Appendix 1

Review of international best practice for postharvest management of sweet cherries

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Content

Introduction

The Australian cherry industry is in a strong phase of growth with forecast increases in production over the next five years. The continued profitability of the Australian cherry industry with this increased production will rely on increased sales on both domestic and export markets (Australian Cherry Strategic Investment Plan 2017-22). While it is important to maintain and grow the domestic market, the future of the Australian cherry industry will rely on exports. Indeed the Cherry SIP identified that there is a very high possibility that unless there is an effective intervention of improved quality and consumption, prices on the domestic market will decline further to the point of negative returns for many businesses (Cherry SIP 2017-22). It is therefore essential to take advantage of the growing demand for cherries in nearby export markets by consistently delivering high quality cherries.

The global trade of cherries in 2016 was US$2.4 billion. While Australian cherry exports have steadily increased 24% since 2012, the consistent delivery of high quality fruit is essential. There is tremendous scope to increase exports, but must be predicated on delivering high quality cherries onto export markets. The Australian cherry industry can learn from large world exporters, such as Chile and USA which contribute over 52% of world trade in cherries. These countries produce and market high quality fruit on distant export markets such as China. The export of highly perishable fruit such as cherry fruit to distant export markets require best practice production and postharvest practices to counter the marketing time and complexities of export supply chains.

Cherries are a perishable fruit with high growing, harvesting and packing costs. It is critical that the cherries transition to a premium with higher quality, larger fruit with better flavour and nutrition. To capitalise on improved quality, it is essential that the postharvest handling and presentation of fruit to the consumer is improved. If Australian cherries are premium quality, then consumers must feel justified in paying premium prices and this can be justified with premium packaging.

Packaging is an important part of marketing and product differentiation. High quality packaging of premium fruit can justify premium returns to the grower and packer. As production and handling costs rise, improved packaging and marketing can assist justify the increased returns to growers. The future success of the Australian cherry industry will depend on the application of international best practice for the management of cherries both for the domestic and export markets.

This report reviews (1) the critical factors involved in postharvest handling and deterioration of cherries, (2) the current postharvest requirements of cherries and (3) identifies opportunities for industry investment in strategic research and development in key areas in cherry handling and supply chain management to improve fruit quality and consistency.

Sweet cherry, *Prunus avium* L. is a stonefruit of the Rosaceae family which is widely grown in Australia. While sour cherry (*Prunus cerasus*) is grown and used in processing overseas, it is not commercially grown in Australia. This review will only discuss the postharvest requirements for sweet cherry.

Fruit physiology

Cherry fruit are still alive and respiring even after they are harvested from the tree. Therefore it is important to understand the physiology of the fruit to properly manage their behavior and ultimate quality in storage and during marketing. The physiology of fruit can be classified into two different categories depending on their ripening patterns; climacteric and non-climacteric. Climacteric fruit undergo a pronounced increase in respiration and ethylene production coincident with ripening and it is during the climacteric that all the other changes characteristic of ripening occurs (Wills and Golding, 2016). Examples of climacteric fruit include banana and apple. However non-climacteric fruit, such as cherries, do not exhibit this respiratory climacteric and the changes in ripening are generally slower (Wills and Golding, 2016). This means that cherry fruit do not rapidly ripen with big increases in sugar levels during storage, like banana fruit. The quality of cherries at harvest is generally the optimum quality. Postharvest handling and technology can only minimise the decline in quality after harvest. Postharvest technology cannot improve fruit quality.

Fruit respiration rate is a good indicator of storage life and behavior. The respiration rate of cherries is moderate compared to other fruit (Wills and Golding, 2016). Respiration rate can vary from 30 to 90 mg CO_2 $kg^{-1}h^{-1}$ at 20°C (Wills et al., 1983; Crisosto et al., 1993) and the rate depends on cultivar and stage of maturation (Wang and Long, 2014). However of most importance is that strong relationship between storage temperature and respiration rate (Table 1), where lower storage temperatures result in lower respiration rates. This is the primary mechanism to maintain quality during storage (*Temperature Section*).

Table 1. Effect of storage temperature on generalised respiration rates of cherries

Temperature	Respiration rate (mg CO_2 kg^{-1} h^{-1})
0 °C	6 to 10
5 °C	16 to 28
10 °C	20 to 36
15 °C	28 to 64
20 °C	30 to 90

Adapted from Mattheis and Fellman (2016)

Cherries also have a very low ethylene production during the ripening (Gong et al., 1994). Ethylene is a hormone promoting fruit ripening and can influence postharvest life of both climacteric and non-climacteric fruits by influencing their quality attributes and the development of physiological disorders and postharvest diseases (Wills and Golding, 2016). Exogenous ethylene has been shown to have no effect on respiration rate and firmness loss during fruit ripening (Li et al., 1994). In addition fruit skin colour is not affected when treated with the ethylene perception inhibitor 1-methylcyclopropene (1- MCP) (Gong et al., 2002; Mozetić et al., 2006) and shows that the changes in these parameters occur independently of ethylene. Li et al. (2016) concluded that exposure to 1-MCP may enhanced cherry fruit stress tolerance, which consequently reduces development of physiological disorders during storage. However Piazzolla et al. (2015) reported that exposure to 1-MCP at 1 mL L^{-1} slightly reduced respiration rates of 'Ferrovia' cherries stored at 4 ^{o}C and 20 ^{o}C, but concluded that this treatment did not prevent quality loss and was not recommended for cherries.

Gong et al. (2002) also showed that exogenous ethylene accelerated the development of stem browning in cherries, even though 1-MCP had been applied. Cherry stems are an important quality attribute are will be discussed in more detail (*Water Loss and Packaging Sections*).

Consumer preferences

Consumers are the ultimate determinant of cherry fruit quality. Cherry consumption is driven by appearance, flavour, taste, and texture and delivered at an affordable price. The quality of cherries is determined by a range of parameters including fruit size, skin colour, flavour, sweetness, sourness, firmness and stem colour, as these attributes have been found to be closely related to consumers' acceptability and market prices (Dever et al., 1996). It is important to consistently deliver high quality fruit as once the consumers develop a certain degree of preference based on its sensory and organoleptic attributes, it is very unlikely consumers to change their preference (Brennan and Kuri, 2002). Thus sensory traits have a profound influence on consumers' expectations of end-product quality, purchase intent and buying habits and therefore it is important to have clear understanding of consumers' expectations of high quality cherry fruit for which they are willing to pay a premium.

Visual appearance is an important quality attribute for a consumer to select and purchase cherries (Miller et al., 1986; Crisosto et al., 2003). Uniformity in fruit colour and size, intense colour, glossy and defect-free skin, and having fresh, green, and turgid appearance stems without browning and discolouring are important attributes (Alonso and Alique, 2006). Consumers prefer sweet, juicy, large dark full red or black cherries, with a glossy appearance (Lyngstad and Sekse 1995; Wermund and Fearne, 2000). Uniformity of colour and fruit size have been shown to be the most useful parameters for predicting visual liking, with fruit colour uniformity having the highest importance (Romano et al., 2006). Indeed visual appearance is becoming increasingly important quality attribute, as previous consumer selection criteria such as texture (fruit firmness) is becoming more difficult for consumers to assess firmness in-store due the transition from bulk displays to the use in pre-pack punnets and bags.

Many studies have confirmed correlations between physicochemical properties of cherries (weight, appearances of skin and stem, SSC, TA, SSC/ TA ratio, firmness) and cherry fruit acceptability by taste panelists and consumers (Crisosto et al., 2003; Dever et al., 1996; Kappel et al., 1996). Indeed the level of sugars has been shown to have a positive relationship with the consumer acceptability (Crisosto et al., 2003). However it is the balance between sugars and acids that determine the overall cherry fruit flavour. Indeed, TA can also affect consumer acceptance, but only when SSC is low (Crisosto et al., 2003). Each market has its own preferences and opinions on what constitutes a high quality cherry. Crisosto et al. (2003) showed that for 'Brooks' and 'Bing' cherries, need to be a full bright red or dark mahogany skin colour, respectively with a minimum SSC of 16 % Brix to satisfy the majority of American consumers. Crisosto et al. (2002) also showed that the ratio SSC/TA has been found to be related to the perception of sweetness, sourness or cherry flavour by trained judges. High TA negatively affected consumer acceptance in the American market if SSC was below 16% and 13% for ‘Brooks’ and ‘Bing’ cherries, respectively, while consumer acceptance was high for both cultivars with SSC exceeding 16%, irrespective of TA (Crisosto et al., 2003). Kappel et al. (1996) also showed that a minimum of 15% SSC, but preferably 17–19% SSC was preferred by consumers; however the authors emphasized the importance of the balance between sweet and sour. For example, low sugar and high acid contents result in a sour taste, while low acid and high sugar contents result in a bland taste (Romano et al., 2006).

In a study of US consumers, Turner et al. (2008) showed that consumers preferred cherries which were large (30 mm or larger) and dark in colour (e.g. ‘Regina’). As expected, sweet tasting cherries were preferred the most (65%) while cherries that lacked flavour or were too sour were preferred the least. Turner et al. (2008) showed that ‘Regina’ rated the highest for overall taste preference of the six different cultivars examined and showed that although visual appearance and size matters for their initial decision, taste and flavour of the sweet cherries are the final factors determining the ultimate preference.

The use of dry matter as a measure of consumer acceptance has been recently demonstrated. Using ‘Bing’ and ‘Chelan’ cherries in California, Escribano et al. (2017) showed higher acceptance by consumers for cherries with high dry matter content (as well as for cherries with high SSC). Indeed dry matter content was equal to or superior to SSC for predicting flavour intensity and balance of sweet to sour taste as assessed by consumers (Escribano et al., 2017). Considering the revealed importance in sensory evaluation of dry matter content, as well as SSC, in the eating quality of cherry, Escribano et al. (2017) suggested that the use of handheld NIR devices could be used as a non-destructive analysis of cherry quality. This is discussed in more detail in the *New Technologies Section*.

Texture is an interesting and poorly studied sensory attribute. Interestingly, no texture attributes have been identified as being strongly associated with overall liking / acceptance in some of these studies (Cliff et al., 1996; Crisosto et al., 2003; Chauvin et al., 2009), but others made note that firmness was significantly correlated with overall acceptability (Guyer et al., 1993), or was an important contributor to overall liking in principle component analysis (Dever et al., 1996). Another sensory texture attribute, juiciness, was only identified as a preference driver by Dever et al. (1996). The absence of texture as a preference driver in some studies may have arisen if all samples presented for evaluation were of acceptable or good texture.

Fruit firmness is measured with a compression instrument such as a FirmTech 2 Fruit Firmness Tester (BioWorks, Wamego, KS, USA) and is widely used in commercial and research laboratories. Hampson et al. (2014) showed a linear relationship between firmness as measured on the FirmTech 2 instrument and consumer ratings of firmness acceptability on the Just-About-Right scale whole cherry crispness and flesh firmness by untrained panelists. The ‘acceptable’ cherry firmness range (combining scores of 3–5, or ‘slightly too soft’, ‘just about right’ and ‘slightly too firm’) in that study was identified as approximately 2.6–4.7 N (Hampson et al., 2014).

Whilst several international studies have been conducted (Kappel et al., 1996; Crisosto et al., 2002; Crisosto et al., 2003), more consumer work with current cultivars for both Australian consumers and overseas consumers is needed to understand what our consumers would actually want and will purchase.

Preharvest factors affecting storage life

The time of harvest has the largest impact of cherry fruit quality. Fruit harvested too early does have sufficient colour or sugar levels, whilst fruit harvested too late, will be soft and will not have good storage potential. Cherry fruit undergo important biochemical and morphological changes during maturation, in general, fruit weight, SSC, and SSC/TA ratio increases as cherry skin colour changes from full light red to full dark red. Therefore fruit colour and SSC are the main indicators of maturity.

The increase in fruit colour during development is due to the production of anthocyanins in the peel and flesh. Figure 1 illustrates the accumulation of anthocyanins in 11 different cherry cultivars during development. Anthocyanins also contribute to the antioxidant and health properties of cherries, and therefore optimal anthocyanin / colour development is also an important harvest trait. In addition it is important to recognize differences in fruit maturity both within and between trees which contributes to variability in fruit quality. Patten et al. (1986) showed that fruit colour, size and SSC levels decrease with delay in flower anthesis and fruit location, progressing from the top to the base of the plant.

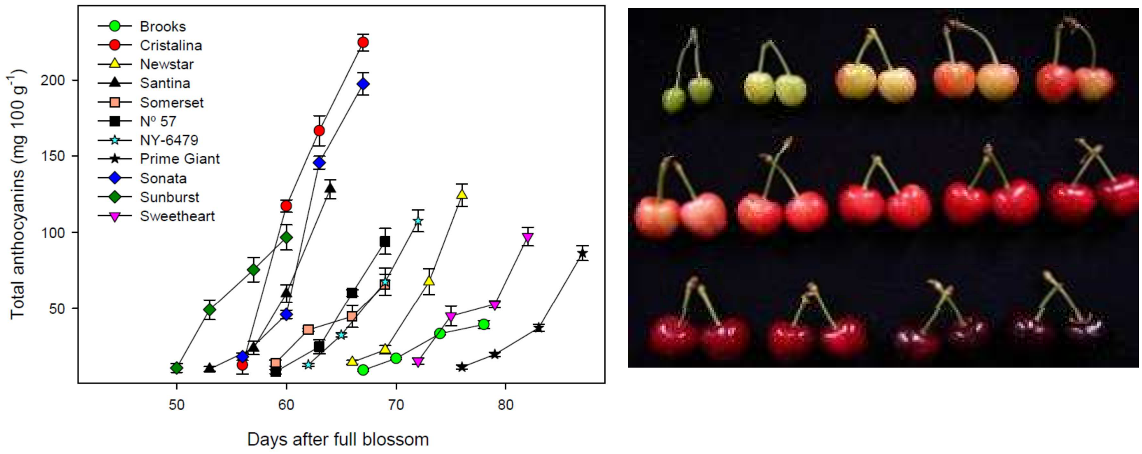


Figure 1. Concentration of total anthocyanins (mg cyanidin 3-glucoside equivalent per 100g) in different cherry cultivars during development and ripening stages (right) [Data are mean SE (*n*=5). LSD (P<0.05) = 8.95]. Maturity stages of cherry fruit. (*From Díaz-Mula et al., 2009)*.
Maturity stages of 'Sonata' cherry *fruit (Photo from Huertas Díaz-Mula, Spain)*

A number of preharvest factors such as example rootstock, irrigation, pruning, nutrition, climate and stress, can affect fruit quality and postharvest storage life of cherries (Whiting et al., 2005; Neilsen et al., 2007; Velardo-Micharet et al., 2017). However research to examine and understand these preharvest factors on postharvest storage is scarce.

It is well known that fruit quality parameters such as fruit weight and SSC are affected by fruit to leaf ratio (Patten et al., 1986; Whiting and Lang, 2004) and tree density (Eccher and Granelli, 2006) and pruning (Measham et al. 2017). However there has been limited research has been undertaken on its effect on subsequent storage behavior and consumer satisfaction. For example the level of orchard nutrition on the effect of fruit quality and storage behavior has been examined in limited trials. Neilsen et al. (2007) examined the effect of nitrogen (N), phosphorus (P) and potassium (K) nutrition on the yield and quality of 'Lapins' cherries on Gisela 5 rootstock and showed high N applications reduced fruit size and fruit titratable acidity (TA), but had no effect on fruit firmness or soluble solids content (SSC). They also showed that annual P and K fertigation by sprinklers was generally ineffective, having minimal effects on tree PK nutrition and fruit quality with the exception of increased fruit firmness associated with P fertigation in one season, when yield was low. They further showed that drip-fertigated trees were small, frequently had fruit with elevated SSC. In Tasmania, Swarts et al. (2017) showed increased N nutrition resulted in reduced fruit firmness at harvest and at storage in 'Lapins' cherries on F12 rootstock and recommended preharvest N application must be carefully managed to avoid over-supply of N and consequent detrimental impacts on fruit quality at harvest and during storage.

Water availability is a major limiting factor in many Australian cherry growing regions. Yin et al. (2011) showed that drip irrigation applied to 'Lapins' cherry trees consumed only 21–29% of the irrigation water compared to micro-sprinkler irrigation but it enhanced marketable fruit by 7 to 12% and did not impact fruit yield or firmness, colour, and size (Yin et al., 2011). Low-frequency drip irrigation has also been shown to increase SSC in 'Cristalina' and 'Skeena' cherries (Neilsen et al., 2014). However, irrigation levels did not affect SSC, TA, and fruit weight of the cherries of the '900-Ziraat' cultivar (Demirtas et al., 2008). However the effects of storage life from these preharvest treatments are limited. Velardo-Micharet et al. (2017) reported that supplementary irrigation did affect fruit size but had no effect on fruit quality (firmness, SSC, TA, stem colour, weight loss) during storage at 4 ^{o}C. However they did show higher rot incidence during postharvest storage in irrigated trees as compared to non-irrigated trees (Velardo-Micharet et al, 2017).

In addition to the lack of water during the growing season, growers often have to deal with rainfall at harvest which can cause fruit cracking. The use of preharvest treatments such as the cuticle supplement Parka+^{TM} is used to reduce the incidence of cracking or delay the cracking of fruit by some Australian cherry growers. Parka+^{TM} is a patented blend of phospholipids designed to supplement the cuticle which forms an elastic organic biofilm of edible components which is sprayed onto fruit in anticipation of rainfall. However if it doesn't rain and the cherries are harvested and packed, these products can affect final fruit storage and eating quality. Cliff et al. (2017) showed with 'Skeena' cherries in the Okanagan Valley (Canada) that had a preharvest Parka+™ application lower firmness (as measured with FirmTech instrument) and lower sensory firmness (with higher juiciness) than untreated fruit. In addition, fruit treated with the Parka+™ cuticle supplement had reduced water loss, less pitting, and lower stem-pull force, resulting in higher frequency of detachment of the stems. Thus preharvest treatments and orchard management can all affect final fruit quality. However, in general, the effect of preharvest growing conditions on postharvest behavior is poorly understood, due to the inherent difficulties of conducting controlled experiments in this area, especially over many different growing seasons. Neilsen et al. (2007) showed different trends and results of different nutrition and growing conditions depending on the different growing seasons, where differences in rainfall, growing temperatures etc. all differentially interact and affect tree and fruit growth. This makes research and subsequent recommendations difficult and this is not only an issue with cherries, but all horticultural commodities (Wills and Golding, 2016).

Calcium sprays are widely used in industry to maintain fruit firmness, where up to 4-5 sprays of calcium chloride can be applied through the main fruit growth period. However calcium is also widely used in the food industry to reserve and maintain firmness in different food products (Martín-Diana et al., 2007). Díaz-Mula et al. (2017) showed that postharvest treated cherries with calcium chloride slowed down the rate of deterioration during storage of 'Cristalina' cherries and suggested the application of calcium solutions could be a good tool for postharvest application with the aim to retard the postharvest ripening process of cherry and in turn to extend the storability of cherries. However this work was done with vacuum infiltrated fruit and more work is required for more practical application methods, for example in commercial hydrocoolers with compatibility using current sanitisers. Indeed more work should be conducted on the efficacy of preharvest calcium sprays on fruit firmness, storage behaviour and eating quality.

Storage performance of selected cherry cultivars

Postharvest characteristics of cultivars are difficult to generalise because of their high dependence on orchard management practices and the environmental conditions in which the cultivar is grown (Zoffoli et al., 2017). This summary is adapted from Zoffoli et al. (2017) and James (2010) where fruit characteristics relevant to postharvest performance are discussed for some key cultivars as examples. Other references include Drake and Fellman (1987), Cliff et al. (1995), Dever et al. (1996), Drake and Elfving (2002), Kappel et al. (2002), Crisosto et al. (2003), Toivonen et al. (2004), Kappel and Toivonen, (2005), Harb et al. (2006), Kappel et al., (2006), Remon et al., (2006) and Agulheiro-Santos et al. (2014).

