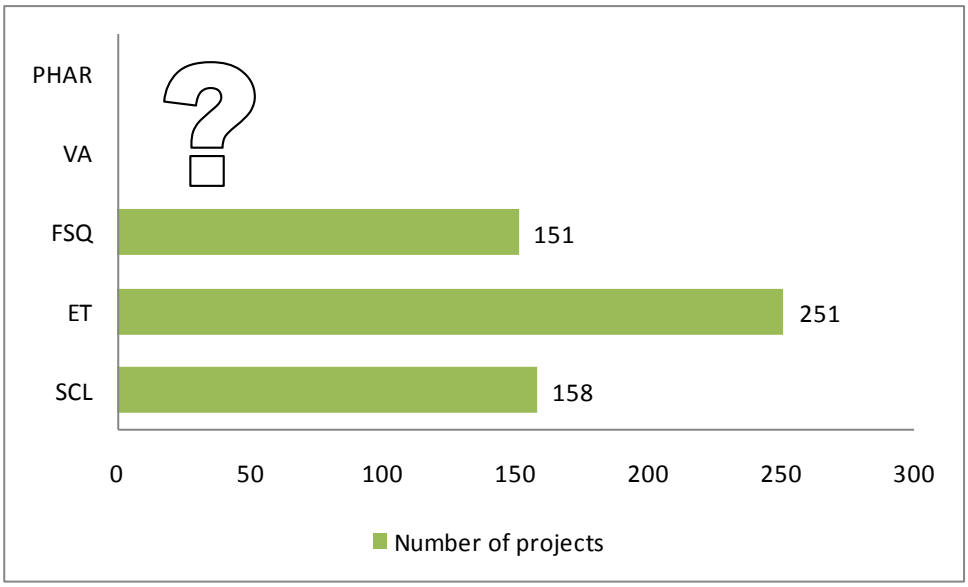


Figure 9. Comparison of projects developed in the five emerging technology areas investigated in project VG08087. Codes: SCL= supply chain & logistics; ET= environmental technologies; FSQ= food quality & safety; VA= value addition; PHAR= production and harvesting.

The Australian Horticulture Plan "Future Focus" emphasized the need for innovation in quality-related technologies. The potential cumulative payoffs from three subprograms related to quality (commercial/marketing, novel products and eating quality platforms) represent $1.48 billion (Horticulture Australia Limited, 2008). This is unlikely to be achieved if the investment of HAL (as represented by number of projects) peaks in 2010 and then declines.

Therefore, there is a need to review current HAL policies on the quality area, in view of the expected outcomes stated in "Future Focus".

Tables 13 and 14 summarise the analyses performed for the quality evaluation and extension technologies discussed, respectively.

Table 13. Summary of the status of the selected emerging technologies used for quality evaluation.

CATEGORY	EMERGING TECHNOLOGY	STAGE OF TECHNOLOGICAL DEVELOPMENT	PREDICTABILITY		LIFE CYCLE (Benchmark: 2009)		INVESTMENT	HAS HAL INVESTED ON THIS AREA?	LEVEL OF ADOPTION
			Technical	R&D costs	Time to commercialisation	Time to R&D decline			
External evaluation	**Computer imaging**	MATURE	HIGH	HIGH	Already commercialised	7 years	Between $100 K to $1 m	NO	MEDIUM
Internal evaluation	**X-ray imaging**	GROWTH	FAIR	HIGH	2-7 YEARS	Over 30 years	Cost per grading line aprox.US$1,040/day	NO	LOW
	Multispectral (MS) and hyperspectral (HS) imaging	EMBRYONIC	POOR	POOR	7-15 years	Over 30 years	UNKNOWN	NO	LOW
	Magnetic resonance imaging	EMBRYONIC	POOR	POOR	7-15 years	Over 30 years	UNKNOWN	NO	LOW
	Fluorescence (DLE) imaging	EMBRYONIC	POOR	POOR	7-15 years	Over 30 years	UNKNOWN	NO	LOW
Aroma	**Headspace fingerprinting mass spectrometry**	GROWTH (AS A TECHNIQUE FOR GRADING LINES)	FAIR	HIGH	2-7 YEARS	Over 30 years	UNKNOWN	NO	LOW
	Electronic nose	GROWTH	FAIR	HIGH	2-7 YEARS	Over 30 years	$8,000-$60,000	NO	LOW
Firmness	**Acoustic impulse response**	GROWTH	FAIR	HIGH	2-7 YEARS	Over 30 years	Bench version about $2,000. Grading line: unknown	NO	LOW

	Impact analysis	GROWTH	FAIR	HIGH	2-7 YEARS	Over 30 years	Bench version about $2,000. Grading line: unknown	NO	LOW
	Ultrasound	EMBRYONIC	POOR	POOR	7-15 years	Over 30 years	UNKNOWN	NO	LOW
Taste	**NIR, FTIR**	GROWTH	FAIR	HIGH	2-7 YEARS	Over 30 years	UNKNOWN	NO	LOW
	Spatially and time-resolved spectroscopy	EMBRYONIC	POOR	POOR	7-15 years	Over 30 years	UNKNOWN	NO	LOW
	Electronic tongue	EMBRYONIC	POOR	POOR	7-15 years	Over 30 years	UNKNOWN	NO	LOW
Microbial spoilage & contamination	**Piezoelectric sensors**	GROWTH	FAIR	HIGH	2-7 YEARS	Over 30 years	UNKNOWN	NO	MEDIUM IN MANUFACTURED FOODS, LOW IN FRESH PRODUCE COMPANIES
	Enzymatic-electrochemical sensor	GROWTH	FAIR	HIGH	2-7 YEARS	Over 30 years	UNKNOWN	NO	MEDIUM IN MANUFACTURED FOODS, LOW IN FRESH PRODUCE COMPANIES
	Biosensor coupled with RFID	GROWTH	FAIR	HIGH	2-7 YEARS	Over 30 years	UNKNOWN	NO	LOW

Table 14. Table 13. Summary of the status of the selected emerging technologies used for quality improvement/extension.

CATEGORY	EMERGING TECHNOLOGY	STAGE OF TECHNOLOGICAL DEVELOPMENT	PREDICTABILITY		LIFE CYCLE (Benchmark: 2009)		INVESTMENT	HAS HAL INVESTED ON THIS AREA?	LEVEL OF ADOPTION
			Technical	R&D costs	Time to commercialisation	Time to R&D decline			
Improvement of quality traits and nutritional content	**Functional genomics**	GROWTH	FAIR	HIGH	2-7 YEARS	GROWTH	UNKNOWN	YES	LOW-MEDIUM
	Hormesis	EMBRYONIC	POOR	POOR	7-15 years	Over 30 years	UNKNOWN	NO	LOW
Reduction of pathogens and spoilage	**Irradiation**	GROWTH	FAIR	HIGH	2-7 YEARS	Over 30 years	between US$0.01/lb and US$0.08/lb	YES	LOW
	Ozone	GROWTH	FAIR	HIGH	2-7 YEARS	Over 30 years	UNKNOWN	YES	LOW
	Electrolysed water	EMBRYONIC	POOR	POOR	7-15 years	Over 30 years	UNKNOWN	NO	LOW
	Microbial antagonists/ biopreservation	EMBRYONIC	POOR	POOR	7-15 years	Over 30 years	UNKNOWN	YES	LOW
	Ultraviolet light	GROWTH	FAIR	HIGH	2-7 YEARS	Over 30 years	UNKNOWN	YES	LOW
	Cold plasma	EMBRYONIC	POOR	POOR	7-15 years	Over 30 years	UNKNOWN	YES	LOW
	Chlorine dioxide	MATURE	HIGH	HIGH	Already commercialised	7 years	5 times more expensive than chlorine	NO	MEDIUM

	Hurdle technology	DEPENDS ON THE HURDLES	HIGH	HIGH	Already commercialised	7 years	DEPENDS ON THE COMBINATION OF TECHNOLOGIES	NO	MEDIUM
Control of environmental conditions	**MA**	MATURE/DECLINE	HIGH	HIGH	Already commercialised	7 years	DEPENDS ON THE APPLICATION	YES	HIGH
	Dynamic MA (HarvestWatch)	GROWTH	FAIR	HIGH	2-7 YEARS	Over 30 years	UNKNOWN	NO	LOW
	1-MCP	GROWTH	FAIR	HIGH	Already commercialised	Over 30 years	UNKNOWN	YES	LOW
	Hypobaric storage	EMBRYONIC	POOR	POOR	7-15 years	Over 30 years	UNKNOWN	NO	LOW

From Tables 13 and 14, the following observations can be drawn:

- Out of the 16 technologies investigated for quality evaluation, only one (computer imaging) can be classified as mature. The other technologies are still in development and even in experimental phases.
- Out of 14 technologies investigated for quality extension, only two technologies (chlorine dioxide and MA) can be classified as mature. The other technologies are still in development and even in experimental phases.
- In view of the points above, most of the technologies investigated will not become obsolete until 2040. Adoption and commercialisation of the technologies that survive the "valley of death" is likely to occur in 10-15 years. Costs of R&D remain uncertain and high.