- 'Early Burlat' is an old cultivar but relatively new to Australia. It is attractive because of its early harvest time, but the fruit is small, soft and very susceptible to mechanical damage. It is difficult to store longer than 15 days at 0 °C. The soft texture renders this cultivar incompatible with water flume handling systems that are present in all mechanized cherry packing lines.
- 'Empress' is an early maturing cultivar originally from Young, NSW. Fruit is rounded in shape and the colour ranges from deep red to mahogany. Optimum flavour is with reached when it has a mahogany colour. It has reported erratic performance and suffers increasing competition from better early season varieties.
- 'Merchant' is a dark-fleshed and softer than mid and late season maturing varieties, however its fruit is still firm enough to withstand transporting. However it can have problems with uneven maturity.
- 'Summit' and 'Newstar' have large fruit with good flavour, but with a soft texture susceptible to pitting. 'Sonata' is considered a cultivar with large fruit having high acidity at harvest that is maintained during storage, with low soluble solids and soft texture. The fruit is susceptible to pitting and is not suitable for long term storage (15 days maximum).
- 'Brooks' is a light red cherry, the fruit is large and firm with high soluble solids, but it is very susceptible to postharvest cracking due to absorption of condensed moisture in packaging, therefore modified atmosphere packaging (MAP) is not recommended.
- 'Santina' has large fruit, with low acid and sugar contents, suitable for long-term storage (45 days at 0 °C, with MAP), but it has a tendency to develop a pebbled texture (Figure 9) on the surface of overripe fruit after long term storage.
- 'Van' is a dark, firm cherry with a high sugar content and a short stalk but is very prone to cracking in wet conditions. It is susceptible to 'pitting' injury during storage (see *Pitting Section*).

- ‘Bing’ has been the standard cultivar for fresh market producers in the Pacific Northwest and California, USA and is frequently used as the base cultivar for comparisons. It is considered to be a long-term storage cultivar with high sugar content, firm texture and excellent flavour. It is prone to rain cracking and its popularity is declining in Australia. Fruit are suitable for long storage periods for up to 45 days at 0 °C in MAP.
- ‘Rons seedling’ was widely grown NSW, but its production has declined. It can store well but it is susceptible to fruit softening.
- ‘Rainier’ is a bicolour fruit having a yellow flesh and background colour with red blush on the skin. It is sweet, large and firm, but susceptible to rubbing injuries and bruising as the light-coloured skin readily show these injuries. The packing line needs to be adjusted to avoid friction that leads to fruit surface discolouration. It has good storage performance for 45 days at 0 °C in MAP.
- ‘Lapins’ fruit have good size and flavour. It is the most planted self-fertile cultivars worldwide. Conditions at harvest are important because under high temperatures, the fruit softens rapidly on the tree and becomes susceptible to pitting. Over-ripe fruit tend to develop a pebbled texture during storage. Fruit can be stored in MAP for up to 45 days at 0 °C.
- ‘Stella’ produce large attractive fruit that markets well it only has moderate fruit firmness and is declining in popularity, particularly in export markets.
- ‘Sweetheart’ is the most reliable cultivar for containerised ocean shipment up to 45 days at 0 °C in MAP. The fruit is large, with good flavour and firmness. Its tendency to over crop, however, can lead to pitting and decay susceptibility.
- ‘Sweet Georgia’ is a late maturing Tasmanian selection of Lapins.
- ‘Kordia’ is a large, firm and mahogany red in colour with very long stems. This cultivar is highly regarded for its firmness and excellent flavour.
- ‘Regina’ is a medium-large, heart shaped fruit

Other Australian cultivars from the National Cherry Breeding Program based in Lenswood, South Australia have been described by James (2010). All cultivars are reported to be firm and have good postharvest storage capacities and long thick green stems (James, 2010). Examples of the three released cultivars from this program are ‘Sir Don’, ‘Sir Tom’ and ‘Dame Roma’. In all of these examples, James (2010) report that the fruit have long, green but very robust stems that handle postharvest and storage well. Stem length can cause difficulties with cluster cutting.

As part of the ‘CherryNet’ project, Professor Azarenko from Oregon State University (USA) presented the results of storage trials of five benchmark cultivars were obtained from the collaborators’ orchards that were located in northern (Cobram) to southern Victoria (Wandin) (Azarenko, 2005).

This is the summary of Prof. Azarenko’s observations of these cultivars in Victoria:

- *‘Merchant’* This early season cultivar may have export market potential in some years and from some locations but quality is generally marginal for those markets. Fruit quality was at its best in 2002-2003. In the other three years, export potential was very site dependent and clearly some fruit would not satisfy the minimum criteria for export. This cultivar is highly susceptible to stem bowl and some nose cracking. Optimum fruit colour should approach a colour rating of 4.5-5. Generally this cultivar has marginal firmness in most locations, high risk of cracking, and on average a tendency towards the lower end of acceptable SSC. Stem pull force is generally acceptable at harvest but decreases in storage. The earliness of this cultivar creates a niche where lower values than the proposed criteria may be acceptable.
- *‘Ron’s Seedling’* Fruit firmness was good to exceptional. Fruit size ranged from small to medium. Stem pull force was high and stem quality was exceptional. Fruit acidity is moderate to low while SSC was low to acceptable. Optimum colour at harvest should be between 5 and 6 in order to achieve higher SSC. At a lesser colour, fruit taste will tend to be bland. This cultivar has a tendency to double. Fruit quality remained quite good in storage after 2 weeks and even after 4 weeks. The greatest limiting factor for this cultivar is its small to moderate fruit size and tendency to double. This cultivar is extremely well suited for the domestic market because of its long shelf life and good stem quality. Additional horticultural techniques to enhance fruit size such as early season plant growth regulator applications, additional foliar N and B applications, delayed spring heading techniques, multiple gibberellin applications, etc. should be evaluated.

- *'Bing'* Fruit firmness was generally good to very good. Fruit size ranged from medium to large. Optimum fruit colour should be between 4 and 5. SSC was generally as good or better than the recommended criteria. Stem pull force was highly variable between years. In 2003-2004, stem quality and retention was excellent. Goemar and Retain treatments at straw colour appeared to further increase stem pull force after two and four weeks in storage in 2003- 2004. Dormancy breaking products may have reduced stem pull force especially in unseasonably hot temperatures. In 2004-2005, stem retention was poor and stem pull force was quite low. 'Bing' cherries grown in Victoria generally achieve the desired criteria and are comparable in quality to North American grown cherries. The greatest limiting factor is its susceptibility to rain cracking. This cultivar performs reasonably well is a range of growing conditions.
- *'Van'* The firmness of 'Van' fruit has been excellent. Large fruit size was attained. SSC was acceptable and acidity was moderate. Optimum fruit colour was between 4 and 5. The weaknesses of this genotype that will always limit its potential for export are the strong tendency to crack at the stylar end of the fruit and its low stem pull force and retention. Horticultural practices that increase stem retention, for instance balanced cropping, good soil moisture management, foliar N programs, and other plant growth regulators, should be practiced. Shading trees in environments with excessive heat during harvest might be of benefit. Caution should be practiced when planting this cultivar in hotter districts.
- *'Lapins'* Fruit firmness was generally good to very good. Fruit were large with acceptable to high SSC and low acidity. Optimum fruit colour was 5. Stem pull force was highly variable across the seasons. In 2003-2004, stem retention was very good. However, during 2002-2003 and 2004-2005, stem pull force was low to very low and stem retention poor. The factors that appear to reduce stem retention were high heat and excessive rainfall. Additional management strategies such as growth regulator application at straw colour, balanced cropping, tree shading, and consistent intensive irrigation should be evaluated to increase stem pull force. Stylar cracking can be a problem in years of rain at harvest. This genotype has good export potential because of excellent fruit size, firmness and SSC.

This extract was taken from Azarenko A.N. (2005) 'Enhancing Profitability with Superior Fruit Quality', presented at 36th Australian National Cherry Conference in Hobart.

Limitations in maintaining quality deterioration – storage issues

Cherry fruit are a perishable product and quality deteriorates after harvest. The major limitations in the storage and marketing of cherries are: the development of postharvest rots, fruit softening, water loss, stem browning and the development of postharvest disorders, such as pitting, bruising and pebbling. The causes and factors associated with each of these issues will be briefly discussed here. The management of these issues will be discussed in the '*Postharvest Management Section*'.

Decay

The development of postharvest rots is a significant and on-going challenge for the storage of cherries, even though the Australian cherry industry extensively uses sanitisers and postharvest fungicides to manage postharvest decay. Adaskaveg et al. (2000) and Zoffoli et al. (2017) report that the major postharvest pathogens are brown rot (caused by *Monilinia* spp) and grey mould (caused by *Botrytis cinerea*). While these pathogens are important in many instances, these cherry rots look similar (Figure 2) and a recent Hort Innovation project showed that different pathogens are potentially involved. Barry et al. (2016) showed that *Botrytis cinerea* was found to be the dominant rot pathogen in orchards surveyed in southern Tasmania whilst *Alternaria alternata* was a dominant pathogen causing rot in orchards in Orange and Young in NSW. *Monilinia* species have long been thought to be the major cause of rots in cherries (Adaskaveg et al., 2000), but the results from this local disease survey suggest this is not the case and reinforces the need for local research and development. Other postharvest decays commonly found in cherries include: *Penicillium* spp. (blue mould), *Mucor* spp., *Rhizopus stolonifer, Aspergillus niger* and *Cladosporium* spp. (Mattheis and Fellman, 2016; Zoffoli et al., 2017). Postharvest decays usually are due to pre-harvest infections and these are often associated with skin fracture (Dugan and Roberts, 1994). Indeed fruit can also be infected via rain splits or wounds that occur at harvest. Infections can also be caused and exacerbated during packing and storage by contaminated water and humid conditions. Børve (2014) reported that brown rot is increased from 13% to 28% and Mucor rot from 11% to 26% by free water contact in packing. Moreover, fruit packaging such as use of polyliners creates a saturated environment. While the use of liners reduces water loss, it also favours condensation and thus promotes fungal decay (Zoffoli et al., 2017).The use of preharvest fungicides in the orchard are critical to manage fungi rots in the field and also contribute to reducing postharvest rots. However the use of postharvest sanitisers and fungicides are also integral to the control of decay during storage.

Sanitisers. Cherries come in direct contact with water during various postharvest operations such as hydrocooling, movement in water flumes, washing and fungicide treatment. Sanitation of postharvest water is essential to reduce the microbial populations including those of foodborne bacterial pathogens (e.g. *Salmonella*). The presence of optimum concentration of a sanitiser in postharvest water is critical to minimise the risk of bacterial pathogens and reduce the fungal spores. A number of sanitisers with different chemistries are currently available in the market and registered like fungicides with APVMA. Each sanitiser has its own merits and demerits of adoption. The selection of sanitiser is influenced by a number of factors such as price, water source (channel, ground or council) and quality (pH, hardness), method of application and monitoring (manual vs. automatic), packingline machinery (corrosiveness) and buyer's requirement etc. Following the label guidelines and manufacturers' instructions can ensure correct and safe use of sanitisers at recommended concentrations and conditions. These are discussed in more detail in the *Decay control – Sanitisers Section*.

Fungicides. There are two registered fungicides for postharvest use; fludioxonil and iprodione. The use of these fungicides are discussed in the *Decay Control Section*. However, postharvest use of synthetic fungicides in many countries including the European Union countries and large cherry producing countries such as Turkey are prohibited due to fungicide regulatory issues. The lack of an effective postharvest treatment against postharvest pathogens in these countries highlights the need for developing new control methods and strategies.

Fruit softening

Fruit firmness is a critical fruit quality parameter for consumers, where consumers prefer firm rather than soft fruit (Crisosto et al., 2003). However fruit firmness often changes during storage and shipping. The mechanism for cherry fruit softening is not clear, indeed it is not always consistent that fruit always softens during storage and marketing.

The phenomenon of fruit softening during storage is contentious (Zoffoli et al., 2017). Excessive softening is described as a common problem during long-term storage in some cultivars, but varies depending on the season (Kappel et al., 2002). However, increases in firmness are commonly observed and reported under modified atmosphere cold storage of 'Sweetheart' (Meheriuk et al., 1997), 'Bing' (Chen et al., 1981), 'Lapins' and 'Skeena' (Wang et al., 2015), and 'Rainier' (Drake and Fellman, 1987). Changes in firmness during cold storage of early season ('Suite Note™'), mid-season ('Sweetheart') and late season ('Sentennial™') cherries in two years of study (2014 and 2015) are presented in Figure 3 and show that in general, in these selected cultivars that firmness was maintained during cold storage in an MA bag over the two different seasons (unpublished data from Dr. Peter Toivonen, Agriculture and Agri-Food Canada).

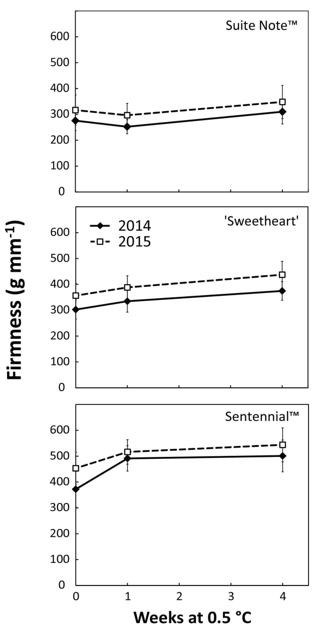
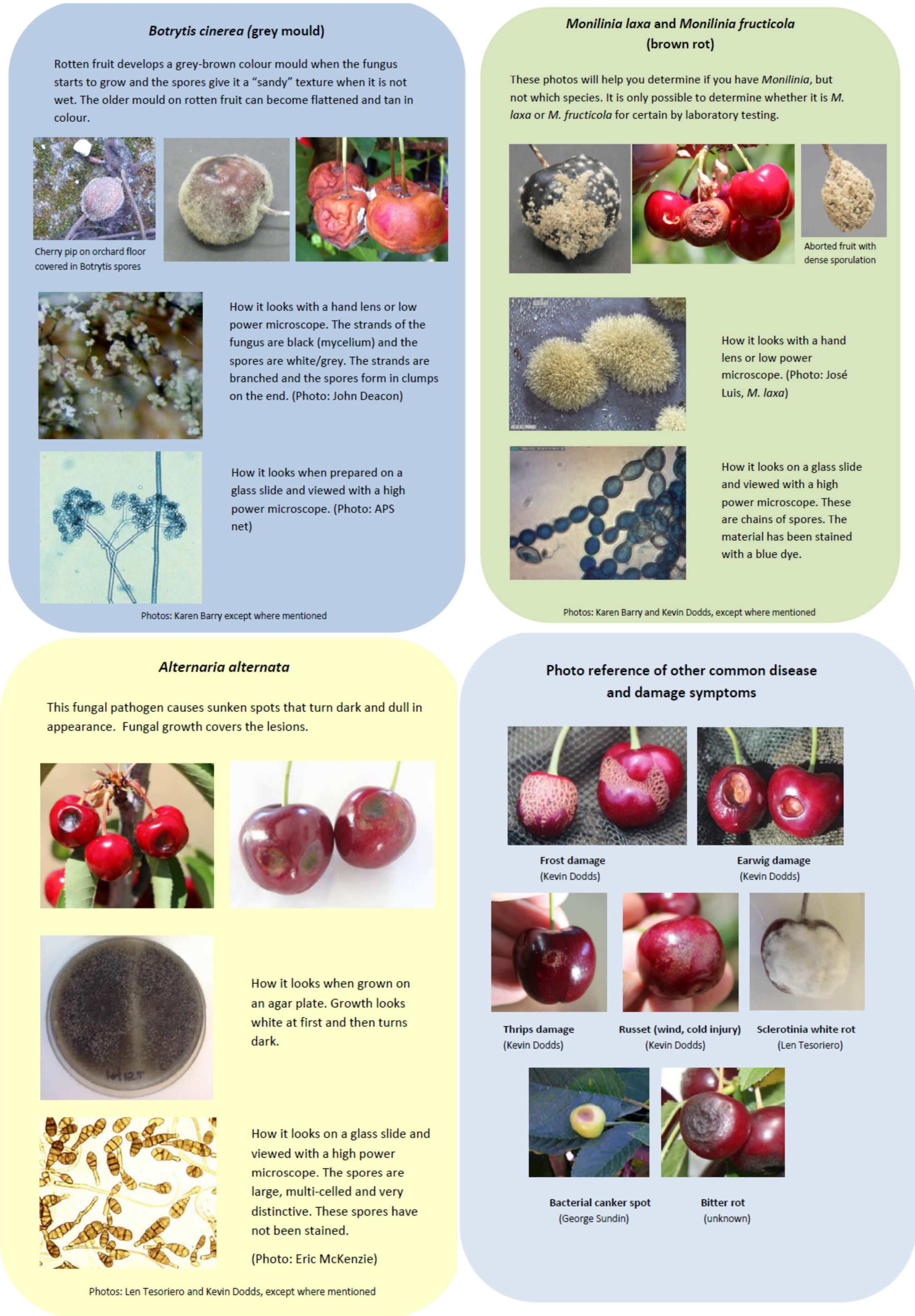


Figure 3. Changes in firmness during cold storage of early season ('Suite Note™'), mid-season ('Sweetheart') and late season ('Sentennial™') cherries in two years of study (2014 and 2015).

The cherries were harvested at colour stage 6 on the CTIFL cherry colour maturity chart. The cherries were cooled to 0.5 °C before time zero measurement of firmness and stored at 0.5 °C, while sealed within a commercial cherry liner bag.

(Data and Figure from Dr. Peter Toivonen, Agriculture and Agri-Food Canada).

Figure 2. Guide of common cherry rot pathogens in Australia *(from Barry et al., 2016).*



from: Barry et al. (2016) Hort Innovation Final Report.
Optimal management of pre-harvest rot in sweet cherry. (CY13001)

Physiological basis of cherry fruit softening. The middle lamella is a morphologically distinct layer, rich in pectin polysaccharides between the primary cell walls of adjoining cells in cherry fruit. The middle lamellae and primary cell walls are subject to structural changes during ripening which lead to cell separation and tissue softening (Bartley and Knee, 1982). During softening, an increase in the content of soluble pectin polysaccharides is observed (Bartley and Knee, 1982). The major difference between soft and crisp cherries is the degree of polymerization of pectin side chains, being higher in crisp fruit and lower in soft fruit (Bartley and Knee, 1982). However, the biochemical mechanisms involved in cell wall disassembly vary widely among species, and the understanding of the processes underlying firmness loss in cherry fruit is particularly poor, although a critical role for β-galactosidase (β-Gal) activity has been suggested. The softening enzymes polygalacturonase (PG), pectin methyl esterase (PME) and β- galactosidase (β-gal) have been detected in cherry fruit, but activity of PG is low at ripening. β-gal was detected at early ripening stages and changes in PME have not been associated with changes in fruit traits during maturation (Barret and Gonzalez, 1994). Indeed Belge et al. (2017) showed β-xylosidase (β-Xyl), pectate lyase (PL), α-L-arabinofuranosidase (AFase) and pectin methylesterase (PME) activities were apparently connected to ripening-related firmness changes in 'Somerset' cherry cultivar, but found no role of β-Gal.

The mechanisms that affect postharvest firmness are not fully understood. A relationship between reduced turgor and softening has been suggested (Glenn and Pooviaiah, 1987). In addition, fruit moisture loss, water allocation in the fruit, skin toughness and cell wall modifications have all been suggested to be associated with softening (Wang and Long, 2014). As presented, a full understanding of the mechanism of cherry fruit softening remains elusive (Zoffoli et al., 2017).

Dehydration and water loss

A driving force was fruit water loss from the fruit and stem is related to the vapour pressure deficits (VPD) experienced during handling and storage. Water loss can contribute to fruit softening and lack of freshness, but as most cherry fruit are sold by weight, loss of water also incurs a direct financial loss. To maintain fruit quality and freshness, and manage water loss from the fruit, it is important to appreciate the factors that drive water loss from the fruit.

Water vapour moves from an area of high relative humidity (high VP) to one of low relative humidity (low VP). The greater the difference in humidity (VPD), the faster water moves. This factor is important because the rate of water movement directly affects the fruit's transpiration rate which is determined by the environment in which the fruit is stored. Temperature, relative humidity and air flow around fruit affect the transpiration rate from the fruit. Storage temperature and packaging are the major determinants to affect these parameters, where low storage temperatures, and high humidity reduce any potential water loss. This will be discussed in more detail in the *Packaging Section*.

Water loss from the fruit

Cherry fruit are covered by a natural waxy layer of cutin secreted over the epidermis which makes the fruit look glossy and shiny. This hydrophobic or water repellent layer protects the plant from dry environments in the orchard and during storage and handling. Belge et al. (2014) showed that the major contributors of cuticular waxes were the triterpene ursolic acid, the alkane nonacosane, linoleic acid, and β-sitosterol, whereas the cutin composition was dominated by C18-type monomers. In spite of being comprised of similar chemical families, cultivar-related have been identified in the abundance and the evolution of some compound families during cold storage (Belge et al., 2014). The wax is often arranged as platelets on the surface of the skin. The well-ordered overlapping wax platelets or continuous wax provides greater resistance to permeation of water vapour than structures without these structures and the cuticle has shown to increase during storage (Belge et al., 2014). However any mechanical damage (such as pitting and bruising) may increase water loss by rupturing the natural barriers (waxy cuticle and suberised outer cell layers). Coating fruit with additional wax formulations is used commercially to reduce water loss in other horticultural crops (such as oranges) and its application to cherry fruit will be discussed in the *Novel Packaging Section*.

Stem browning

While cherry stems are not consumed, stem quality (particularly colour and freshness) greatly influences consumer perception of cherry quality, where consumers prefer cherries with plump fresh looking stems (Drake et al., 1991). Therefore water loss and mechanical damage to the stem which browning which is highly undesirable. While the fruit itself has a thick waxy cuticle to protect from water loss (Belge et al., 2014), stems have a much thinner epidermis and cuticle layer, resulting in a higher sensitivity to the impacts of postharvest handling and storage such as water and carbon dioxide losses (Sekse, 1996, 1988). The resistance to water vapour transfer in the stem is much lower than that of the fruit. Hence, cherry fruit stems show up to eightfold higher water losses, independent of whether detached from or still attached to the fruit (Linke et al., 2010). Therefore green stems are often used as indicators of overall cherry fruit freshness. These sorts of indicators are very helpful and important for consumers to guide their buying decisions (Linke et al., 2010). However it also makes it is more important to maintain stem quality to the consumer.

Similar to maintaining fruit quality to prevent water loss with low temperatures and high air humidity during storage and transport, maintaining stem quality with low temperature storage with high humidity can also maintain stem quality. Indeed Golding et al. (2017) clearly showed that water loss from the cherry stems was strongly affected by storage temperature and relative humidity. They showed that water loss from the stems was greatest in the high temperature (20 ^{o}C) and low humidity storage (70 %) and the lowest water loss from the stems were observed in low temperature storage (5 ^{o}C) with high relative humidity (100 %). These observations have consequences in the display of cherries on the retail environment (Golding, 2017). This will be discussed in more detail in the *Packaging Section*.

Pitting

Pitting is a serious postharvest defect in cherry fruit that develops during storage. Pitting is characterised by irregular hardened pits in the fruit surface, predominantly on the shoulders (Porritt et al., 1971) after the fruit has been mechanically damaged (Grant and Thompson, 1997) (Figure 4). Golding (2012) showed pitting was the most common defect found in Australian cherries on the domestic market during two seasons. Pitting detracts from the overall visual appearance of the fruit when on display and when severe it detracts from the eating experience of individual fruit. Pitting also increases the rate of respiration and is a site of decay development, thus reduces shelf and market life. (Ogawa et al., 1972; Mitchell et al., 1980).

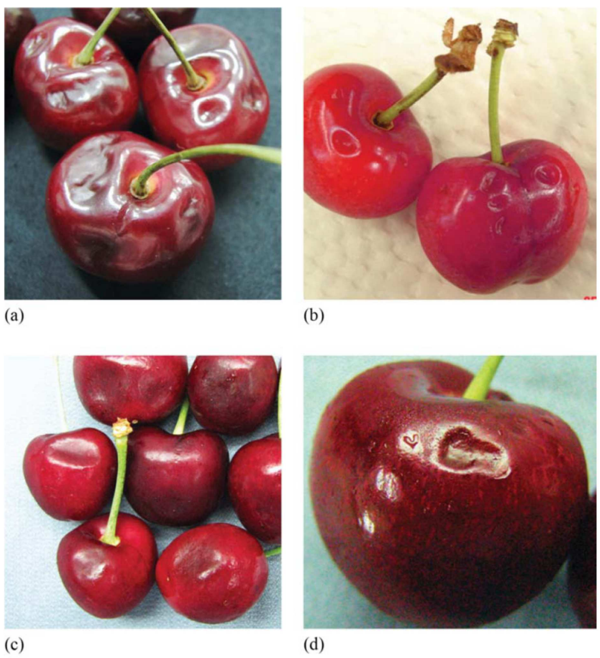


Figure 4. Surface pitting produced by mechanical damage where the symptoms differ due to their origin of the damage during harvest and packing.
Figure 4a shows shoulder depression damage due to incorrect picking. Figure 4b shows impact damage produced by rotating blades of the cluster cutter. Figure 4c show the impact damage caused in a hydraulic cluster separator and Figure 4d shows damage on the fruit skin caused by stem puncture.
(*All photos from Zoffoli et al., 2017)*

Figure 4e. Commercially unacceptable - major pitting symptoms in cherry fruit.
(Photo from Australian Cherry Quality Guide, 2004)

The development of fruit pitting is complex with several different types of pitting occurring and numerous factors contributing to its incidence (Facteau, 1982; Patterson, 1987; Wade and Bain, 1980). Previous surveys have linked pitting to physical damage, where damage is especially severe when impact forces are concentrated over a small area of the fruit. Studies of handling damage often highlight deficiencies in packing line design resulting from increased velocity at the moment of impact. The greatest damage is often caused by cluster cutters and shower-type hydrocoolers (Thompson et al., 1995; Thompson et al., 1997). The height of drop onto the sorting belt also has been identified as a critical point for mechanical damage (Grant and Thompson, 1997; Candan et al., 2014). In a survey of different packinghouses in Australia, Golding et al. (2012) showed, a drop distance of 25 cm from the belt into the bottom of the box. This large drop from the belt (sampling position number 10) and consequent impact damage (pitting) to the fruit should be minimized (Figure 5).

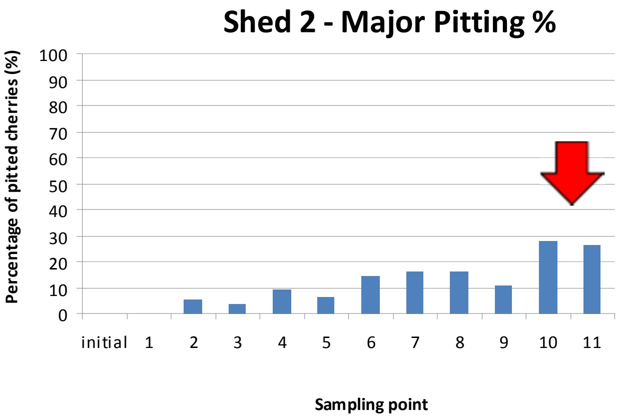


Figure 5. The percentage of fruit with major pitting (>5mm in diameter) in 'Lapin' cherry fruit removed from different sampling points in a different cherry packing line and stored for four weeks at 0 ^{o}C. The different sampling points in the line sampling point 1 - from the tree, sampling point 2 - from the picker's basket, sampling point 3 - from the field tub, sampling point 4 - into bin before hydrocooling, sampling point 5 - before the cluster cutter, **sampling point 6 - after the cluster cutter**, sampling point 7 - after pre-sorting, sampling point 8 - before sizing, sampling point 9 - after the sizing run, **sampling point 10 - from the packed box (largest drop), and sampling point 11 - from the packed box (smallest drop)** *(from Golding et al., 2017).*

The incidence and severity of pitting is difficult to predict as it has been shown to vary from year to year, between cultivars and even between trees of the same cultivar (Porritt et al., 1971; Facteau and Rowe, 1979). Cultivar differences in pitting susceptibility have been studied under different growing conditions (Toivonen et al., 2004; Kappel and Toivonen, 2005; Kappel et al., 2006). Fruit weight and SSC have been shown to be inversely related to incidence of surface pitting (Facteau and Rowe, 1979), whereby riper fruit (higher SSC) are less severely affected. In addition, firmer fruit have been shown to have shown to have less pitting symptoms (Facteau and Rowe, 1979; Lidster et al., 1980; Facteau, 1982; Toivonen et al., 2004; Kappel and Toivonen, 2005). Li et al. (2016) reported that exposure of 'Sweetheart' cherries to the inhibitor of ethylene action, 1-MCP at 1 mL L^{-1} reduced development of fruit pitting by 15%, whereas exposure to ethylene increased surface pitting by 18% (unpublished data). But there have been no other reports on this effect of 1-MCP on fruit pitting.

In the Horticulture Australia Limited (HAL) cherry fruit quality survey of selected Australian packinghouses, Golding et al. (2012b) showed that cluster cutters were a source for the development of pitting (Figure 6). Grant and Thompson (1997) have also consistently identified cluster cutters to contribute to pitting and further showed that lowering the cluster cutter speed reduced the level of pitting.

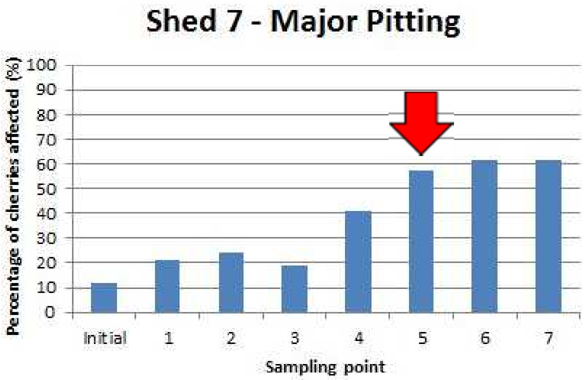


Figure 6. The percentage of fruit with major pitting (>5mm in diameter) in 'Stella' cherry fruit removed from different sampling points in a cherry packing line and stored for four weeks at 0 ^{o}C. The different sampling points in the line sampling point 1 - cold store, sampling point 2 - start of line, sampling point 3 - water dump, sampling point **4 - after cluster cutter**, sampling point 5 - size conveyor, sampling point 6 - hand sort, and sampling point 7 - prior to pack *(from Golding et al., 2017).*

Flesh temperature of the fruit at the time of injury is critically important, with fruit expressing more severe pitting at 0 °C than at higher temperatures (Lidster and Tung, 1980; Crisosto et al., 1993; Candan et al., 2014). The incidence of pitting doubles when fruit is handled during the packing process at 2 °C instead of at the slightly warmer temperature of 5 °C (Zoffoli and Rodríguez, 2014a). Over-cropping also renders fruit more sensitive to mechanical damage, while fruit thinning reduces that sensitivity (Zoffoli et al., 2008).

Suggested strategies to improve performance

A dual strategy of growing fruit that is less prone to pitting and minimising the level of physical damage to the fruit that occurs postharvest is required. Harvesting and postharvest handling and packing practices need to be continually monitored to ensure physical damage is minimised. Cluster cutters have been identified previously as a major source of damage leading to fruit pitting and require particular attention (Patten et al., 1983). Pitting can only be prevented if the source of the problem is identified. It is suggested that monitoring and follow up assessment of fruit pitting is integrated into QA practices (Kupferman and Sanderson, 2001). As well as good equipment design and product flow, equipment needs to be operated at its optimum speeds and throughput.

Bruising

Bruising is the physical damage (compression and compaction) of the cherry fruit flesh (Kupferman and Sanderson, 2001) and was found to be the second most common major defect in Australian cherries in a two year market fruit quality survey (Golding et al., 2012). Bruised fruit are less visually attractive than sound fruit and are more susceptible to the development of postharvest decay. In addition, if the consumer perception of fruit texture is negative due to the presence of bruising, it will affect buying behaviour. For example, when a consumer picks up a bruised fruit and it is soft and mushy, a purchase may be lost. If bruised fruit are purchased, then the fruit will either be later discarded or if eaten it will generally leave the consumer with an off flavour in their mouth to go with the initial disappointment of its lack of texture (crunch).

Bruising can be induced at harvest and in the packing line. Figure 4a shows large depressions (bruising) of the tissue on the shoulders of fruit and can be induced by pickers crushing the fruit in their hand during harvest.

Bruising can occur in the packingline at key areas such as the water dump, cluster cutters and onto hard surfaces such as grading belts (Figure 7). Bruising can be a major defect downgrading fruit unacceptability (Figure 8) but can also be minor which can be acceptable (Figure 8).

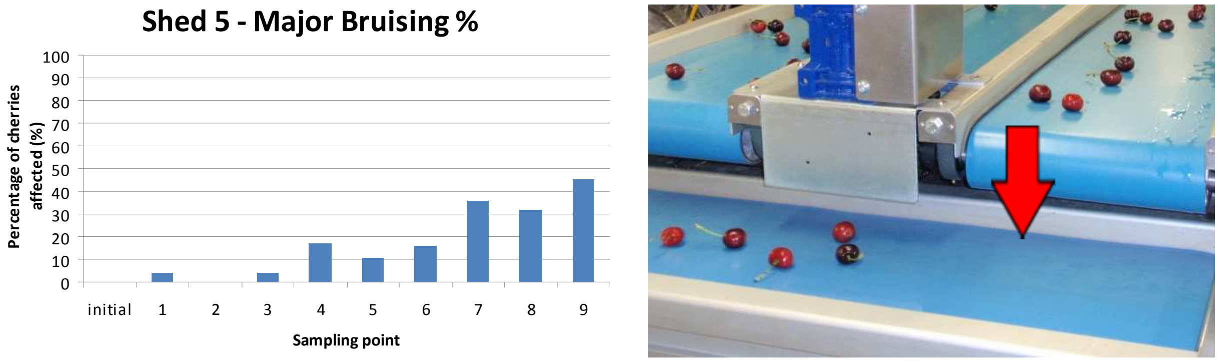


Figure 7. The percentage of fruit with major bruising (unacceptable bruising) in 'Sweet Georgia' fruit removed from different sampling points in a cherry packing line and stored for four weeks at 0 °C. The different sampling points in the line; sampling point 1 - from bin from the cool room, sampling point 2 - from conveyor after fruit transfer, sampling point 3 - before the cluster cutter, sampling point 4 - after the cluster cutter, sampling point 5 - after the sizing run, sampling point 6 - from the flume onto the conveyor, sampling point **7 - from the hand sorting conveyor**, sampling point 8 - from the packed box, sampling point 9 - from the re-packed box.
(from Golding et al., 2017)

Figure 8. Commercially unacceptable - major bruising symptoms (left) and minor bruising symptoms - this is acceptable for commercial sale within customer specifications.
(Photo from Australian Cherry Quality Guide, 2004)

Pebbling

Pebbling is a physiological storage disorder that occurs during associated with cherry fruit stored for a long time (45 days) at 0 °C, although it is not exclusive to postharvest handling since it is possible to detect even at harvest on the tree (Zoffoli et al, 2017). Pebbling is also referred to as 'orange peel', 'lizard skin' or 'alligator skin' and is expressed as a uniform skin roughness that can cover a large surface of the fruit (Figure 9). It is characterized by alternating areas of depression and elevation giving it a finely 'sculptured' appearance. The altered topography is accompanied by a loss of shine (more diffuse, reflected light), which detracts from the fruit's 'fresh' appearance (Figure 9).

The mechanistic basis of pebbling and the factors affecting its severity are unknown (Zoffoli et al., 2017). However Schlegel et al. (2018) recently showed that water loss from the skin is causal in pebbling where the water loss from the skin occurs both by two routes: (1) transpiration to the atmosphere and also (2) by osmotic dehydration to the flesh. Schlegel et al (2018) suggest that from a practical point of view, the postharvest handling of fruit under minimum transpiration (i.e. at low temperature and in a high humidity environment) decreases the likelihood of pebbling, but it does not eliminate the problem. They suggest that the only strategy to minimise pebbling is to minimise storage duration and to grow fruit of cultivars known to exhibit low susceptibility to the disorder. Indeed Zoffoli et al. (2017) and Schlegel et al. (2018) reported that the disorder is more frequent to find in fruit of certain cultivars, such as 'Regina', 'Santina', 'Lapins' and 'Sweetheart', that are harvested at a more advanced stage of maturity.

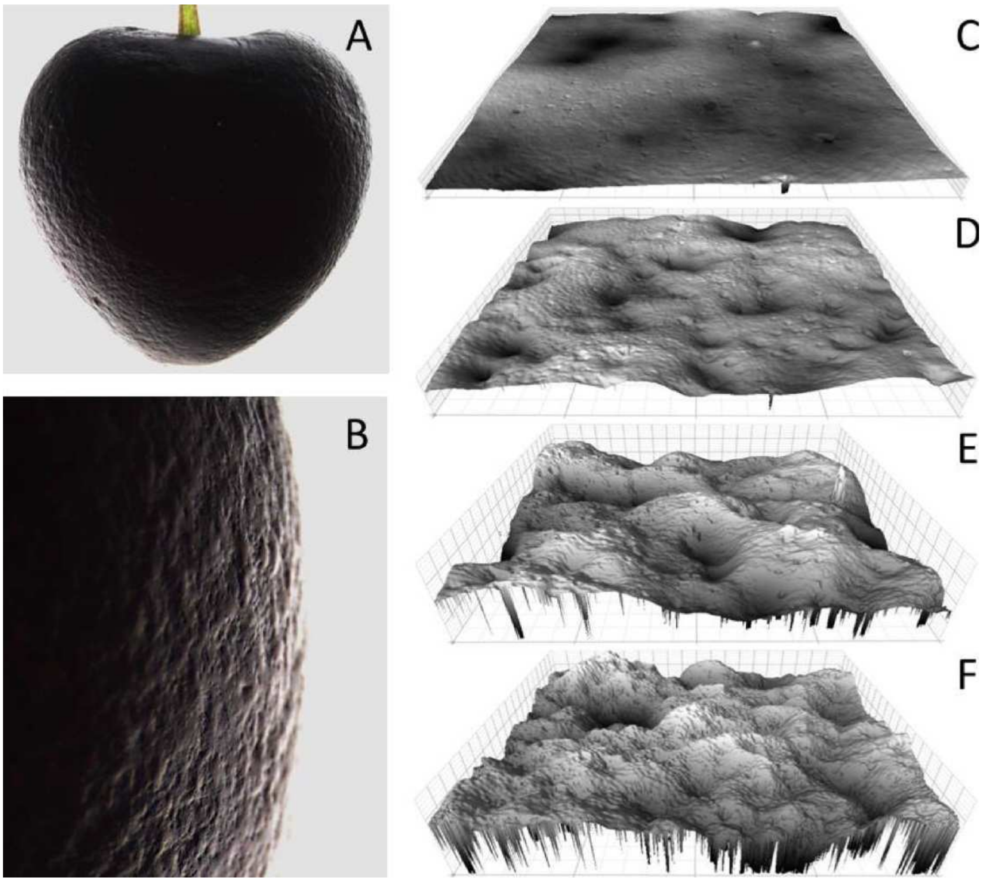


Figure 9. Overview and detail of severe pebbling or orange peel disorder symptoms on a whole fruit (A) and in the shoulder (B) of a 'Sam' cherry fruit following storage for 28 days at 2 °C and 76% relative humidity (RH).
C to F: Surface scans representative of fruit without symptoms of pebbling (C, score 0) and with slight symptoms (D, score 1), intermediate symptoms (E, score 2), and severe symptoms (F, score 3) using a four step scoring scale. For these images, the score, roughness, and maximum range in height were 0, 2.8 µm, and 28.3 µm for freshly-harvested fruit (C); 1, 5.4 µm, and 43.8 µm for fruit held for 14 d at 2 °C, 76% RH (D); 2, 7.9 µm, and 64.7 µm for fruit held for 28 days at 2 °C, 76% RH (E), and score 3, 12.3 µm, and 95.9 µm (F) for fruit held for 28 days at 2 °C, 76% RH.

(All photos from Schlegel H.J., Grimm E., Winkler A. and Knoche M. (2018) Orange peel disorder in sweet cherry: Mechanism and triggers. Postharvest Biology and Technology 137, 119-128)

Managing the storage environment to maintain quality during storage

Cherries have a short harvest period and marketing window, however with increasing global production and trade, there is a need to maintain and improve cherry fruit quality during longer storage and marketing times. However cherries are highly perishable and their shelf-life is relatively short due to their moderate rates of respiratory activity and susceptibility to rapid microbiological decay during storage (Alonso and Alique, 2006). Therefore, managing the storage environment such as temperature, relative humidity and atmosphere with packaging, and the use of fungicides are critical factors to maintain fruit quality during handling, storage and marketing of cherries. The following are the current practices used to maintain quality through the supply chain to the consumer.

Temperature

The most important factor affecting storage and market life of cherries is temperature. This is because temperature has a great effect on the rates of biological and physical reactions, such as metabolism and respiration. Over the physiological range of storage from 0 to 30 °C, increasing temperatures cause an exponential rise in respiration. The Van't Hoff Rule states that the velocity of a biological reaction increases 2 to 3-fold for every 10 °C rise in temperature (Wills and Golding, 2016).

The temperature quotient for a 10 °C interval is called the Q_{10}. The Q_{10} can be calculated by dividing the reaction rate at a higher temperature by the rate at a 10 °C lower temperature. These typical Q_{10} values allow the development of a table showing the effect of different temperatures on the rates of respiration or deterioration and relative shelf life (Table 2). This table shows that if a commodity has a mean shelf-life of 7 days at 20 °C it can be stored for as long as 50 days at 0 °C, but will last no more than 2 days at 40 °C (Saltveit, 2016). However these relative tables only illustrate the effects of temperature along on metabolism and often other factors are responsible for the terminating shelf life.