Given these challenges, there seems to be little incentive for growers to invest in emerging technologies for quality management. However, we discussed before the need to invest in quality systems that will provide Australian farmers with the competitive edge necessary to achieve the goals of the "Future Focus" strategic plan.

One potential strategy to invest in quality-related technologies is the application of the "virtuous circle" concept as presented by Banks et al. (2009). In a virtuous cycle, the changes introduced in a system receive a positive feedback in the form of valuable consequences of that change. Fresh produce supply chains can enter a virtuous cycle of innovation when the positive effects of consumers having superior eating experiences are fed right back through the chain, encouraging all participants to support innovations 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 et al., 2009). This further supports the need to monitor and trace quality issues (and positive feedback) across the chain: the understanding of the changes and innovations that deliver product that sells requires the monitoring and evaluation of quality from the field to the consumer.

We have discussed that the projects funded in HAL are traditionally small (i.e. about $72,000 per project). This type of decentralization of competitive R&D funding can stimulate innovation because the competitive pressure on providers enhances the diversity of approaches used, encourages researchers towards being maximally creative and also encourages effective use of resources (both in staff members and budgets). However, decentralization also divides the total innovation expenditure into smaller, less powerful projects and can lead to select overlapping projects. The likelihood of achieving critical mass for any particular initiative is low (Banks et al., 2000).

Innovation in quality systems requires an integrative approach. A small (e.g. less than $40 K) project that investigates the use of ultraviolet pulses in lettuce is good. A portfolio (e.g. over $100 K) that investigates the use of emerging technologies on vegetable quality improvement is better, because the project can accommodate several researchers from different institutions. Diffusion of new knowledge among research groups can be encouraged through meetings and forums on quality evaluation or extension technologies.

HAL as a promoting agent of these "meetings of minds" is able to fulfil this role better than any other R&D organisation.

Throughout this report, it has been established that improving quality and reliability of horticultural products provides the opportunity to considerably lift the volumes of fruit purchased domestically and internationally. However, one of the greatest barriers to innovation can be the industry itself. As Banks et al. (2000) point out:

"Ironically, some industries have been resisting implementation of these technologies as there has been concern for what would be done with the half of the fruit population that is, by definition, below average. Such thinking entrenches poor production practice as, without systems for detecting fruit with high inherent but invisible quality, it is difficult to devise workable incentives for producing better tasting and longer lasting fruit. New measurement systems will create an environment in which new production practices that address these issues can become worthwhile. In this way, engineering will supplement enhancements to fruit quality being sought through breeding programmes, creating systems in which average quality is improved and the spread of quality around the average reduced."

A recent hurdle that has affected the uptake of new and mature technologies in postharvest quality evaluation and extension is the reduction of R&D funding dedicated to address production and marketing of horticultural products. CSIRO, DPI and universities carried out research on innovative technologies such as acoustic and impulse measurements for firmness, packaging films for fresh horticultural produce, mathematical modelling, modified atmosphere storage, HarvestWatch and 1-MCP, among other technologies. Now CSIRO and DPI have decreased its research on postharvest and little funding is dedicated to postharvest quality.

Professor Barry McGlasson[18] pointed this out in his address to the Senate Committee Inquiry about food production in Australia (Feb 2009)[19]:

"The adverse publicity arising from these Federal and State government decisions and the generally bad news about the agriculture sector have deterred students from considering tertiary courses in agriculture, horticulture and food. Since funding of university teaching programs is largely dependent on student numbers, as numbers have fallen universities have not replaced academic staff in agriculture, horticulture and food. This has resulted in the closure of courses at some universities. In 1994 at UWS Hawkesbury there were about 300 students in horticulture including undergraduate, Graduate Diplomas, course work Masters and higher degree research students. Today we have less than 20 undergraduate students, no coursework Diplomas or Masters Courses and about 10 PhD students working on horticultural topics at any one time. "