In real life situations, Toivonen and Hampson (2017) showed that although differences in the postharvest respiration rate among cherry cultivars were not detected at 0 °C but higher storage temperatures influenced the respiration rates of different cultivars differently. For example the respiration rate of ‘Sweetheart’ and ‘Staccato’ cherries was found to be relatively stable and showed the least response to temperature rise from 0 ^{o}C to 10 ^{o}C, while ‘Lapin’ cherries showed a large rise in respiration rate at higher storage temperatures (Toivonen and Hampson, 2017). Respiration rates and temperature abuse have significant implications to the storage and marketing of cherries, where high respiration rates at non-recommended storage temperatures lead to an increase in CO_2 production. As cherries are packaged and marketed in sealed modified atmosphere (MA) bags, the high CO_2 generated by the cherries can cause storage issues within the bag. This is discussed in more detail in the *Modified Atmosphere Section*.

Table 2. Effect of temperature on generalised rate of deterioration.

Temperature (^{o}C)	Assumed Q_{10}	Relative rate of deterioration	Relative shelf life
0	-	1.0	100
10	3.0	3.0	33
20	2.5	7.5	13
30	2.0	15.0	7
40	1.5	22.5	4

Adapted from: Saltveit M. (2016) ‘Respiratory metabolism’ In K.C. Gross, C.Y. Wand and M. Saltveit (Eds.), The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks: USDA Agriculture Handbook Number 66.

Maximum postharvest life of cherries is attained with storage temperatures just above freezing. The relationship between the SSC level of the cherries and freezing temperature has been studied (Whiteman 1977; Jie et al., 2003) and show that for fruit with high SSC (around 22.5% Brix) freezing occurs at < -2.5°C, but for fruit closer to SSC 16.7%, freezing temperature is -1.8 °C. Therefore the recommended stored temperature is between -0.5°C to 0.5°C. Exposed to non-optimal storage temperatures generally increases respiration rates, leads to stem dehydration and accelerated fruit softening. However, the recommended temperature for harvesting and handling is between 10 °C and 20 °C as within this temperature range the incidence of impact bruising damage is lower (Crisosto et al., 1993).

The time taken to initiate the cold chain and its maintenance are important elements of the postharvest temperature management of cherries. Delays in cooling have been shown to reduce storage quality. Rapid cooling from the orchard slows down fruit respiration rates, fruit softening and stem dehydration. In addition, delayed cooling also increases the risk of bacterial or fungal infection of any skin wounds present on the fruit. Muñoz et al. (2017) assessed in-field hydrocooling immediately after harvest to optimize storage and shelf life. In field experiments in Spain, they showed precooled in the field fruit had a higher acceptability index (SSC / TA), and improved appearance, due to their greener and more turgid pedicels, and their minor visual dehydration (Muñoz et al., 2017). However the fruit had a slight increase in mechanical damage and maybe due to set-point being 1°C, where a set point of 5 – 7 °C would have been better to reduce these defects. However if the fruit is quickly transported back to the packinghouse and hydrocooled within 2 hours, these benefits would not be observed.

The cold chain should be established as soon as possible after harvest to remove the field heat from the fruit in the orchard, especially in hot weather and for (warm) fruit picked late in the day. The elimination of the field heat from the fruit in the orchard should be conducted as soon as possible to bring the temperature of the fruits down to 0 °C for maximum quality and shelf-life (Alonso and Alique, 2006). However, Bernalte et al. (2003) showed that holding 'Van' sweet cherries at 22 °C for up to 15 hours before transferring to cool storage at 4 °C did not negatively impact the quality of the fruit after storage.

As previously discussed, getting the fruit to the correct temperature is critical to maintain quality but regardless of the type of cooling, fruit cools quickly at first, then slowly over time. This is illustrated in the Figure 10 and demonstrates an important concept of cooling which is the seven-eighths (7/8) cooling. This is the time needed to remove 7/8 (87.5%) of the temperature difference between the initial temperature of produce and the temperature of the cooling medium. It is measured from the time produce is first placed on the forced-air cooler. For hydrocooling the cooling medium is water and forced air cooling it is air (these are discussed below). Achieving 7/8 cool time ensures most of the field heat has been removed, the respiration rate of the produce has been lowered and the produce is very close to its optimum holding temperature. In theory, produce never reaches the cooling medium temperature. However, the 7/8 cool time is intended to get produce as close as practical to the temperature of the cooling medium.

In the example in Figure 10, shows the initial internal temperature of the fruit was 32°C and was being cooled with refrigerated air at 0°C. In this example, it took 9 hours for produce to reach 4°C, representing an 87.5% drop. Therefore, the 7/8 cool time was 9 hours. In theory, 7/8 cool time is three times the ½ cool time. Therefore, produce taking 9 hours to cool to 4°C should take 3 hours to reach 16°C. This is seldom true, since cooling conditions and temperatures in a cold storage rarely remain constant. However, this cooling curve relationship helps predict when produce will reach a certain temperature. This example in Figure 10 used cold air as the cooling medium, but for the cooling of cherries using hydrocooling is recommended for removing the field heat, where hydrocooled cold water removes heat 15 times more quickly than air.

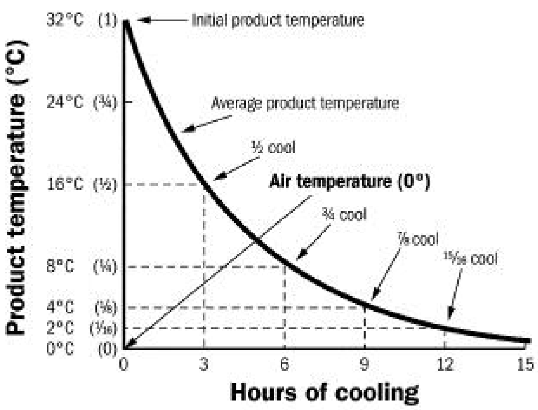


Figure 10. Example of fruit cooling from 32 °C down to 0 °C and 7/8ths cooling principle.
From Frasier (2014).

Commonly, the packaging is designed to quickly achieve a saturated atmosphere to reduce dehydration, but is should also be free of condensation. Usually a water-absorbent pad is placed under the packed fruit to absorb any free water, otherwise the fruit will crack. Packaging materials, especially box design and perforation area of the liner bag affect the flow of cold air and time of cooling times (Wiley et al., 1999). These must be considered in the design of cooling equipment.

There are several different types of cooling that are used in the handling and storage of cherries: (1) hydrocooling, (2) forced air cooling and (3) passive room cooling.

1. *Hydrocooling*

Hydrocooling is one of the fastest methods of cooling and is widely used and recommended for cherries. Hydrocooling moves chilled water over the warm cherries to cool the fruit down. The cold water very rapidly cools the fruit (about 15 times faster than air) and cooling is uniform. After passing over the warm fruit, the water is then re-cooled and recycled. However care must also be taken to maintain the sanitation of the hydrocooling water. There are a number of sanitisers but this is usually chlorine. This is discussed in the *Sanitisers Section*. Hydrocooling is very effective for reducing stem shrivel and browning and maintaining fruit turgor. However, it is important the hydrocooled fruit is allowed to drain fully before packing; else the wet fruit at the bottom of the pack will crack. Free water promotes the spread of fungal disease. These issues are discussed in more detail in the *Stem Dehydration Section*.

For cooling the water, many hydrocoolers have a vapour-compression refrigeration system similar to an air conditioner or refrigerator The most common hydrocoolers, cool open field containers of fruit (bins containing picking boxes) with a vertical flow of water, with the effluent water being collected from the bottom, re-cooled to near 0 °C and pumped to an overhead drip pan to recirculate over the fruit. A water flow of 600 to 1,000 L / min / m^3 of drip pan surface area is recommended (Thompson and Chen, 1989).

2. *Forced air cooling*

Forced air cooling is used on packed fruit to remove heat remaining after hydrocooling and that may have accumulated during packing. The most common air cooling is forced-air tunnel cooling. A tunnel is formed by placing one row of stacked pallets of packages on each side of an exhaust blower. Pallets are placed tightly together within the row, and a space of 1 m (approximately) is left between the two rows (Figure 11). A tent covers the upper part of the tunnel and the air is exhausted from the covered plenum creating a slight vacuum. Cold air from the cool-room must then flow through the vent opening and around individual fruit to reach the low pressure area. (Thompson, 1996).

Figure 11. Post-pack cooling of cherries in packed sealed boxes for storage and marketing in Spain. Note forced air cooling of the fruit with some ventilation holes in the boxes to allow air flow / cooling.
(Photos - John Golding, NSW Department of Primary Industries)

The box design (perforation size and total area), the amount of materials or barriers all affect the convective air flow. Conductive cooling greatly reduces the rate of cooling and increases the risk of condensation. Differential cooling occurs with the fruit on the room-side of the tunnel being cooler than that are inside of the tunnel. This difference becomes extreme when perforated bags are compared with modified-atmosphere bags. Accurate evaluation of pulp temperature should be done depending on the packaging materials used.

3. Room cooling

The palletised fruit are stored in a cold room, where the primary objective is to maintain the -0.5 °C (± 0.5 °C) pulp temperature. While most cherries are packed into MA bag there is little water loss from the sealed MA bags. However in circumstances where perforated liner bags are used it is critical to avoid dehydration of the fruit. This can be done by maintaining high relative humidity (~ 90%) and to reduce air flows to 0.3 - 0.42 m/s. The flow during cooling and the effect of packaging component has been modelled using computational fluid dynamic in table grapes (Delele et al., 2012).

Fruit stacking should leave a 20 cm between rows of pallets and a spacing of 30 cm from the walls to allow sufficient circulation to maintain uniform temperatures around the cold room. Pulp and air temperature should be carefully monitored also considering where fruit is located relative to the evaporator and the retuning air flows.

Harvesting

The optimal harvest time for cherries often involves balancing a number of potentially conflicting factors such as the availability of harvest materials, the number of trained pickers and differences in priority among cultivars. These factors then interact with agronomic practices and environmental characteristics to define the best time to harvest of a particular orchard.

For an individual cherry, the optimal harvest time is within quite a narrow period of time (the harvest window). This window embraces a particular physiological stage of fruit development at which fruit quality peaks. Because of uneven flowering times and asynchronous flowering, multiple selective harvests are usually required to complete the harvest of a particular cherry tree / orchard. These harvests are usually spread over a period of one or two weeks (the extent of the spread of fruit ripening also depends on climate). If a cherry tree is strip-picked at some 'optimal' time, then significant proportions of fruit will always be found to be over-ripe, or ripe, or under-ripe. Among the changes that occur during fruit development, the change in skin colour has been shown to correlate best with the other maturity indices - the accumulation of soluble solids, the loss of fruit firmness (softening) and the development of the cherry's distinctive flavour. The selection of a time for harvest that balances a high SSC with minimum softening is usually the first step to be taken in maximising the storage life of the fruit, the acceptability of the fruit to the final consumer.

Maturity index

As discussed in the *Fruit Physiology Section* and *Fruit Development Section*, both fruit SSC and the skin red colour increase during maturation. The early change in colour occurs at the beginning of Growth Stage II, when the exocarp colour changes from green to white or light-yellow (Azarenko et al., 2008). Chlorophyll degrades and anthocyanins then accumulate resulting in the special background colour and the red colour that are characteristic for each cultivar (Muskovics et al., 2006; Gonçalves et al., 2007). The change in skin colour from light- to dark-red correlates with decreases in firmness and with the accumulation of SSC (Crisosto et al., 2003; Drake et al., 2002; Mitcham et al., 1998; Toivonen et al., 2004). Consumer purchase decisions are based upon visual acceptance, with colour being one of the most important external traits, together with accumulation of SSC (Crisosto et al., 2003; Chauvin et al., 2009).

The characteristic red colour of cherries is an expression of the accumulation of different anthocyanin pigments in the skin (Gao and Mazza, 1995). The accumulation of anthocyanin changes the skin colour from red to mahogany, with dark mahogany and black at more advance stage of maturation (Gonçalves et al., 2007). The evolution of colour can be followed by chromometric measurements of the skin using L (Luminosity), C (Chroma) and h (Hue) values, where L, C and h which all diminish with maturation (Mozetic et al., 2006; Remón et al., 2006). Colour scales such as the comparing against colour plates of the 'Australian Cherry Colour Guide' describe the evolving red skin colour have been developed and are used commercially to help define harvest time. A conceptual computer vision to be applied outdoor has been proposed with the possibility to help the picker and provide with accurate rating of sweet cherry colour in the future (Wang et al., 2012).

Skin colour has long been accepted as the best indicator of harvest maturity across a number of sweet cherry cultivars (Crisosto et al., 2003; Drake and Fellman, 1987; Drake and Elfving, 2002) with dark red/mahogany proposed as the colour at which to harvest most cultivars. (Kappel et al., 1996; Drake and Elfving, 2002). At this stage, the acceptability to the consumer is maximised, depending on the concentration of SSC reached. The harvest at an earlier colour stage stops the accumulation of SSC and the increase in fruit size and mass (Grandi et al., 2017). Meanwhile, late harvests can compromise storage life because of loss of firmness and increasing skin pitting (Chauvin et al., 2009; Diaz-Mula 2009; Wang and Einborn, 2017).

Initiation of the harvest at a light mahogany colour index is required when large orchards are harvested or when soft cultivars are involved or when the weather is very hot. A harvest at an advanced black mahogany skin colour must be reserved only for some cultivars which remain firm and stable until the end of maturation even under high temperatures at harvest (Toivonen et al., 2004). Therefore, it is very important to understand the physiology of ripening of each cultivar as some soften faster and with lower accumulations of soluble solids at the colour changes stage which does not allow long periods of storage. Conversely, for some other cultivars these are the optimum conditions for storage. Specifically for 'Sweetheart' cherries, Chauvin et al. (2009) showed that cherries harvested at mid-harvest were the most preferred of the harvest times (as compared to early and late harvest) despite not having the highest intensities of colour, sweetness, or flavour. This indicated the importance of colour, sweetness, and flavour of cherries on the overall acceptance and the possible interaction of these attributes in consumer acceptance. Furthermore, Chauvin et al. (2009) suggested that standard harvest maturity indicator (i.e. red colouration of the skin) was appropriate for optimum consumer acceptance of 'Sweetheart'. More broadly, these results suggest that there is some flexibility for the grower with regards to 'Sweetheart' cherry harvest and acceptable sensory properties (Chauvin et al., 2009). But other research is required for other cultivars.

Pre-harvest factors such as crop load, heat stress and water availability explain the variation found in SCC for fruit of the same colour but among different orchards (Wang and Einhorn, 2017). This is discussed in more detail in the *Preharvest factors affecting storage life Section*. Proper characterisation of these differences, allows the segmentation of fruit quality into the different markets.

Harvest Management Cherries are harvested at a ripening stage when their respiration rate is high and fruit are prone to rapid deterioration (Zhao et al., 2013). Because of this, the cool-down period after harvest for fruit must be as short as possible (Toivonen, 2014). In addition, exposure of the fruit to the sun should be avoided and physical damage minimized (Kupferman and Sanderson, 2005). Figure 12 shows the benefits of reducing the time in the sun with improved firmness and stem quality. Ideally picking should be initiated when the fruit is cool, soon after dawn and concludes around midday, after which fruit temperatures usually peak (usually around 3pm).

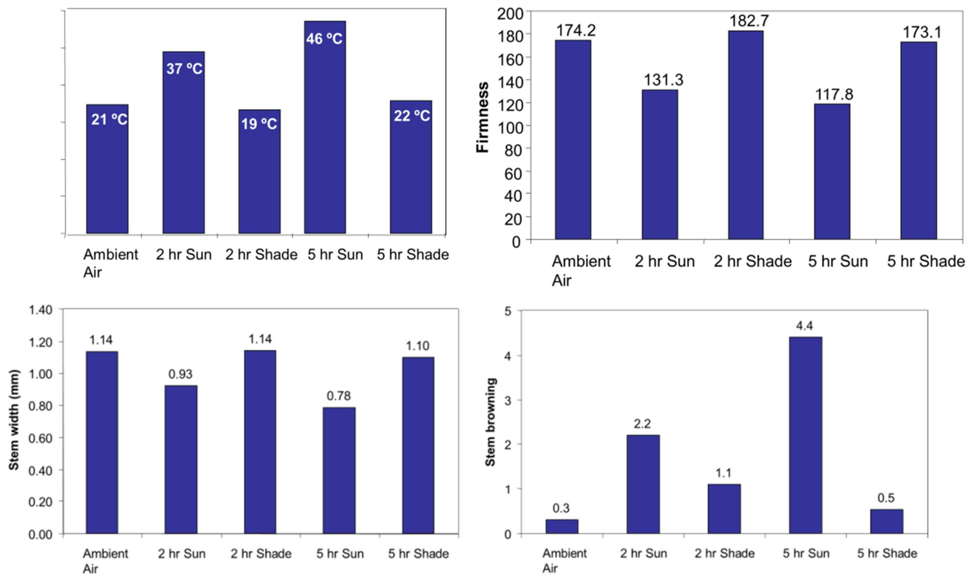


Figure 12. Effect of time and shading on fruit temperature (top left), fruit firmness (top right), stem width (lower left) and stem browning (lower right).
(Figure from Eugene Kupferman formerly of Washington State University, USA).

Cherry harvesting is manual with pickers paid by the weight / volume of picked fruit. Hence, the efficiency of the pickers (kg per hour) should be optimized by staff training and selection of the appropriate harvest equipment (basket or bag, ladder etc.) that align with the orchard's training system and size (Ampatzidis and Whiting, 2013). The use of ladders, mobile platforms or pedestrian harvesting have great effects on harvest efficiency and so need special attention so as to minimize the cost of harvest to the grower and maximize the income for the picker

(Seavert and Whiting, 2011). A tracking system for each picker will help gather information associated with the amount and quality of the fruit harvested. Digital or manual collection of the data should be available on time. (Ampatzidis et al., 2012). Pickers should also be trained in the safe use of ladders, the correct way of removing the fruit from the spur, correct fruit handling and the types of defect that serve as reasons for later discarding a fruit. Cherry fruit are generally be harvested directly into small (3 kg) or large (9-10 kg) plastic picking baskets and then stacked inside bins for later collection and transport to the packing facility. Alternatively, the fruit can be harvested into a picking bag and then poured gently into large, shallow plastic boxes. In this case the incidence of bruising can be higher but the control of fruit quality better, as the fruit can be seen more clearly by the supervisor.

Cherry fruit are very sensitive to physical damage which cannot be easily detected at harvest. The symptoms of impact or compression damage are a depressed area or a small pit (impact) or a deep depression (compression) (Zoffoli et al., 2017). Unfortunately, these are not usually evident until about 10 days after harvest. The individual selection of fruit on the tree and then the picking motion, holding them by the pedicel and dropping them gently into the picking box, is part of the re-training pickers must receive each season. Most of the compression damage in stored fruit is caused at harvest by the pickers, while pitting is attributed mainly to the packing line operation. (Thompson et al., 1997). The types of fruit damage are discussed in the *Pitting* and *Bruising Sections*.

The classic symptoms of stem dehydration appearing during storage (such as stem yellowing and browning) are an expression of accumulated weight losses resulting from physical factors associated with the water vapor pressure deficit of the environment. As discussed in the *Stem Browning Section*, the highest water vapour pressure deficit and therefore the highest rates of water loss, occur during harvest with warm fruit and hot dry winds. The use of reflective tarps (Figure 13), shading nets and refrigerated transport are among the protections that are effective at reducing postharvest water loss (Schick and Toivonen, 2002). The period from picking to placement in hydrocoolers should also be minimized, and anyway should be much less than four hours. This usually involves frequent transportation of picked fruit from orchard to the packing facility hydrocooler, or perhaps to a nearby mobile hydrocooler (Toivonen, 2014). Some growers have an immediate water shower before proper hydrocooling to take the hot field heat from the fruit to minimise excessive cooling requirements of the hydrocooler.