HAL supports R&D in postharvest quality through investment. However, HAL and vegetable grower organisation can also support universities in reversing the loss of students in postharvest areas, which are the lifeblood of innovation. Support can be provided through meetings and forums that address the challenges faced in postharvest education in Australia. Further, a study that analyses the opportunities and issues for postharvest

[18] Adjunct Professor, Centre for Plant and Food Science, University of Western Sydney Hawkesbury campus

[19] http://www.aph.gov.au/hansard/senate/commttee/S11752.pdf

education and compiles aspects such as the education programs in postharvest quality existent in Australia and overseas, the R&D programs undertaken in these institutions and the potential synergies among R&D providers, would be helpful. Such analyses can be used to design strategies to overcome the current loss of human resources in education and research. The detected gaps in Australian postharvest R&D could be filled through universities and R&D institutions overseas, through student exchanges or collaborative R&D projects, for example.

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Appendix 1. Studies on the application of hypobaric treatments on fruit and vegetables

PRODUCT	STORAGE CONDITIONS				EFFECTS ON PRODUCT QUALITY		REFERENCES
	T (°C)	P (atm)	RH (%)	ST (Days)	POSITIVE	NEGATIVE	
Black beans	4.5	0.164	50-60	730	After 2 years, the beans exhibited quality factors characteristic of fresh beans, such as short cooking time, small quantities of solids loss during cooking, low quantities of electrolytes leached to the cooking water, and low percentage of hard-shell after cooking.	None reported	J. J. Berriosa, B.G. Swanson, W. A.Cheong. (1999). Physico-chemical characterization of stored black beans (Phaseolus vulgaris L.). Food Research International 32, p.669-676
Asparagus	3 ± 1	***Stage 1:*** 0.148±0.05 ***Stage 2:*** 0.247±0.05 ***Stage 3:*** 0.444±0.1	***Stage 1:*** 80-85 ***Stage 2:*** 85-90 ***Stage 3:*** 90-95	***Stage 1:*** 3 ***Stage 2:*** 7 ***Stage 3:*** 15	Senescence (as loss of texture) retarded under the 3-stage hypobaric storage.	Off-odours	W. Li, M. Zhang. 2006. Effect of three-stage hypobaric storage on cell wall components, texture and cell structure of green asparagus. Journal of Food Engineering 77: 112–118
Avocado	6 ± 1	0.079	80-95	70	LP conditions markedly delayed the ripening of avocados. All fruits ripened normally several days after being transferred to atmospheric pressure and 14°C, thus there was no damage to the fruit. Avocados retained their ability to ripen normally and develop proper texture and taste.	None reported	(1) A. Apelbaum, G. Zauberman, and Y. Fuchs. 1977. Prolonging Storage Life of Avocado Fruits by Subatmospheric Pressure. HortScience 12(2): 115-117. (2) Burg, S.P. 2004. Postharvest physiology and hypobaric storage of fresh produce. CABI Publ. Cambridge, USA . P 376-377.

PRODUCT	STORAGE CONDITIONS				EFFECTS ON PRODUCT QUALITY		REFERENCES
	T (°C)	P (atm)	RH (%)	ST (Days)	POSITIVE	NEGATIVE	
Cantaloupe (1)	7.2	0.019	95	20	Storage was significantly improved at these conditions, with respect to trials at 4.4 °C.	Growth of rots is possible in the presence of carbon dioxide	Burg, S.P. 2004. Postharvest physiology and hypobaric storage of fresh produce. CABI Publ. Cambridge, USA . P 381
Cantaloupe (2)	4.4 ± 1	0.079	95	18	None reported	No advantage was observed with respect to normal refrigerated storage at the same temperature. Decay developed in both.	Burg, S.P. 2004. Postharvest physiology and hypobaric storage of fresh produce. CABI Publ. Cambridge, USA . P 381.
Cucumber	14 ± 1	0.099	98	30	External colour remained stable, possibly due to slower chlorophyll transformation into carotenoids under low oxygen conditions. Texture (as a measure of compression force) remained constant during storage.	None reported	P. Zapotoczny, M. Markowski and K. Majewska. 2003. The Quality of Cucumbers Stored under Hypobaric Conditions. Acta Hort. 600: 193-196.
Loquat	3 ± 1	0.395-0.493	Not reported	49	Reduction of enzymatic activity, respiration rate, ethylene production and general deterioration, with respect to a control batch kept at atmospheric conditions and at the same temperature.	None reported	H.Y. Gao, H.J. Chen, W.X. Chen, Y.M. Jiang, J.T. Yang and L.L. Song. 2006. Effect of Hypobaric Storage on Physiological and Quality Attributes of Loquat Fruit at Low Temperature. Acta Hort. 712,269-273.
Green banana (with and without ethylene pre-treatment)	14± 1	0.067	Not reported	28	The bananas remained green and firm during storage. The product ripened normally after being taken out of the LP system.	Peel pitting, some development of stem-end rot.	Burg, S.P. 2004. Postharvest physiology and hypobaric storage of fresh produce. CABI Publ. Cambridge, USA . P 378-379.
Mushroom (Golden, Light White Button, Shitake, Enokitake and Matsutake cultivars)	5 ± 1	0.013-0.474	98	21	At these conditions, the eatibility (as measured by a hedonic scale) was high after 21 days of storage.	At temperatures close to 10°C, there is a risk of development of botulism toxins. Temperature control is critical under these low oxygen conditions; product should be taken out of the package before placing in hypobaric conditions.	Burg, S.P. 2004. Postharvest physiology and hypobaric storage of fresh produce. CABI Publ. Cambridge, USA . P 411-412.

Notes: T= temperature; P = pressure; RH = relative humidity; ST = Storage time.

Appendix 2. Reported cases linked to consumption of fresh produce in Australia from 1991 to 2008

YEAR	PRODUCT	ORIGIN OF OUTBREAK	PATHOGEN
1991	Unpasteurised orange juice	Australia	*Norovirus*
1994	Alfalfa sprouts	Australia	*Salmonella*
1995	Cucumber	SA	*Campylobacter spp*
1998	Imported garlic	Australia	*Salmonella virchow*
1999	Unpasteurized orange juice	SA	*Salmonella typhimurium*
2001	Lettuce, salad mix	QLD	*Salmonella bovismorbificans*
2004	Salad mix	Australia	*Salmonella*
2004	Gourmet rolls/red onion	VIC	*Salmonella typhimurium*
2004	Vegetable dish	Australia	*Salmonella*
2005	Strawberries	ACT	*Unknown*
2005	Alfalfa sprouts	WA, QLD	*Salmonella oranienburg*
2005	Cut fruit	NSW	*Salmonella typhimurium*
2005	Freshly squeezed blood orange juice	NSW	*Unknown*
2006	Paw paw	WA, QLD	*Salmonella litchfield*
2006	Rock melon	NSW	*Salmonella saintpaul*
2006	Bean shoots	VIC	*Salmonella saintpaul*
2006	Alfalfa sprouts	VIC	*Salmonella oranienburg*
2007	Watermelon	NSW	*Unknown*
2007	Fruit salad	VIC	*Norovirus*
2007	Mushrooms and cos lettuce	NSW	*Unknown*
2007	Baby corn (imported from Thailand)	QLD	*Shigella sonnei*
2007	Fresh fruit juice	NSW	*Unknown*
2008	Salads and sandwiches	VIC	*Hepatitis B*

Sources: Food Science Australia and Minter Ellis, 2002; OzFoodNet, 2001-2008; Food Science Australia, 1995-2007.

Note: the cases highlighted in green are controversial: in the red onion case, slices of red onion tested positive for Salmonella but whole onions did not, thus suggesting cross contamination during the roll's preparation. In the case of the bean shoots, beans stored in an open container showed contamination, but beans from a sealed packaged tested negative. A produce-related outbreak involved a tomato and cucumber salad. This table attributes the outbreak to cucumber only.

Appendix 3. Recall procedures involving fresh produce in Australia (1991-2008)

Year	PRODUCT	Manufacturer	Retailer/wholesaler	Market	PATHOGEN
2003	Alfalfa sprouts	North Coast Sprouts	North Coast Sprouts	NSW	Listeria monocytogenes
2003	Alfalfa sprouts (organic)	North Coast Sprouts	North Coast Sprouts	NSW, SA, QLD	Salmonella
2003	Pre-packed salad	Woolworths Fresh Brand	Woolworth's	WA	Listeria monocytogenes
2003	Organic salad	North Coast Sprouts	North Coast Sprouts	NSW, SA, QLD	Salmonella
2006	Alfalfa sprouts,garlic chives, broccoli sprouts, onion sprouts, mung beans, beans shoots	Parrilla West Pty Ltd		VIC, TAS	Salmonella and Listeria
2007	Green Sprouts Pure Onion	Sprout Farms Pty Ltd	Woolworth's	QLD, NSW, NT	E. Coli

Sources: Food Standards Australia New Zealand (FSANZ), Product Recalls Australia, 2008.