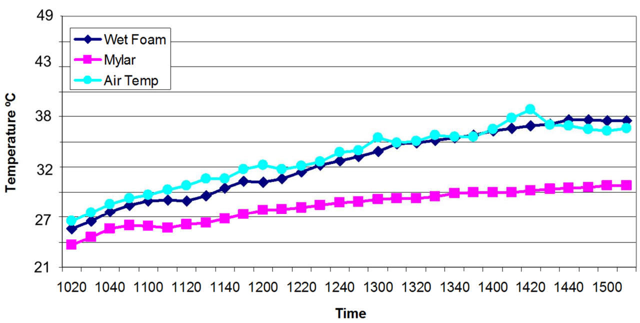


Figure 13. Use of reflective tarps over the bin of harvested cherry fruit in the orchard (left) and demonstration of benefits of the Mylar tarp reducing the increase in fruit temperatures in the bin in the orchard *(Photo and Figure from Eugene Kupferman formerly of Washington State University, USA).*

Fruit sorting and grading

After harvest and pre-cooling, cherries need to be separated into single fruit. There are several types of cluster cutters: (1) metal blade saws and (2) water hydraulic cherry cluster separator. Fachaux^{TM} is the only company to have a global patent on a water hydraulics cluster cutter (Figure 14). The main advantage of the saw cutters is precision and robustness, while the hydraulic cluster separator is generally softer on fruit. But both machines can cause physical damage to the fruit (see *Pitting and Bruising Defects Section*).

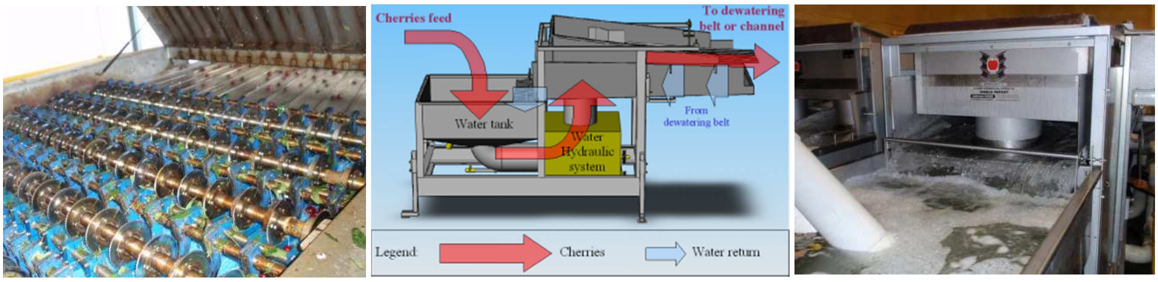


Figure 14. Different types of cluster cutters – traditional blade cutters / saws (left) and water hydraulic cherry cluster separator schematic (middle) and hydraulic cluster separator in action (right).
(*Photo of the water hydraulic cherry cluster separator schematic was from Fachaux™* *www.cal-fachaux.com* *(accessed 6 February 2018). Other photos - John Golding, NSW Department of Primary Industries)*

After harvest, fruit needs to be thoroughly sorted, graded and packed to meet market expectations. It is critical that fruit that do not meet market expectations are removed. There are a range of different grading systems available around the world. Some of the major grading systems include:

- GP graders www.gpgraders.com
- Unitec https://en.unitec-group.com/
- Compac www.compacsort.com/en
- Others such as – Ellips (https://ellips.com)

Each system has its own benefits and limitations. A fundamental of any sorting and grading system is that it must be gentle on the fruit with consistent grading to increase the efficiency of sorting. While it is not only important to remove the fruit that do not meet expectations, it is equality important is to minimise the removal the fruit that meet expectations, which are accidently removed (false positives).

Most modern cherry sorters have the ability to sort the internal and external quality of cherries - size, colour, internal defects, external defects, softness, absence or presence of stalk, soluble solids content (SSC, Brix). This is done with the use of high definition cameras. Each defect (such as pitting, thrip damage) have limits of commercial acceptability for each customer which need to be finely tuned with the grader software.

For just one example, the GP Graders systems electronic AirJet® grader uses black and white, colour and near infra-red (NIR) cameras that are located directly over the rotating cherry to take synchronized images of the fruit and ensuring no parallax errors corrupt the image analysis. High-intensity pulsing LED lighting provides intense illumination of fruit under the cameras and the removal of 'light glare' (Figure 15). In this system, 30 images of the total surface area of each cherry are captured for analysis with a reported 650kg per lane per hour yielding high productivity while maintaining grading accuracy (GP Graders, 2018).

There are a range of different grading systems available with benefits of volume through-put, accuracy, reliability and most importantly reducing grading and sorting staff to improve packing efficiency.

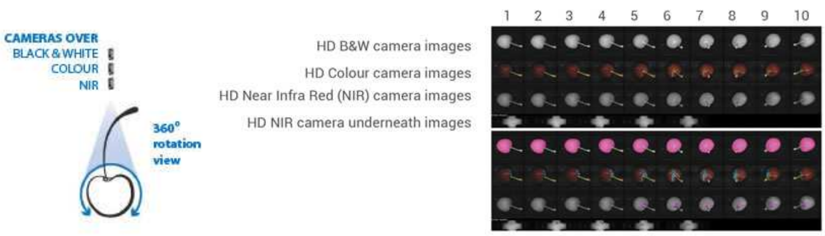


Figure 15. High definition images of individual cherries (left) and 360° rotation black and white, colour and NIR cameras are used to grade each cherry for GP Graders' electronic AirJet® grader.
* Note there are many different graders and packing systems available (see above)
(Photos from GP Graders (www.gpgraders.com) accessed 6 February 2018)

Assessment of impact damage

To assist with identifying any potential injury points within a packingline, we have previously collected samples from different parts in the cherry packing and sorting line (Golding et al., 2012). At each of the sampling points four different lots (replicates) of 25 fruit were removed from the line and stored for later assessment (Figure 16). This handling procedure is time consuming and costly, but enabled problem areas of the packingline to be identified and rectified (Figures 5-7).

Figure 16. Packing of sample fruit from different parts of the cherry packing line (left). Storage of samples at 0^{o}C before assessment for fruit quality and defects (right) *(from Golding et al., 2012).*

The use of an artificial cherry (eCherry, Ag Vision, Chile) which can record impacts in the packingline has been developed and would assist identify potential damage points in the line. The eCherry is a 34-mm diameter sphere molded with silicone rubber or similar material and contains a microcontroller, a static memory, a three axis accelerometer and a battery (Bro and Rojas, 2017). The accelerations measured with the eCherry were found to have very close agreement with theoretical values determined when the device was mounted in a centrifuge. The impacts from drops onto steel or sponge rubber were found to differ mainly in the duration of the impact, as opposed to the magnitude of the initial impact. The eCherry has been found to detect low magnitude accelerations that might cause damage during transport and processing (Bro and Rojas, 2017). This could be used to identify and improve packinglines to minimise damage (Figure 17), but its commercial availability is unclear (March 2018).

Figure 17. Demonstration of the artificial electronic cherry by Ignacio Rojas from AgVision S.A. for recording impacts in the cherry packingline.

(from AgVision Chile. http://agvision.cl/wp-content/uploads/2012/06/20120623_1121041.jpg. Accessed 12 February 2018).

Packaging

Packaging is an increasingly important part of marketing and product differentiation. High quality packaging of premium fruit can justify premium returns to the grower and packer. As production and handling costs rise, improved packaging and marketing can assist justify the increased returns to growers.

Packaging is an essential component of getting cherry fruit from the orchard to the consumer and in preventing food losses and waste. Cherry packaging is unique due the perishability of the fruit and its optimal storage conditions. There are different levels of packaging for cherries, where cherry fruit can be packed into plastic bags or clamshells. These clamshells are then packed onto plastic lined box or crate which are then stacked onto pallets for mechanical handling by forklift. All of these different levels of packaging have different functions and requirements. This discussion will focus on the primary source of packaging, where the cherry fruit itself is packed into a punnet, bag or bulk packed in plastic lined boxes. This section is based on a review of packaging for CABI (Golding, 2017).

Role of packaging

Packaging serves many complimentary roles in getting cherries from the orchard to the consumer (Wills and Golding, 2016) (Figure 18) and includes:

- Protect against mechanical damage during handling, storage, transport and at the retail level. This should also stabilise and secure the fruit against movement within the package during handling.
- Allow for cooling and may offer a degree of insulation from external heat.
- Maintain product quality by minimising transpiration-induced water loss and shrinkage.
- Utilise gas properties of plastics and films unique properties to optimise the gas concentration within the package and avoid any risk of anaerobiosis.
- Is transparent (e.g. clamshells and retail bags) at the retail environment.
- Provide consumer information such as handling instructions and labelling. This can also extend to marketing information to encourage future sales.
- Most importantly, the package should be cost-effective in relation to the value and the required extent of protection of the contents.

Figure 18. Prepack bag of cherries with features of good packaging – protection against the external environment, holes to allow cooling and air flow and prevent condensation, and bright graphics for consumer and marketing information, eg QR (Quick Response) codes for consumer information (right).
(Photos - John Golding, NSW Department of Primary Industries)

The inherent properties of the package should be:

- The package strength is relatively unaffected by moisture content when wet or at high relative humidity which is commonly found in cold storage.
- Should not contain chemicals which could transfer to the produce and taint it or be toxic to the produce or to humans.
- Should offer security for the contents, and/or ease of opening and closing in some marketing situations.
- Should display product information (e.g. contents, origin, packing time, best before etc.) which is required at different levels in the supply chain.
- The package should also be easy to dispose, re-use and /or recycle.

Prevention of mechanical damage to the fruit

The primary role of packaging is to prevent mechanical damage to the cherries during handling and storage. Any damage to the fruit can lead to loss in quality. There are four major mechanical damage types that can occur due to poor packaging and rough handling; impact, compression, vibration damage and cuts (Wills and Golding, 2016).

- Impact damage or bruising is caused by dropping boxes of fruit onto hard surfaces. These impact shocks can occur during handling and transport and are insidious as the damage often does not become apparent at the time of damage and is only expressed after some time.
- Compression damage occurs when there is physical compression of one produce onto another. This can occur when the box fails in conditions of high storage humidity or free with the resultant weight of all the produce in the stack compressing onto the fruit at the bottom of the failed stack. Current box design (with reinforced corners etc.) is normally sufficient to prevent this.
- Vibration or abrasion injury can occur when loosely packed and uncushioned products are damaged during transport, particularly on rough roads. This is less of a problem with cherries, where the fruit are generally tightly packed into bulk samples. But care needs to be taken in packs with hard surfaces such as punnets where the fruit may become damaged due to excessive vibration which can occur during transport resulting in abrasion or rub marks on the skin.
- Cuts in the skin from punctures from the stems of other fruit can occur in fruit that is prone to damage and is exposed to rough handling (Figure 19).

Figure 19. Damage and punctures caused by stems of other fruit.
(Photo - John Golding, NSW Department of Primary Industries)

To avoid mechanical damage it is essential that the package and not the produce should bear the stacking load and that the produce does not move or sustain vibration injury. It is critical not to either (1) overfill the package (which increases compression and impact bruising) or (2) underfill the package, which can increase vibration damage and cuts, whereby individual fruits are moving around and impacting each other or to the walls of the package. To avoid mechanical damage, it is important that all the produce is held firmly, but not too tightly, within the package. This is generally the case with cherry packaging, but care must be taken to reduce rough handling, particularly of pre-packaged fruit.

Facilitate cooling

As previously mentioned, temperature is the primary mechanism to maintain produce quality. Cherries have an optimum storage temperature for long term storage at 0 ^{o}C and packaging is an important component that mediates the transfer of heat (cool) from the produce. Cherries are a unique commodity in that the use of sealed MA bags and liners are routinely used, where there is no direct air flow over the fruit. Air flow is the major mechanism of transferring heat from the packed fruit to the storage atmosphere, but when the fruit are packed in sealed plastic bags and boxes then cooling and maintaining temperatures in packed fruit is problematic. It is difficult to cool down recently packed fruit from the packingline at 5-10 ^{o}C, to the recommended storage temperature of 0 ^{o}C. But can be achieved with post-pack cooling and this is discussed in *Temperature Section*.

Even at low storage temperatures, cherries continue to respire, albeit at very low rates and this produces heat as a by-product. This heat needs to be continually removed with refrigeration to maintain the correct storage temperature. If this heat of respiration is not removed from the package or stack of boxes, then these localised hot spots can significantly affect final product quality. Having sufficient ventilation between boxes and is essential to allow this heat to be removed.

An exception in the use of MA or poly liners in the storage of cherry fruit is the use of perforated liners where cherries are to be treated with a gas fumigant after packing (Figure 20). Some export markets require cherry fruit to be treated with gas fumigant such as methyl bromide to kill any quarantine pests, such as Queensland fruit fly before export. The ventilation holes in the carton and the perforated liner should be sufficient to allow fumigation treatments (Figure 20).

Figure 20. Specialist cherry bags in box for quarantine fumigation – note the vent holes in box to allow access to the fumigant. Polyethylene bags with small perforations also allow access to the fumigant gas but also maintains high relative humidity around the fruit.
(Photos - John Golding, NSW Department of Primary Industries)

Minimising water loss

One of the major roles of packaging is to maintain high humidity and minimise the loss of water from the fruit. Water loss occurs when there is a vapour pressure difference between the cherry and the surrounding environment. Thus packaging provides a barrier around fruit and also prevents surface air movement. The use of plastic or MA liners prevents any water loss from the fruit to the outside atmosphere, as the plastic liner retains water inside the sealed liner. While the cherry fruit and stems can still lose water due to respiration and transpiration within the box, the rate of water loss is minimised. As previously discussed, relative humidity (RH) has been found to relate to the water loss of fruits and stems, where the stored fruit in low RH causes increased water loss from the fruit and stem and results in softening of the fruit and stem browning (Golding et al., 2015). The optimum relative humidity for the storage of sweet cherries is between 90 and 95%, where this range of RH is good at maintaining the green colour of the stem, when the storage temperature is at its optimum (Alonso and Alique, 2006). However the build-up of condensation and excess water within the sealed liner can be an issue, especially as cherry fruit are packed wet. This can be further exacerbated if poor temperature management is poor. Water absorbent pads are therefore routinely used at the bottom of the box to capture and hold the free water resulting initially from condensation, which is followed by droplet formation and finally pooling within the package (Figure 21). These are used for absorbing free water following packing and also absorbs and any cherry juice from any damaged or rotting fruit during storage which would normally be substrates for pathogens.

Figure 21. Absorbent pads are commonly placed at the bottom of the box to absorb excess water and any juice.
(Photo - John Golding, NSW Department of Primary Industries)

Managing stem browning

Cherry stems are an important component of the acceptability of fresh cherries (Dever et al., 1996). Although cherry stems are not consumed, consumers use the stem as an indicator of freshness (Kappel et al., 1996). However cherry stems have a much thinner epidermis and cuticle layer than the fruit, are very susceptible to water and carbon dioxide losses. Their resistance to water vapour transfer is much lower and can lose water up to eight-times faster than from the fruits (Linke et al., 2010). Therefore maintaining high relative humidity (low VPD) with the use of plastic liners greatly assists the maintenance of stem quality during storage.

While not widely used in Australia, the use of unlined fibreboard boxes with the clear plastic cover is common for marketing into local markets in other growing regions such as Spain (Figure 22). Dry fibreboard cartons are not generally recommended as the fibreboard can absorb considerable amounts of moisture from the produce and environment. The ‘open’ boxes (no liners) have reduced protection of water loss from the fruit (and stems) and dictate that this fruit is for direct rapid marketing with not storage. This can be overcome by increasing the moisture resistance of fibreboard packages with a surface or internal plastic laminate. Alternatively the use of non-absorbent packaging material like plastic or polystyrene can protect and minimise water loss. Although on environmental grounds, the use of polystyrene should be minimised as it is non-biodegradable and is difficult to recycle.

Figure 282 Use of 5kg fibreboard boxes with clear plastic lid (with no liner) for local marketing of cherries in Spain.
(Photos - John Golding, NSW Department of Primary Industries)

In prepack systems that use clear transparent plastics for retail display such as clamshells, condensation or fogging on the inside plastic surface is a problem which affects consumer attraction to see the produce (Figure 23). This can be overcome with the addition of anti-fogging chemicals into the plastic during their manufacture. This treatment does not affect the quantity of moisture inside the packs, but these treatments work by minimising the surface tension of the condensed water so that it forms sheets rather than discrete drops, thus allowing clear vision into the punnet / clamshell.

Figure 23. Condensation with the package of a clamshell (left) and in bag (right).
(Photos - John Golding, NSW Department of Primary Industries)

Mechanical strength of the box

As mentioned previously, the major role of the packaging is to protect the produce from mechanical damage from the farm to the consumer. There is a common adage that "*the package should support the produce and the produce should not support the package*". This it true where the package must maintain its strength throughout its storage life, right through to the final customer. This is a significant issue for packaging of horticultural produce due to the high levels of moisture in the storage environment, where many packages can lose their strength when they become damp or wet undermining their integrity and function.

Fibreboard. Fibreboard boxes (cartons) are the main packaging type used in the world for the handling and distribution of cherries. Corrugated fibreboard is made from paper / card board materials material consisting of a fluted corrugated sheet between flat linerboards. It is the alignment and use of the fluting between the inner and outer liners that give it is strength (Thompson and Mitchell, 2002). Fibreboard can be made stronger by use of two or more thicknesses, such as the bottom and lid of fully telescoping cartons which is widely used in many industries. Fibreboard is widely used due to its relative strength, flexibility and cost. Other significant advantages of fibreboard are that it can be laminated and printed with attractive product and marketing information and can easily be recycled. However fibreboard boxes are inherently weak if they are not correctly stacked, and must be stacked using their load bearing supporting corner sections (Figure 24).

Figure 24. Fibreboard cartons showing the single fluting (generally used for lid, but in this case is used for a base) and double fluting with reinforced corners provide additional strength to the carton and also facilitates stacking and inter-locking for the cartons (right).
(Photos - John Golding, NSW Department of Primary Industries)

The strength of fibreboard is determined by a number of storage factors such as relative humidity of the storage environment, storage time and stacking arrangement. Fibreboard loses strength over time when it is supporting weight. For example Thompson and Mitchell (2002) describe that a corrugated fibreboard box supporting weight for 10 days will have only 65% of its original factory strength, and after 100 days, it will only be 55% of its original strength. Plastic wrap often with the use of pallet corners (Figure 25).

In addition, under normal storage conditions i.e. high humidity, fibreboard cartons rapidly lose strength as they absorb moisture. While each carton specification is different, as an example Thompson and Mitchell (2002) reports that laboratory testing of fibreboard boxes retains only 40% of its original stacking strength when used in a storage environment at 90% relative humidity, as compared to storage at 50% relative humidity.

Figure 25. Use of fibreboard boxes with stretch wrap and returnable plastic crates (RPC) on pallets (left) and fibreboard boxes with pallet corners to increase pallet strength (right) in packinghouse coolroom awaiting distribution to market.
(Photos - Adam Coleman (left) and John Golding (right) NSW Department of Primary Industries)

Thus the use of fibreboard boxes face some challenges for use in hot wet conditions and in high humidity cool storage. This is a particular problem where cold fruit in fibreboard boxes are exposed to hot and humid conditions. Ideally this should not happen with cherries, where it is critical to maintain the cool chain to maintain fruit quality, especially in the MA conditions. However in these situations, water from the humid atmosphere condenses or drips refrigeration units onto the box and is absorbed into the fibreboard boxes, significantly weakening the boxes causing collapse. However the absorption of water from the humid storage environment and box strength can be slowed by adding or impregnated the fibreboard with low molecular weight polyethylene, resins, plastics or wax. However this process is expensive and many packages such as waxed fibreboard are difficult to recycle.

Plastics. The use of solid plastic returnable plastic crates (RPC) are becoming increasingly common in closed loop horticultural supply chains, such as in retail markets. For cherries, retail bags of fruit (500g) are packed into a poly lined PRC for transport and marketing into supermarkets (Figure 26). These crates are made of recyclable plastics which are not affected by the relative humidity in the storage environment and provide complete protection for the produce, as they are made of hard plastic with smooth inner walls. There are several types of fold down or collapsible crates that are used and these have gained acceptance as they only a small amount of space for the return journey from retail store to the distributor. For example, after use on the retail shelf, RPC are folded down, transported back to a centralised cleaning centre where they are hygienically washed before returning to the farm as needed. The major benefits of RPCs are that they are able to achieve stable unit loads through the interlocking design and are cross-stackable for load stabilisation over long distances. In addition, many RPC have the unique barcodes which can be used to track products along the supply chain. A major disadvantage of RPCs is their initial cost but they are often available in a hire / rental system within the closed loop supply chain. Although the upfront purchase cost and on-going transport and washing costs are significant costs, RPCs can be re-used for many years without a decline performance and then can be finally recycled.

Figure 26. Cherries in 500 g pre-pack bags within poly-lined returnable plastic creates (left) for distribution to market (right). *(Photos - Adam Coleman, NSW Department of Primary Industries)*

Types of packaging

There are many different types of packaging used for marketing cherries. Traditionally cherries were sold onto the market in 5 kg (and 2 kg) fibreboard cartons with liners and sold in an open retail displays for consumers to select and purchase what and how much they required (Figure 27). The most common had been the use of bulk 2 kg or 5 kg cardboard boxes with polyethylene or MA liners.