Appendix 4. Major genetic modifications for quality improvement of horticultural products

Table 4.1. Effects of modifying gene expression from ethylene biosynthesis on postharvest quality.

Gene	Type of modification	Plant species	Ripening processes	Changes[a]
ACS	Antisense or cosuppression	Tomato	Ethylene production	↘ (99%)
			Pigment formation	↘
			Chlorophyll degradation	↘
			Firmness	↗
			Aroma production	↘
ACO	Antisense	Tomato	Ethylene production	↘ (97%)
			Acidity	↗
			Pigment formation	↘
			Cracking and damage	↘
	Antisense	Melon	Ethylene production	↘ (99.5%)
			Rind yellowing	↘
			Climacteric respiration	↘
			Peduncle abscission	↘
			Flesh softening	↘
			Aroma	↘
			Chilling injury	↘
	Antisense	Broccoli	Ethylene production	↘ (90%)
			Respiration	↘
SAMase	Overexpression	Tomato	Ethylene production	↘ (80%)
	Overexpression	Melon	Ripening duration	↗
			Sugar content	↗
			Peduncular abscission	↘
ACC deaminase	Overexpression	Tomato	Ethylene production	↘ (85%)

[a] Arrows indicate increase (↗), inhibition (↘), or no effect (→) on ripening or quality attributes

Source: (Bernadac et al., 2003)

Table 4.2. Effects of modifying gene expression in cell-wall degradation on tomato postharvest quality.

Gene	Type of modification	Ripening processes	Changes[a]
PG	Antisense or cosuppression	Pectin degradation	↘
		Mechanical damage	↘
		Fungal diseases	↗
		Viscosity for processing	↗
PME	Antisense	Soluble solids content	↗
Cel (Egase)	Antisense	Ripening and firmness	→
Exp	Antisense	Firmness	↗
β-gal			
-TBG1	Antisense	Firmness	→
		Galactosyl residues	↘
-TBG3	Antisense	Firmness	→
		Galactosyl residues	↘
		Postharvest deterioration	↘
-TBG4	Antisense	Firmness	↗
		Galactosyl residues	↘

[a] Arrows indicate increase (↗), inhibition (↘), or no effect (→) on ripening or quality attributes.

Source: (Bernadac et al., 2003)

Appendix 5. The effect of 1-MCP on the metabolism of fruit and vegetables

Table 5.1. Generalizations regarding the effects of 1-MCP on metabolism of fruit and vegetables (Watkins, 2006b)

	Attribute or process affected	**Enzyme activity or associated gene expression**	**Increased (↑), decreased (↓), or unchanged (↔)**
Ethylene metabolism	Ethylene perception	ETR1, ERS1	↓↔
	Ethylene production		↓↑
		ACC synthase (ACS) expression and activity	↓
		ACC oxidase (ACO) expression and activity	↓
Respiratory metabolism	Respiration rate		↓↑↔
	SSC		↓↑↔
	TA		↓↑↔
Pigments	Chlorophyll degradation		↓
	Lycopene accumulation		↓
	Anthocyanin accumulation		↓
		Chlorophyllase activity	↓
Phenolic metabolism	Total phenolic content		↓
		Phenylalanine ammonia lyase (PAL) activity	↓
		Polyphenol oxidase (PPO) activity	↓
Cell wall metabolism	Soluble polyuronide content		↓
		Polygalacturonase (PG) activity	↓
		Pectin methylesterase (PME)	↓
		Endo-β-1,4-glucanase (EGase)	↓
		Glycosidases	↓↔
Volatile compound metabolism	Esters		↓
	Aldehydes		↔
	Terpenoid biosynthesis		↔
	Acetaldehyde and ethanol accumulation		↓↑
		Alcohol acyl transferase activity	↓

		Alcohol dehydrogenase activity	↔
Nutritional	Vitamin C loss		↓
	Anthocyanin contents		↓
	Phenolic contents		↓ ↔
	Antioxidant activity loss		↓
Physiological disorders	Senescent disorders		↓
	Chilling injury		↓↑
	Superficial scald (apples and pears)		↓
	Ethylene-induced disorders		↓
	Controlled atmosphere-induced		↑
	Abscission		↓
Pathological disorders	Susceptibility to pathogens		↑↓↔
	Fungal growth		↓↔

Appendix 6. Commercially available modified atmosphere packaging systems for small and large quantities of produce.

Product	Description	Use
Pallet Package System	Pallet box wrapped in heavy gauge polyethylene, with a silicone membrane window to allow gas exchange regulation and a calibrated hole for pressure regulation.	Apples, pears and other perishables
Marcellin System	For room storage: regulates the atmospheric composition via a parallel series of rectangular bags of silicone rubber; can be installed in or out of storage area and maintains a fairly consistent atmosphere.	Various perishables
Tom-Ah-Toes (Natural Pak Produce)	Long, narrow box overwrapped with gas permeable film; contains a sachet containing calcium chloride and activated lime to absorb CO_2.	Avocados, tomatoes, mangoes
Maptek FreshTM (SunBlush Technologies Inc.)	Maptek FreshTM is a post-harvest biotechnology where specific features and conditions are applied for each type of product to stabilize the produce and place it in a state of hibernation.	Fresh-cut produce: pineapple, fruit salad, cut tomatoes, mango, kiwi, melon, citrus fruits
MAPAX® (AGA, Sweden)	This system incorporates the optimal atmosphere by testing, to choose the exact gas mixture and the best film for each product considering respiration rate, temperature, packaging film, pack volume, fill weight and light.	Fresh-cut produce, lettuce, mushrooms, prepeeled potatoes
FreshHold (Hercules Chemical Co.)	Polypropylene label with calcium carbonate embedded in it.	Broccoli, asparagus, cauliflower and cherries
P-Plus films (Courtaulds Packaging)	Spark perforated films which result in non-uniform perforations throughout the film to facilitate gas exchange.	Brussels sprouts, lettuce, broccoli, fresh mushrooms, and bean sprouts
Laminated boxes (Georgia Pacific, Weyerhaeuser and Tamfresh Ltd.)	Cartons with films laminated within the cardboard or coated on the inside of the cardboard liner. Reduces moisture loss and potentiates air flow	Strawberries, broccoli, and other perishables
Edible films		
TAL Pro-Long (Courtaulds Group)	Blend of sucrose esters of fatty acids and sodium carboxymethylcellulose; depresses internal O_2 and is edible.	Pears

Nutri-Save	N, O-carboxymethychitosan edible film.	Pears, apples
PacRite products (American Machinery Corp.)	Variety of products, water-based carnauba–shellac emulsions, shellac and resin water emulsions, water-based mineral oil fatty acid emulsions, and so forth.	Apples, citrus, tomatoes, cucumbers, green peppers, squash, peaches, plums, nectarines
Primafresh Wax (S.C. Johnson)	Carnauba-based wax emulsion.	Apples, citrus and other firm-surfaced fruit
FreshSealTM (Planet Polymer Technologies Inc. has licensed CPG Technologies of Agway, Inc. to produce)	A patented coating that slows the ripening process by controlling the O_2 and CO_2 and water vapour flowing in and out of the product. It can be tailored to the individual respiration rates of different fruit and vegetable varieties.	Currently available for avocado, cantaloupe, mangoes and papaya. Use on limes, pineapples and bananas is currently under investigation.
Intelligent systems		
Activated Earth Films	Typically polyethylene bags with powdered clay material made of powdered aluminum silicates, incorporated into the film matrix. Possibly reduces ethylene concentration by facilitating its diffusion out of the bag.	Variable
Temperature Responsive Films (Landec Labs)	Films increase their gas permeabilities in response to temperature increases as well as increases in respiration. Stabilizes the modified atmosphere so it remains the same under various temperatures.	Specific for each product
CO_2 Scavengers FreshLock (Mitsubishi Gas Chemical Co.), Verifrais (Codimer Tournessi, Gujan-Mestras)	Sachet type product which is placed directly in the package and absorbs both carbon dioxide and oxygen.	Fruits and vegetables, coffee
Ethylene absorbents Ethysorb (StayFresh Ltd), Ageless C (Mitsubishi Gas Chemical Company), Freshkeep (Kurarey), Acepack (nippon Greener), Peakfresh (Klerk Plastic Industrie, Chantler Packaging Inc.)	Sachet type product which is placed directly in the package and absorbs ethylene. They are composed of a variety of products such as aluminum oxide, potassium permanganate, activated carbon, and silicon dioxide.	Fruits and vegetables

Source: (Sandhya, 2010)