Figure 27. Retail displays of cherries in loose bulk boxes (left), pre-pack bags (centre) and clamshells (right). *(Photos - John Golding, NSW Department of Primary Industries)*

Since the bulk packaging and display, there has been an evolution in packing types and sizes. Pre-packaging is a growing trend where cherries are packed into smaller sealed units in punnets / clamshells, overwraps, display boxes or bags (Figure 28). Pre-packs are generally prepared in the packinghouse but can be re-packed in secondary processors close to market. The use of pre-packs is convenient to many consumers and their use has significantly increased over recent times. This has provided opportunities for specialist packaging and has allowed package space to provide consumer information such as handling instructions and labelling. This can also extend to marketing information to encourage future sales. As this additional packaging prevents consumers from handling the produce in open displays, this improves the sanitation and hygiene of the product and prevents handling damage to fruit on display. A significant driver for the use of pre-packs in supermarkets has been the reduced risk of litigation by consumers slipping on loose fruit such as individual cherries, which have fallen on the retail floor in open displays. Small pre-packages have been used for many years with small and sensitive fruit such as strawberries, and this is now common for the marketing of cherries.

However the use of pre-packing does not allow the consumer to select different individual fruit from a bulk display, as the consumer has to purchase the entire package. This may be a disincentive for many consumers who prefer to select their cherries and many consumers are resistant to excessive packaging. In addition, the costs of disposing of the entire pre-pack or removing a single rotten fruit from the package and then re-packaging needs to be factored into the cost and use of pre-packs. This is further compounded with the use of pre-set weight pre-packs, where any removal of rotten fruit from the pre-pack will affect final selling weight which is normally printed on the label.

It is important to balance the cost of additional packaging with the benefit and value of using additional packaging. However of greatest precaution to prevent mechanical damage is to carefully pack and handle all produce. Packaging cannot overcome poor handling and transport.

Prepack bags

Prepack bags are widely used for the marketing of cherries in supermarkets. The original prepack bags were a plastic bag and fruit sold as catch-weight. Newer prepack bags are generally gusseted bags which is folded at the bottom so it stands upright when on display. They are relatively new to the market, but have been widely accepted in many supermarkets. The main benefit for the gusseted bag is improved protection of the fruit from mechanical damage due to the bag's rigidity, both in transit and on retail shelves, and improved display due to the bag's upright design. In addition they allow high definition graphics for consumer and marketing information and the fruit are presented well on the retail shelf. Prepack bags have been welcomed by retailers as supermarket produce employees need little or no training to set up displays with the pouch bag, so each presentation display can be consistent (Figure 28). However the display still needs some attention by the retailer workers, as poor displays can occur (see *Retail Display Section*). However these pouch bags costs a lot more to pack than bulk boxes or regular catch-weight bags, putting the cost back onto the packer. In addition, new equipment and systems are required to adopt prepacks to existing packing lines and pack out rates can be significantly slowed. However increased sales and returns of prepacked fruit should return profits to growers.

Figure 28. Prepack bags for cherries (right), but care still must be taken to maintain good presentation in the retail store. Packaging can only support good retail handling.
(Photo - John Golding, NSW Department of Primary Industries)

Clamshells

Clamshell containers are more widely being used in the marketing of cherries in supermarkets. Clamshells were originally created for strawberries, a fruit that needed rigid plastic containers for field packing and could be cooled fast. However cherries are very sensitive to water loss and the high air flow in clamshells can dry out the cherry stems at the retail level. However clamshells can work very well in some formats and for some retailers and are still widely used. The current clamshells mainly used in Australia are 300g (Figure 29), but there are a range of different punnet types which are used for different small fruit (Figure 30), which maybe suitable for the marketing of cherries in Australia. Marketing varied package sizes also may assist in reducing food waste by enabling smaller households to purchase the amounts of cherries they actually need. Other clamshell types which are used in Europe are presented in Figure 31.

Figure 29. Pre-pack clamshells / punnets provide convenience and food safety for consumers and retailers. Note the large holes in the lid to allow air exchange and minimise condensation.
(Photo - John Golding, NSW Department of Primary Industries)

Figure 30. Other punnet types and sizes (300g, 510 g, 680g and 900g retail punnets of cherry tomatoes, USA).
(Photos from www.naturesweet.com. Accessed 20 January 2018)

Figure 31. Alternate cherry punnets used in Europe.
(photos from NCX Drahorad, Italy (http://www.ncx.it – accessed 4 March 2018)

Other pre-packs

Other pre-pack options for cherries are available such as the use of flow wrapping also known as fin-seal wrapping, horizontal bagging or pillow-pouch wrapping (Figures 32 and 33). Flow wrapping is a horizontal process in which the punnet of cherries is wrapped in a clear or printed polypropylene film, where the result is a flexible package with non-lap type seals on the bottom and crimped end seals. Sealing of punnets or packages provides additional security and further opportunities for branding (Figure 33).

Figure 32. Packing cherry in punnets and with flow pack wrapper (HFFS) in fiber board trays for market.
(Photos - John Golding, NSW Department of Primary Industries)

Figure 33. Cherry packaging in flow pack wrapper (HFFS) in punnets (left) and strawberries with punnet sealing (right). *(from www.ulmapackaging.com. Accessed 20 January 2018)*

Premium packaging

There is a need to receive a high return for premium quality cherries. This requires premium packaging which allows for differentiation and strong branding, however it absolutely critical that premium high quality fruit is always used in high end packaging to justify the premium packaging and cost. A number of alternative high end packing types are presented in Figure 34. For example the 'Glamour Cherries' are specialty out of season cherries are sold for £3 each cherry (AUD $5 each) in premium UK supermarkets (Glamour Cherries, Spain).

New alternative packaging types such as Amcor's PushPop design, where the pouch is squat and has a patented perforated line that makes it simply to open for anyone, presenting no problems for younger consumers and those with hand-strength problems (Figure 35). This packaging was used to market Utopia's new-season cherries sold through leading UK retailer Waitrose (Market Intelligence Ltd - Fruitnet.com 2018. Accessed 4 March 2018). New developments and innovations in packaging continue to be made and need to be assessed and implemented for the Australian cherry industry.

Figure 34. Different premium packaging types. Top - SOL cherries (China) *(Photos: from FreshPlaza accessed 3 March 2018).* Top left - Glamour Cherries (Spain) *(photo from http://www.flavortreefruit.com/cherries-glamour-.html, accessed 4 March 2018)*. Bottom - Reids fruit (Tasmania) *(with permission)*

Figure 35. Amcor's 'PushPop' design was used to market new-season cherries sold through leading UK retailer Waitrose. *(Photo from Market Intelligence Ltd - Fruitnet.com 2018. Accessed 4 March 2018).*

Modified atmosphere (MA) packaging

Cherry fruit benefit from storage at low oxygen (O_2) and high carbon dioxide (CO_2) levels, which lowers their respiration rate and maintains quality during storage (Beaudry, 1999). This can be achieved by either using controlled atmosphere storage, or by the use of modified atmosphere (MA) packaging. MA packaging is where the composition of gases around the produce are changed with the use of sealed plastic bags. Both O_2 and CO_2 come to equilibrium within the MA packed based on the respiration rate of the produce, the specific permeability of the MA film, the surface to volume ratio of the package and the amount of produce within the MA package. The produce within the sealed bags is prevented from becoming anaerobic by alterations or inherent characteristics of the films that are partially permeable to O_2 and CO_2. The generation of high CO_2 and O_2 levels within the package by respiration of the produce is termed passive MA packaging and can take days or over a week to reach its desired equilibrium O_2 / CO_2 concentration. To speed up this process and immediately gain the benefits of MA, the package can be flushed with nitrogen or the appropriate concentrations of O_2 and CO_2. This is termed active MA packaging.

MA packaging is widely used in the storage and handling of cherries for the maintenance of quality during storage (Figure 36). The most common form of MA packaging involves the generation of the beneficial atmospheres within the package by: the respiration of the produce within a sealed bag with specific film permeabilities (eg polymer type), which is a function of physical characteristics of the plastic film (e.g. density, presence of additive, film thickness) or by holes in the film. In general, plastic films are 4 – 6 times more permeable to CO_2 than O_2 (Beaudry, 1999). However the relationship between O_2 and CO_2 permeability and water vapour is complex. It is important to follow the manufacturer's recommendations when using MA packaging. Each MA package is specifically designed, engineered and manufactured for a specific use and application and it is not recommended to use different produce volumes / weights or storage temperatures for which it is not designed.

Figure 36. Different MA bags used for cherry industry - Note there are many different commercial MA bags available and used for domestic and export.
(Photos - John Golding, NSW Department of Primary Industries)

Apart from the primary effects of low O_2 and high CO_2 suppressing cherry fruit respiration rate (Kupferman and Sanderson, 2001), changes in the levels of O_2 and CO_2 can also affect other quality parameters such as pigment metabolism, phenolic metabolism and volatile compound metabolism (Goliáš et al., 2007). However the levels of CO_2 and O_2 need to be carefully maintained as excess CO_2 or too low O_2 can cause irreversible fruit injury and induce off-flavours and therefore shorten their storage life. Under regular low O_2 and/or high CO_2, many positive effects of atmospheric-controlled storage of cherries have been reported, including maintaining TA content, and retarding the decline in SSC, retention of firmness, stem colour and brightness, and the reduction of surface pitting and microbial decay (Serradilla et al., 2012; Wang and Vestrheim, 2002). MA packaging has also been shown to suppress the development of postharvest pathogens in cherry (Spotts et al., 1998, 2002; Karabulut et al., 2001).

At 0 ^{o}C storage, cherries have been shown to tolerate very low oxygen levels (0.02 % O_2 for 21 - 25 days) and can be stored for several weeks in 0.5% - 1% O_2 or 20% - 40% CO_2 (Dangyang and Kader, 1992; Golding et al., 2012). Studies of various CA conditions have been conducted and the use of 10 - 30% CO_2 and 5 - 20% of O_2 were reported to be effective in maintaining cherry fruit firmness, vitamin C and TA levels without the development of off-flavour (Wang and Vestrheim, 2002; Tian et al., 2004).

However there is a discrepancy on the critical level of CO_2, as some studies reported cherries developed off-flavour when stored in higher than 10% CO_2 and up to 5% O_2 CA conditions (Goliáš et al., 2007). The benefits of MAP on cherries have been reviewed (Wani et al., 2014). These benefits of MAP are the same as CA where low O_2 and high CO_2 could be used to reduce respiration rates, chemical oxidation rate, and growth of aerobic microorganisms, which consequently increases the storage life of the fruit (Meheriuk et al., 1995). However Agulheiro Santos et al (2014) reported that while 'Sweetheart' cherries stored under CA conditions (10% CO_2 and 8% O_2) maintained firmness, this was not noticed by the consumer panelists, who consistently classified fruits stored under CA conditions with lower overall ratings than storage treatments. MAP has also been shown to slow the loss of SSC, fruit softening and reduce weight loss in the fruit during storage (Khorshidi et al., 2011). Active O_2 - enriched MAP has also been reported to effectively delay the respiration peak of cherry fruits, retarding ethylene production, and maintaining firmness and soluble protein and sugar contents in the fruits (Wang et al. 2014).

Polyethylene is widely used in MA packaging as it has good clarity, can be heat sealed, is flexible over a wide temperature range (-50 to 70°C), and is probably the cheapest film in most countries. Low-density polyethylene has a high selectivity toward O_2 and CO_2, allowing a reduction in the O_2 level without an excessive increase in CO_2 within the package but is comparatively impermeable to water vapour. Recent trends are toward the use of linear polyethylene of low and ultra low density, which have a more uniform density, higher O_2 permeability, greater clarity and thermal transparency, and better sealing, compared with conventional ones, although its cost is still elevated (Valero and Serrano, 2010).

A critical issue with the use of MA packaging is that the rate of respiration of the cherries determines the atmosphere levels within the package. Each MA package is specifically designed for an optimal storage temperature range, where the respiration rates of the produce are matched to the gas exchange of the bag. If there is an undesired break in cool chain and the storage temperature increases, then the respiration rate of the fruit increases which can negatively affect the MA composition within the bag. This increases the risk of anaerobiosis and loss of product quality. Thus while the benefits of having produce in smaller packages that can be moved through the supply chain great, so are the risks involved where any change in storage or handling temperature can negatively affect product quality and storage life. Thus maintaining the cool chain is essential for MA packaging. In the future, such risks may be minimised using fail safe (e.g. low melting point polymers) or variable aperture (e.g. bimetallic strips) devices to regulate formation and / or size of holes (Wills and Golding, 2016). Advances in nanoscience, microelectronic and biosensor science are providing technologies that can actively sense and respond in a controlled way to stimuli, such as an increase in temperature (see *Nanotechnology Section*).

The combined use of eugenol, thymol, and menthol essential oils in MAP have been found to enhance the effects of MAP alone, in terms of delaying stem browning, retarding TA loss, and reducing the proliferation of moulds, yeasts, and aerobic mesophilic bacteria during the storage of sweet cherry (Serrano et al., 2005). MAP with eucalyptol essential oil was effective in inhibiting the growth of microorganisms; however eucalyptol essential oil induced oxidation process and accelerated the rates of stem browning and TA loss (Serrano et al., 2005). This is discussed in more detail in the *Innovations section – Packaging Section*.

Other forms of MA packaging

Perforated films

In addition to MA generated by the characteristic of film permeability, perforated films can also generate MA within a sealed plastic bag and can used for highly respiring produce, such as broccoli. O_2 and CO_2 movement through small perforated holes in the bag is proportionally greater in magnitude than water vapour and ethylene as their flux is driven by comparatively large concentration gradients (i.e. % versus ppm or ppb). Thus, perforated films can be used effectively to reduce water loss while avoiding the risk of anaerobiosis. In addition with all other factors being equal, oxygen diffuses somewhat faster in air (e.g. through holes) than carbon dioxide on account of its greater diffusion coefficient (Thompson and Mitchell, 2002). Although cherries have a moderate respiration rate, the use of perforated films has been limited. However PacLife^{TM} are a packaging company in Chile which sells cherry bags with micro and macro-perforations, 0.1 – 0.3% ventilated area (www.envasespaclife.com).

Pallet covers

MA can also be applied over entire pallets of produce and can be referred to as bulk MA (Figure 37). The use of MA pallet covers or shrouds are used on other produce such as blueberries where the application of MA is not practical on the individual punnet / clamshell. Application of MA with a pallet cover provides the benefits of MA to the produce and gives marketing flexibility to increase storage life and quality on a relatively small volume (pallet). This maybe an alternative to the use of MA liners for the use of pre-pack bags or punnets for longer term storage. However it is not ideal to store pre-packs due to the risk of decay which are not re-sorted or handled. In addition the pallet bag over the pallet of packed fruit may increase water loss and stem browning where the cardboard box may draw out water from the fruit, resulting in lower quality fruit and poor box strength.

Figure 37. Pallet covers over pallets of blueberries in storage. The specially designed plastic cover will generate the optimum atmosphere within the cover for long term cold storage.
(Photo - John Golding, NSW Department of Primary Industries)

Another system uses pallet stack bags which use low density polymer bags with macroperforations, over harvested pallets of cherries which remain on the pallets during hydrocooling (www.envasespaclife.com/), but this is not MA.

'Janny MT module' system

The application of MA can also be used before packing, where hydrocooled fruit from the orchard can be temporarily stored in MA containers before packing. This system has the potential to even out the packing processes, where large volumes of fruit are harvested and cannot be packed due to packing capacity constraints. The use of the 'Janny MT module' allows for a passive diffusion of gas through the membrane of the lid of a sealed plastic bin (Figure 38). The generation of the MA in the bin allows fruit to be stored under high RH and low O_2 and high CO_2 before packing at a more convenient time.

Figure 38. 'Janny MT Module' which consists in a 'Tiempo Cap' and a plastic pallet-box (610 litre capacity). Cherries are placed in crates and stored in the 'Janny MT Module' which generates passive MA during storage.
(Photos from http://www.jannymt.com. Accessed 20 January 2018)

Retail displays

While the grower and packer invests considerable time and resources in delivering high quality fruit to the retailer at the correct temperature, fruit quality can be compromised with poor stock management within the retail store. It is critical to maintain fruit quality through the consumer and a previous Horticulture Australia Limited project (CY10012) has shown that retail display is a major area of quality loss for Australian cherries (Golding et al., 2012). As previously described, cherries require special handling and storage requirements and high quality fruit can rapidly deteriorate due to poor storage and display conditions such as temperature and relative humidity abuses. While acknowledging that many large supermarket chains have limitations in staff training, time and resources, it is in the best interest of the growers and retailers to ensure the best quality fruit is displayed and sold. Therefore it is critical that retailers maintain good displays. Poor displays such as those in Figure 39 reflect poorly on the fruit with reduced sales and turnover, perpetuating poor sales during the limited season. Increased and repeat sales are the aim of both the retailer and grower.

Figure 39. Poor displays of loose cherries in open unrefrigerated displays, even in pre-pack bags (right), not only result in poor presentation but also contribute to increasing the rate of declining fruit quality. Actual retail displays in supermarkets (January 2017). Poor fruit quality presented to the consumer results in reduced sales.
(Photos - John Golding, NSW Department of Primary Industries)

The use of pre-pack bags require still require attention by retail staff as decayed fruit can still develop and ruin the whole bag, display and future sales (Figure 40).

Figure 40. Development of postharvest rots in pre-pack bag for sale in supermarket. Fungal hyphae and rot juices leak through entire bag and affect other bags.
(Photo - John Golding, NSW Department of Primary Industries)

A previous Horticulture Australia Limited survey of retail conditions of cherry fruit displays in both Australian supermarket and independent fruit and vegetable stores showed fruit are subject to a wide range of temperatures and relative humidities (RH) resulting in large vapour pressure deficits (VPD) between the cherry fruit and the display environment, depending on their display position within the store (Golding et al., 2012b). The results showed that the supermarket specialist refrigerated table (Figure 41a) provided the best presentation condition to maintain cherry fruit and stem quality. The display low temperatures (average 2 °C and 77% relative humidity) resulted in low VP (637 Pascals, Pa) which is excellent in a commercial situation and still allowed consumers to select fruit from a bulk display. Low VPD is the key to maintaining high quality fruit during storage and retail display. The next best display to maintain fruit quality was the refrigerated wall displays cabinets (Figure 41c). In the survey, the average temperature in the wall display in the supermarket was 6 °C, 92%RH (VP 898 Pa), whilst the independent fruit and vegetable store's refrigerated wall display ranged from 7-10 °C with 88-100%RH (VP 941 to 1,227 Pa). The least ideal display environment is the open ambient display where large VPD can be generated leading to rapid water loss and deterioration in fruit quality. In the survey of retail environments, Golding et al. (2012) showed that at the one sampling day, the average temperature in the air conditioned supermarket was 19 °C with 70 %RH (VP 1,766Pa). Open ambient displays are only satisfactory when the fruit can be rapidly sold and have high turnover of stock where the fruit are not held for long periods of time. The high display temperatures stimulate the development of any latent rots in the fruit and also result in dry / brown the stems (Figure 39).

These observations clearly show it is ideal to maintain the cool chain through the consumer and many retailers have refrigeration space to display small lots of cherry fruit. But when this it is not practical or economic for larger volumes, then non-refrigerated fruit should be handled with care in good displays using pre-packs and returned to the store coolroom in plastic liners (if possible) at the end of the day.

Figure 41. Retail displays of cherry fruit in specialised refrigerated tables (top, a), refrigerated bulk display (lower left) and unrefrigerated bulk displays of cherries on domestic market (lower right).
(Photos - John Golding, NSW Department of Primary Industries)

Stem browning

In a previous study of retail display of Australian cherries in two states in both independent and national supermarkets, fruit quality, particularly stem browning and bruising was affected by the retail environment (Golding et al., 2012). Stem quality of fruit sampled from the retail displays in Adelaide supermarkets was of lower quality (browner) than that of the fruit sampled from the cool room of the same stores averaged over the 10 week survey period (Figure 42). These observations suggest that significant losses in stem quality occur while the fruit is on retail display.

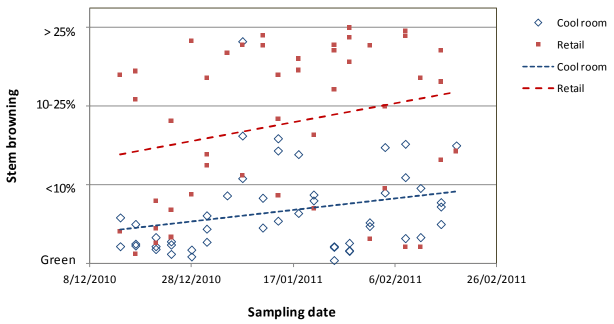


Figure 42. Level of stem browning of fruit sampled from retail display compared with fruit sampled from cool rooms of stores in South Australia during a ten week period in the 2010/11 season *(from Golding et al., 2012).*

The level of stem browning observed on fruit prior to being placed on retail display at each of the three different stores was similar, when averaged over the 10 week sampling period (Figure 43). However the retention of stem quality as reflected by fruit sampled from the retail displays was better at Store A than Stores B and C. This suggests that the practices at Store A were more favourable for the retention of stem quality. Cherries from Stores B and C were almost exclusively sampled from open refrigerated displays while samples at store A were sampled from refrigerated displays approximately 40% of the time and from ambient displays approximately 60% of the time. However cherries having both good and bad quality stems were found from both refrigerated and non-refrigerated retail displays (Figure 44). These results were not obtained under controlled trial conditions and therefore were not comparing like fruit with like fruit and as such should not be relied upon. However these observations suggest that utilising open refrigerated displays is not necessarily the answer to improving the retention of green stems at the retail level (Figure 41). Display at ambient conditions can also have negative impacts on fruit quality (such as firmness and rot development) when compared with display under refrigerated conditions.

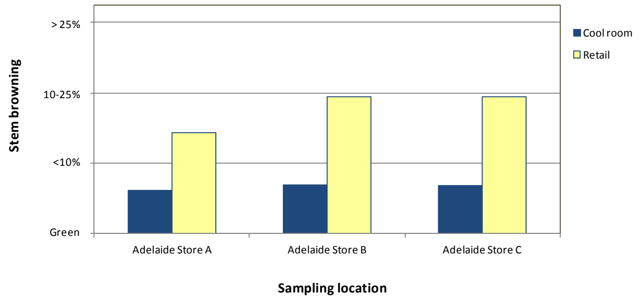


Figure 43. Average level of stem browning of cherries sourced from retail display or out of the cool room at three stores in Adelaide over a ten week period in the 2010/11 season.
(from Golding et al., 2012)

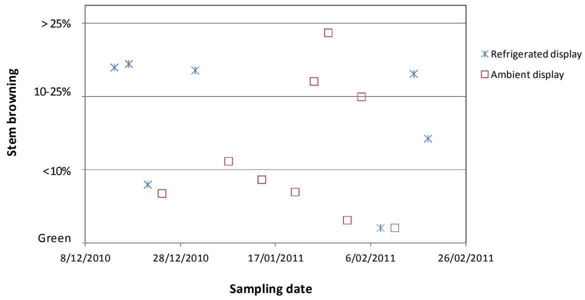


Figure 44. Stem quality of cherries sourced from either an open refrigerated or ambient retail display at store A in Adelaide over a ten week period in the 2010/11 season.
(from Golding et al., 2012)

Fruit bruising

Fruit bruising of fruit in open displays is also a critical issue for the final quality of cherries to the consumer (Golding et al., 2012b). In the same Horticulture Australia Limited survey (CY10012), the average incidence of bruised fruit on the fruit sampled from the open retail display was more than double that on fruit sampled from the cool room of stores over the 10 week survey period (Figure 45) (Golding et al., 2012b). This higher incidence of bruised fruit on retail display was observed at each of the three stores over the season (Figure 46).

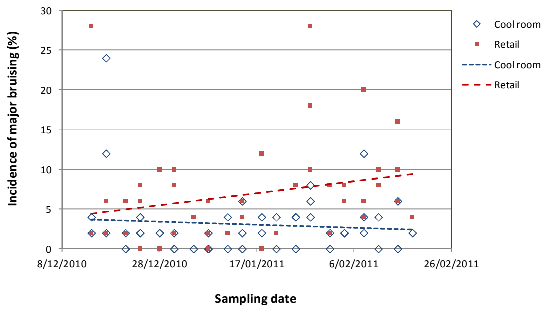


Figure 45. Incidence of bruised fruit sampled from retail display compared with fruit sampled from cool rooms of stores in South Australia during a ten week period in the 2010/11 season.
(from Golding et al., 2012)

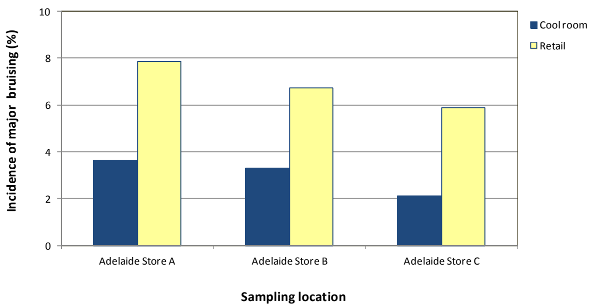


Figure 46. Incidence of fruit showing major bruising sourced from retail display or out of the cool room at three stores in Adelaide over a ten week period in the 2010/11 season.
(from Golding et al., 2012)

The high level of bruised fruit on the retail market is a significant issue for industry. Bruised fruit is less visually attractive than sound fruit and are more susceptible to the development of postharvest rots. However the impact on fruit texture is just or more damaging to consumer perceptions. When a shopper picks up a bruised fruit, its soft and mushy feel is immediately obvious and a purchase may be lost. If purchased, the fruit will either be later discarded or if eaten, will generally leave the consumer with an off flavour in their mouth to go with the initial disappointment of its lack of crunch. Most consumers will not notice the flesh of the fruit has an off-putting brown colour when eaten, therefore minimising the incidence of soft bruised fruit is a key market imperative. However this survey was conducted on bulk samples, where consumers could handle the fruit and pick the fruit they wanted. Many retail displays have moved to pre-pack bags and clam-shells thus removing this potential quality issue.

The interaction of display conditions (such as temperature) and packaging type on final fruit quality and consumer acceptability has not been thoroughly studied. Golding et al. (2012) and Golding et al. (2017) demonstrated the importance of temperature and relative humidity during the retail display of cherries, where low temperature and high relative humidity during display are the best conditions to maintain stem quality. The commercial move towards pre-packs and punnets will help maintain fruit quality and food safety with improved protection against damage and maintenance of high humidity around the fruit.

Food safety

Food safety is the fundamental and non-negotiable requirement for all horticultural industries. Foodborne illness outbreaks linked to the horticultural produce cause huge economic and reputational damage to the industry with a loss of consumer confidence. Product recalls, drops in sales, suspension and termination of suppliers' contracts as well as legal costs are the main contributors to the economic losses. In most countries, the food safety regulations are changing rapidly and becoming stricter in response to the increasing foodborne illnesses and traceability issues in the complex global food supply web.

Australian horticultural industries enjoy the reputation of *'clean, green and safe'* supplier of fresh produce in the domestic and export markets. The maintenance and strengthening of this perception is essential to leverage benefits in long-term access to these markets with major trading share. The competitors pose a challenge of cost-competitiveness to the Australian produce in both domestic and international markets, but our produce attracts the customers willing to pay higher prices for the safe and high quality fruit produced in a sustainable manner. It is therefore utmost important for sustainability and profitability of cherry industry to retain consumer confidence in the produce and export market access.

Major contaminants

Food safety incidents are caused by primarily three distinct classes of contaminants; physical, chemical and microbial. The probability of physical contamination of cherries is low, but small iron nails or splinters from packingline, bins and boxes can possibly pierce the fruit and pose risk to the consumers. The presence of rodents and birds excreta on the fruit surfaces and inside the packing boxes constitutes both physical and microbial contamination. Like human faeces, the excreta of birds, rodents and animals (domestic and wild) are a reservoir of microorganisms of public health concern. Chemical contaminants are mainly in the form of pesticides and other chemical residues. The exposure of consumers to chemical residues above the maximum permissible limits can cause serious health problems ranging from immediate harmful effects to the long-term effects. Microbial or biological contaminants are bacteria, viruses and parasites which are often involved in foodborne illnesses. The most common human pathogens occurring on produce associated with foodborne illness outbreaks are: *Escherichia coli* O157:H7, *Salmonella species*, *Listeria monocytogenes*, *Crytosporidium species*, *Cyclospora* species, hepatitis A virus, and Norwalk and Norwalk-like viruses.

Preventing contamination is the most effective and economical approach to minimise the risks of contamination during field production and postharvest handling. To follow this approach, the knowledge of potential sources and routes of contamination is a prerequisite. Growing produce in open field brings in a number of risk factors that are complex to understand. Therefore, the basic knowledge of food safety risk factors and the procedures to minimise those risks can help achieving safe supply of produce.

There are multiple sources and routes of fruit contamination in the field and after harvest. These need to be recognised and understood by the growers, packers and supply chain operators, especially as contamination of produce can occur at any stage along the supply chain. Supplying safe produce for human consumption is the responsibility and accountability of everyone involved in the supply chain and is the fundamental of any food business.

Sources and routes of preharvest contamination

Agri-chemicals such as plant growth regulators, insecticides, fungicides, and herbicides are applied to effectively manage production, plant protection, and postharvest diseases and disorders. To minimise the risks from chemicals residues on fruit, growers should strictly follow the guidelines and direction on usage in order to implement good agricultural practices (GAP). The withholding periods for different chemicals should be observed carefully. The potential chemical drift from the neighbours and also from the weed control programmes of roads, rail tracks and councils should be considered in chemical risk assessment.

Contaminated agricultural water can infect cherries during growing (e.g. irrigation, nutrient sprays, plant protection sprays, frost protection).The foodborne outbreaks have been known (or suspected to have arisen) from the use of contaminated water during the field production. Ensuring microbial quality of agriculture water is thus critical to mitigate food safety risks in cherry production. Among different sources of agriculture water, surface water sources (e.g. rivers, ponds, creeks) are more likely to be variable in their microbial quality as compared to potable and groundwater. The irrigation water used for sub-surface drip irrigation is not a significant risk for cherries. However, the application of agrichemicals (fungicides, insecticides, plant growth regulators etc.) and sprinklers for frost protection involve direct contact of water with fruit surfaces. The contaminated water if used for these farm operations can infect the fruit on trees.

The quality of water as an important risk factor needs to be managed through regular monitoring and testing of water not only for chemical attributes, but also for microbiological parameters. The required corrective action (e.g. filtration, chlorination, pH adjustment etc.) must be taken to improve water quality before its application. The farm-specific risk assessment is required to ensure the adequate monitoring of agricultural water quality. The weather events such as rainfall, floods can significantly alter the microbiological quality of surface water and need to be considered by growers depending upon the sources of water.

Organic fertilisers are important for maintaining good soil health and fertility in both integrated and organic production systems. However organic inputs such as raw animal manures and composts are considered the sources of contamination of fresh produce, leading to their restricted use with minimum application-to-harvest time intervals. Historically, applications of raw animal manures have been linked to contamination of fresh produce and subsequent foodborne illnesses of public health significance, while commercially mature composts have not been reported in any foodborne outbreak.

The cherry industry can take advantage of commercially mature compost applications during the dormant phase. The compost must be procured from a reliable source, tested and certified against the Australian Standards. The possibility of direct contact between the compost or manure and fruit is generally low, but the heavy winds and storms can facilitate the direct contact and cause contamination. The growers are therefore advised not to use raw animal manures to minimise the associated risks. For specific details on the restrictions of raw manures and compost application in orchards, growers should consult their food safety consultant and/or the supermarket's code of quality assurance.

The wildlife and livestock (including pets) access to the orchard and irrigation water source (e.g. small dam or pond) is another risk factor contributing to spread of human pathogens. The growers should remain vigilant about these risk factors and manage them appropriately. For example, netting of orchards to prevent the damage from birds, flying foxes and bats is also beneficial to manage the on-farm food safety risks as these birds can carry bacteria and viruses of public health importance.

The health and hygiene of workers in the field, especially harvesting and packinghouse crews, is critical to control contamination of fruit due to human handling. The transfer of noroviruses, the most important concern in recent times, is through human handling of the food. The seasonal labour hired through short-term contracts could be a challenge to know the health and wellness of workers. The growers should develop procedures in their contracts to regularly monitor the labour for sickness symptoms. Sick workers should stay away from the farm operations involving direct handling of the fruit in the field or packing house.

Visitors, contractors, sub-contractors, and ex-employees should not be given access without firstly having permission and recording of access within a visitors register. There should be a single point of entry, visitors' identification tag and protective clothing, and should be escorted and monitored at appropriate times. All visitors on the farm should strictly follow biosecurity guidelines ('*Come Clean and Go Clean'*). A deliberate act of sabotage through contamination is a continuing food safety risk for other fresh produce industries. The growers must have a security plan for controlled access to the property with special attention and locking procedures in important areas such as fertigation or water tanks, pump houses, spray tanks, chemical storage, packinghouse, cold store etc.

Sources and routes of postharvest contamination

Major sources of contamination in a packinghouse are water, workers and pests (insects, birds, rodents, and pets). Postharvest water quality is the most important factor in sanitation and is more relevant for cherries because of their longer direct contact with water during hydrocooling, flume transport, washing and fungicide treatment. Washing with contaminated water spreads the pathogens on fruit surfaces (inoculation) and inside through wounds/apertures/splits (contamination), and thus defeats the purpose of sanitation. Potable water is the minimum requirement for wash water.

Packinghouses need to develop a standard operating procedure (SOP) to determine the frequency of water change in flumes, dosing and monitoring of sanitisers. Sanitisers can reduce the number of microbes, but can't kill all. The continuous maintenance and monitoring of the concentrations of sanitisers in the postharvest water is a fundamental requirement to mitigate food safety risks. A detailed description of sanitisers is given in the *Sanitisers Section* (next).

Sanitation of packing line areas, especially those which remain wet, on daily basis is essential to prevent the build of microbial load and biofilm formation. Sanitation schedule for cold rooms, curtains, floors, walls, ceilings is required. A range of sanitization methods and chemicals are available. Refrigeration coils, drip pans, cooling fans, walls and floors in the cold storage/transport environment can also serve as a potential source of contamination. For example, *Listeria monocytogenes* can survive and proliferate under refrigerated conditions and may contaminate produce if condensation occurs from these sources of contamination in a cold room.

A robust pest control program is required to reduce the risks of contamination by insects, birds, rodents and pets. Considering the diversity of pests, a number of pest control practices and techniques are required to be followed for an effective control. Inspection schedule and reporting procedures should be clearly documented in the pest control plan.

Good personal hygiene and health of workers is the second important factor in packing house sanitation systems. Train packinghouse workers about the importance of their personal hygiene and health in relation to food safety. Sick workers should neither be allowed to harvest fruit nor handle fruit in the packinghouse. Provision of hand-washing stations (hot and cold water supply, soap, paper towel and bin), break rooms and toilets in the packinghouse must be there to ensure workers follow good manufacturing practices. Workers should wash hands thoroughly and frequently with soap and warm water for at least 20 seconds before starting work in the packinghouse and after each visit to the toilet. Alcohol gel- based hand sanitisers should not replace hand washing practice. Workers activities such as drinking, eating and smoking should be confined to break rooms and outside the packing areas.

Visitors should first report to the packing house office for their identification, and information about intent to visit. They should be accompanied all the times by the experienced packing house staff and need short training to follow guidelines on workplace and food safety.

Food safety certification systems

Most horticultural growers have quality assurance (QA) programs to meet the suppliers' requirements for quality and food safety. As part of the QA, hazard analysis critical control point (HACCP) based principles are followed to develop guidelines to mitigate food safety risks and to maintain proper records for validation and verification. Harmonised Australian Retailer Produce Scheme (HARPS) has now been introduced which is based on harmonised food safety certification requirements for the major retailers (ALDI, Coles Supermarkets, Costco, Metcash, and Woolworths) in Australia. It is a retailer-led scheme designed to assist with compliance to food safety, legal and trade legislation for suppliers to the major grocery retailers in Australia. Established with the goal of providing a more practical and comprehensive approach, HARPS has the ability to streamline the amount of work undertaken during the audit process (Figure 47). While the amount will differ between businesses, for those currently audited to multiple schemes for multiple customers, one base scheme plus HARPS means the audit duration will reduce, hence overall audit costs should also reduce. More information about HARPS can be obtained from the website https://harpsonline.com.au/

The HARPS scheme is voluntary and application for certification is open to all fresh produce businesses that undertake the following activities:

- Grow produce for retail sale
- Pack produce for retail sale
- Operate as an aggregator, distributor, broker or agent supplying produce for retail sale
- Direct Suppliers or subcontracted supplier, i.e. pack in retailer-branded packaging or bulk loose packs

Under the HARPS Scheme Rules, certification will only be granted once the Supplier is certified to one of the base schemes (Freshcare Food Safety and Quality Code of Practice; GLOBALG.A.P. Integrated Farm Assurance; Safe Quality Food (SQF); British Retail Consortium Global Food Standard for Food Safety) plus HARPS.

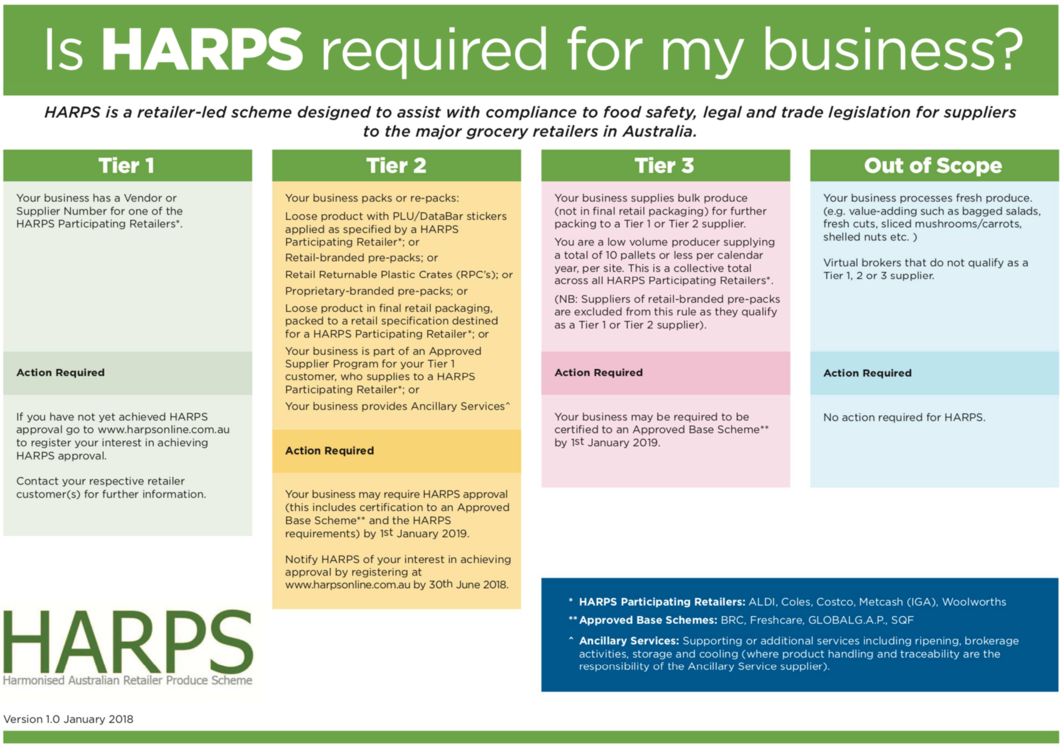


Figure 47. Harmonised Australian Retailer Produce Scheme (HARPS) business requirements.

Decay control

Sanitisers

Cherries come in direct contact with water during various postharvest operations such as hydrocooling, movement in water flumes, washing, and fungicide treatment. The quality of postharvest water will determine the severity of risk of contamination with microbial pathogens. Sanitation of postharvest water is thus required to reduce the microbial populations including those of foodborne bacterial pathogens (e.g. *Salmonella*). The presence of optimum concentration of a sanitiser in postharvest water is essential to minimise the risk of bacterial pathogens and reduce the fungal spores.

A number of sanitisers with different chemistries are currently available in the market and registered like fungicides with APVMA. Each sanitiser has its own merits and demerits of adoption. The selection of sanitiser is influenced by a number of factors such as price, water source (channel, ground or council) and quality (pH, hardness), method of application and monitoring (manual vs. automatic), packingline machinery (corrosiveness) and buyer's requirement etc. Following the label guidelines and manufacturers' instructions can ensure correct and safe use of sanitisers at recommended concentrations and conditions.

Chlorine has been a very popular sanitiser for years. Chlorine-based sanitisers include sodium hypochlorite, calcium hypochlorite, bromo-chloro-dimethylhydantoins and chlorine dioxide. Chlorine, using salts of sodium or calcium hypochlorite is the most common sanitiser used. For the effective use of sodium and calcium hypochlorites, an understanding of the basic chemistry of chlorine is the key to manage its active concentration in wash water. When chlorine is dissolved or added to water, it dissociates into hypochlorous acid and hypochlorite ions, depending upon the pH. The hypochlorous acid is the most active form and its higher proportion over hypochlorite ions is required for proper sanitation. A pH range of pH 6.5 to pH 7.0 is favourable for achieving higher concentration of active chlorine (hypochlorous) and with the increase in pH (> 7.5) much less active form (hypocholorite) predominates. Automatic monitoring using a pH meter and oxidation reduction potential is available commercially (Suslow, 2004).

If wash water is alkaline (pH > 7.0), the addition of chlorine will further increase the pH, leading to poor antimicrobial efficacy of the chlorine present in water. This will require injection/addition of hydrochloric acid to decrease the pH (pH 6.5 – pH 7.5) for chlorine to be effective. A low pH (< pH 5.0) combined with high water temperature will lead to release of poisonous chlorine gas from chlorinated water which is an occupational health hazard for workers. In nutshell, the pH of wash water after addition of chlorine should be maintained between pH 6.5 and pH 7.5. The use of chlorine in wash water requires more efforts and management in monitoring the pH, chlorine concentration and sanitation potential of water. In addition to the pH, organic load also impacts the efficacy of chlorine because active chlorine gets neutralised due to its reaction with debris and dirt present in water.

Effective monitoring of sanitiser concentration and efficacy is utmost important. Chlorine concentration and pH can be monitored using paper test strips which are easily available from chemical suppliers, but digital equipment is more accurate and objective in measurement. Another indirect measure of sanitising capacity of chlorinated water is oxidation-reduction potential (ORP) which can be recorded by using an ORP probe. An ORP reading of >700 mV suggests the acceptable levels of sanitation potential. However, the ORP reading should be interpreted along with wash water pH and proper chlorine concentration. Some companies supply a digital meter with two or more probes to measure pH and ORP simultaneously. These monitoring tools are not expensive and are highly recommended for packinghouses to measure and record data accurately.

Bromo-chloro-dimethyl hydantoins (BCDH) are another option as a sanitiser registered with APVMA. These sanitisers also provide broad spectrum control of microbial pathogens. They represent a unique blend of chlorine and bromine chemistries which provide sanitising activity in a broad pH range especially towards alkaline conditions (pH 7.0 to pH 8.5). The basic chemistry of bromine in water is quite similar to chlorine, except the active form of bromine (hypobromous acid) predominates until pH 8.5 opposed to pH 7.5 for chlorine. It is also less affected by organic load compared to chlorine and relatively lower concentrations are required.

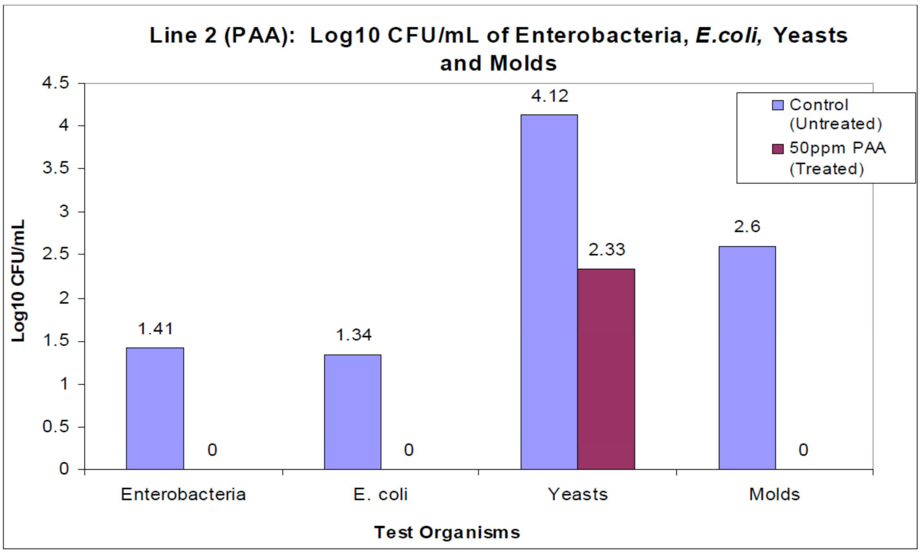
Chlorine dioxide is another form of chlorine sanitiser which is currently available in different formulations with stabilized active ingredient. Because of its very high reactivity, a low concentration (up to 10 ppm) and less contact time is required for wash water treatment and is effective against bacteria, moulds and yeast over a pH range up to pH 8.5. Organic matter in water does not affect the efficacy of chlorine dioxide.

Solution of peracetic acid (PAA) is considered highly effective to reduce contamination by pathogens (Mari et al., 2004), however stem browning has been observed with some formulations (Kupferman, 2008). PAA is very reactive and quickly decomposes to oxygen, water and acetic acid (acid in vinegar). The use of PAA at recommended concentration (up to 80 parts per million, ppm) is effective in reducing microbial load and achieving product sanitation. Unlike chlorine, it is effective over a wide range of pH and requires less management. However, the effective monitoring and recording of PAA concentrations in wash water is critical as for any other sanitiser and can be done using test strips. The corrosiveness of PAA should be considered for machinery and appropriate protection of workers.

Rodrigues and Haworth (2009) conducted a study to compare the relative performance of PAA (50 ppm) and sodium hypochlrorite (NaOCl, 50 ppm) in the rinse water for cherries against that for a simple nonchemical treatment water wash on a cherry packingline in California. The results showed that PAA proved to be more effective than NaOCl in reducing the microbial population levels of enterobacteriaceae and *E. coli* on cherries (Figure 48). The usage of PAA at 50 ppm as an antimicrobial during the processing of cherries at the packing house was shown to alleviate concerns of a potential human health problem as well as extended the shelf-life and freshness of the cherries.

Iodine is an effective sanitiser for water treatment over a wide range of pH with minimal effect of organic load. But the options to adoption are limited due to its availability as a dosing system only. It is corrosive to metals and expensive.

Ozone is a gaseous sanitiser which can be dissolved in wash water by generating it on-site using an ozone generator. Undoubtedly, ozone is very effective in killing microbial pathogens over a wide range of pH, but it also reacts with organic matter (Karaca and Velioglu, 2007). Its highly corrosive nature and high risks to workers health and safety are among the limitations which have though not hindered its use in some packing houses.



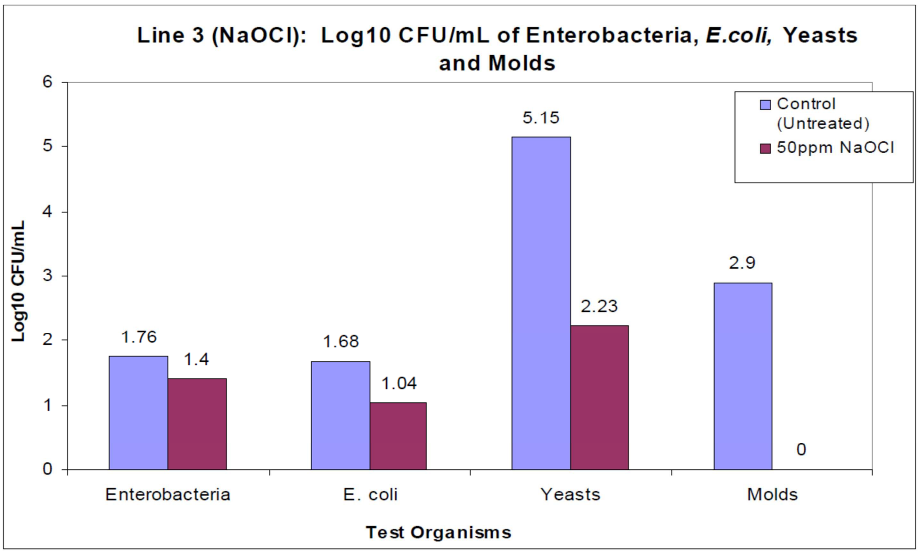


Figure 48. Relative performance of peroxyacetic acid (PAA) and sodium hypochlorite bleach (NaOCl) in achieving postharvest sanitisation against enterobacteria, *E. coli* and yeasts moulds of cherries in a commercial cherry packingline in California.

(From Rodrigues T. and Howarth J. (2009) Comparative efficacy of peroxyacetic acid and sodium hypochlorite bleach against enterobacteria, E. coli and yeasts molds on cherries).

Fungicides

There are two registered fungicides for postharvest use; fludioxonil and iprodione. Fludioxonil is a protective fungicide used as a postharvest treatment registered to control brown rot (*Monilinia* spp.), grey mould (*Botrytis cinerea*) and rhizopus rot (*Rhizopus stolonifer*). It is registered under the trade name Scholar® and is a member of the phenylpyrrole group of fungicides (Group 12).

Iprodione is a member of the dicarboximide group of fungicides (Group 2) and is registered to control brown rot (*Monilinia fructicola, Monilinia laxa*) and suppresses transit rot (*Rhizopus* spp.). The appropriate labels of these fungicides are listed in Figure 49.

Iprodione (2) label

CROP	DISEASE	STATE	RATE	WHP	CRITICAL COMMENTS
Stone Fruit: Apricots, Cherries, Nectarines, Peaches, Plums	Post-harvest Dipping Brown Rot (*Monilinia fructicola*, *Monilinia laxa*), *Transit Rot (*Rhizopus* spp.)	Qld, NSW, ACT, Vic, Tas, SA, WA only			To minimise the development of post-harvest rots handle fruit carefully to avoid fruit injury and dip promptly after harvest. Remove any infected fruit from the packing house immediately and destroy. When dipping, allow sufficient time to thoroughly wet the fruit. Top up dip with 200 mL Cheminova Iprodione 250 in 100 L of water. A non-ionic wetting agent should be added. *Transit Rot is suppressed at this rate. This use is subject to a CropLife fungicide resistance management strategy: 1. For the last pre-harvest spray, use a fungicide with a different mode of action to the fungicide planned for use as a post-harvest treatment. 2. Where alternative fungicide groups are available, rotate to use as many different modes of action as possible. 3. DO NOT dispose of unused dip solutions as a spray to crops or orchards. 4. DO NOT dispose of unused dip solutions within or near the crop or orchard area.

Fludioxonil (12) (Scholar®) label

Stone Fruit – except Apricots and Peaches	Brown Rot (*Monilinia* spp.), Grey Mould (*Botrytis cinerea*), Rhizopus Rot (*Rhizopus stolonifer*)	130 to 260 mL in 100 L water	-	Refer to Application section below for application instructions.
– Apricots and Peaches		130 mL in 100 L water	-	

Figure 49. Label rates for the postharvest use of fludioxonil and iprodione in cherries.
(From APVMA website, Accessed 6 January 2018)

However, postharvest use of synthetic fungicides in many countries including the European Union countries and large cherry producing countries such as Turkey are prohibited due to fungicide regulatory issues. The lack of an effective postharvest treatment against postharvest pathogens in these countries highlights the need for developing new control methods. It is important that the Australian cherry industry remain up to date with the latest developments in this area to remain flexible in a changing regulatory environment and to ensure export market access. These developments will be discussed in the *Innovations Section*.

Effects of market access treatments on quality

Consistently delivering high quality fruit to the consumer is the goal of the Australian cherry industry. However delivering horticultural produce onto some export markets such as China is often restricted due to the presence of quarantine pests (such as Queensland fruit fly (*Bactrocera tryoni*)) in major growing areas. To overcome these quarantine restrictions, end-point disinfestation treatments are often required. The major end – point disinfestation protocols to overcome the presence of quarantine pests are: cold treatment, methyl bromide fumigation and low dose irradiation. The effects of these different phytosanitary treatments are discussed in relation to their effects on fruit quality.

Cold treatment

Cold treatment schedules are closely dependent upon East-West recognition, as it has been shown that the Mediterranean fruit fly requires a longer treatment schedule than Queensland fruit fly (De Lima et al., 2011). The acceptance of the East-West protocols and therefore shorter cold treatment schedules for Queensland fruit fly (3 °C for 14 days) are a priority for industry. All the current cold treatments are listed in Appendix 1 and in general show that Australian cherries are required to be treated at between 0-3 ^{o}C for up to 21 days depending on the market (Appendix 1).

As described in earlier sections, cherry fruit tolerate cold temperature storage (0-3 ^{o}C) and this is the recommended storage temperature. Indeed cold treatment is the basis of cherry exports to many countries, eg Chilean cherries to China. However it is important to deliver fresh high quality cherries to export markets and air freight is the preferred transport to Asian markets. Therefore shorter treatment times are preferred, where possible.

Methyl bromide fumigation

Methyl bromide has been used as a quarantine fumigant for many years, where numerous export protocols are based on its use. It is recognised as an ozone depleting chemical and was used extensively as a pesticide until being phased out by most countries in the early 2000s. However it still can be used as a quarantine fumigant. The current methyl bromide fumigation protocols for export of cherries is presented in Appendix 1, where the major fumigation treatment schedule for the treatment of Australian cherries is 40 g / m^3 of methyl bromide for 2 hours at 17.2 °C or above.

While the sorption of methyl bromide into the fruit during fumigation is substantial (averaging 51 and 56% for 'Bing' and 'Rainier' cherries, respectively) (Moffitt et al., 1992), the desorption of methyl bromide from the fruit following fumigation has been shown to follow approximately pseudo-first-order kinetics (Sell et al., 1988), where after fumigation and ventilation, residue of methyl bromide in fruit decreases quickly (Hansen et al., 2000b). Sell et al. (1988) further showed that the concentration and persistence of the methyl bromide residue was dependent on the load factor, which is the ratio of the volume of cherries to the volume of the fumigation chamber, and the pulp temperature of the cherries. Indeed the calculated half-life of organic bromide in fumigated 'Bing' cherries is reported to be 4.7 to 5.9 hours where all residues are below regulatory tolerances (Tebbets et al., 1983).

There have been many studies on the effects of methyl bromide treatment on the quality of cherries. However many of the results are dependent on the treatment temperature, concentration, time and cultivar. While some reports show some selective negative effects of methyl bromide treatment, such as treatment with 32 g/m^3 for 2 hours at 17 ^{o}C followed by storage at 1 ^{o}C increased the frequency of stem abscission in both 'Ron's Seedling' and 'Lambert' cultivars but there was no effect on other fruit quality parameters (fruit firmness, SSC, weight loss) (Jessup, 1988).

In a comparison of different methyl bromide fumigation treatments (48 g /m^3 for 2 hours at 12 - 17 °C, 40 g/m^3 for 2 hours at 17 - 22 °C and 32 g/m^3 for 2 hours at >22°C) were compared with different cultivars were 'Garnet', 'Brooks,' 'Tulare,' 'Lapins' and 'Sweetheart'. The results showed there was no effect of fumigation on any of the cultivar on fruit quality (fruit firmness, soluble solids, or titratable acids) except for `Brooks,' fumigation (Hansen et al., 2000a). They showed that the reduction in fruit and stem quality was more associated with temperature than with methyl bromide concentration. `Tulare', `Lapins' and `Sweetheart' could be fumigated with minimal change in fruit quality (Hansen et al., 2000a).

Other reports show that fumigation with 32 g/m^3 methyl bromide for 2 hours at 24 °C resulted in complete kill of larvae of *L. pomonella* in harvested cherries with no significant effects on quality or taste of the treated fruits (Anthon et al., 1975).

Drake et al. (1991) showed that methyl bromide fumigation did not significantly affect weight loss, fruit colour or soluble solids of either 'Bing' or 'Rainier' cherries following treatment at $48g/m^3$ for 2 hours at 12 ^oC, and 0 and $64g/m^3$ for 2 hours at 6 °C. But they observed increased pitting and reduced objective and subjective stem colour of both cultivars. They showed that as fumigation temperature increased, bruising and pitting increased and stem colour decreased (Drake et al., 1991).

The increase in stem browning following methyl bromide fumigation is a common, but not necessarily consistent effect reported in the literature (Anthon et al., 1975; Hansen et al., 2000a). Hansen et al. (2000a) reports that any slight difference in stem colour may be unnoticed by regular consumers than individuals experienced in stem colour evaluation. They report that time and temperature of fumigation had a more deleterious influence on fruit and stem quality than did the methyl bromide fumigation, and the higher the temperature and longer the exposure time, the lower the quality (Hansen et al., 2000a). Drake et al. (1991) also noted that the interaction of temperature and fumigation on stem quality. This is not surprising as previously described; cherry stems are extremely sensitive to water loss, where the water loss from the stem is eight times more than the fruit under normal storage conditions – low temperature (Linke et al., 2010).

In summary, methyl bromide treatment can negatively affect some fruit and stem quality parameters however many reports have concluded that methyl bromide treatment does not have a consistent deleterious effect on overall fruit quality (Anthon et al., 1975; Drake et al., 1991; Hansen et al., 2000). Indeed methyl bromide treatment is successfully used disinfestation treatment for cherries exports around the world.

Irradiation

Irradiation is a technologically proven, viable and scientifically sound disinfestation treatment (Follet, 2009). Moreover, irradiation is increasingly becoming an approved and agreed treatment in world trade of food and horticultural products (Richards et al., 2003). Generic irradiation treatments have been approved by U.S. Department of Agriculture - Animal and Plant Health Inspection Service (USDA-APHIS) at doses of 150 Gy (Gray) for tephritid fruit flies and 400 Gy for all insects except pupal and adult Lepidoptera (USDA-APHIS, 2006). Further APHIS rulings and new rulings by the International Plant Protection Convention (IPPC) have approved new minimum doses for 6 fruit fly pests and 14 other plant insect pests regardless of the host product, at doses between 60 and 300 Gy (USDA-APHIS, 2008). An excellent review of irradiation quarantine treatments has been published by Follet (2009). Follet et al. (2017) recently showed that the MA conditions with the MA bag of export cherries (down to 3% O_2 in the bag), did not affect the survivorship to the adult stage in *Drosophila suzukii* pupae irradiated at 60 Gy in cherries. This confirms the use of irradiation as a phytosanitary market access treatment.

Food Standards Australia New Zealand (FSANZ) recently granted food safety approval for irradiation (at 150 – 1,000 Gy) as a technique for insect pest disinfestation of cherries and it has also been approved in several export markets such as Indonesia and Vietnam. Irradiation breaks chemical bonds in DNA and other molecules, thereby sterilizing the pest or preventing it from achieving sexual maturity.

The effect of low dose irradiation (< 1,000 Gy) as a market access treatment on fruit quality has shown there are few consistent negative effects of treatment and subsequent cold storage on cherry quality, whereby fruit integrity is generally not affected (Neven and Drake, 2000; QDAFF, 2013; Thang et al., 2016). In a comparison of methyl bromide fumigation and low dose irradiation as market access treatments, Thang et al. (2016) showed that the target dose of 400 Gy does not adversely or positively impact cherry quality or shelf-life and can serve as a good alternative to methyl bromide fumigation.

Jessup (1990) showed the quality of NSW grown 'Ron's Seedling', 'American Bing', and 'Lambert' cherry was not affected by irradiation doses of 1,000 Gy and similarly Drake et al. (1994) reported that cherry showed minimal quality loss after being irradiated for disinfestation. QDAFF (2013) showed that the fruit quality was only affected by storage time and not by irradiation. They showed that time in storage had a small impact on the skin colour (lightness values) of the cherry fruit where the fruit became slightly darker shade during storage. However they showed that any effects were minor and did not detract from the integrity or overall visual appeal of the fruit (QDAFF, 2013). The findings suggest that an application of up to 1 kGy would not result in any detrimental damage to the quality of cherry fruit.

These results concur with several other studies examining the effects of irradiation and subsequent cold storage on cherry quality, whereby fruit integrity was unaffected (Drake et al. 1994, Kovacs et al. 1995). Drake et al. (1994) also demonstrated that fruit treated to doses of up to 1,000 Gy and stored for up to 21 days exhibited no significant changes in various fruit quality attributes, such as in fruit and stem colour, soluble solids, titratable acidity or sensory characteristics. While not considered low dose for market access treatment, even irradiation doses between 1,000 and 2,500 Gy had no effect on fruit quality attributes such as skin colour, sugar contents (Kovacs et al. 1995).

In a fruit storage trial with five different cherry cultivars from Young and Orange districts (‘Kordia’, ‘Lapin’, ‘Regina’, ‘Simone’ and ‘Skeena’) treated with 150 Gy, showed no treatment effect on stem browning, fruit colour, pitting, cracks, splits, bruising, rots, overall acceptability, SSC, TA and SSC/TA ratio (Golding, 2017). Fruit firmness as measured with the Firmtech instrument did detect a treatment effect, whereby treated fruit were softer than untreated fruit. However the small sensory trial showed consumers (n=12) were not able to detect these differences in texture and treatment also had no effect on overall acceptability, flavour or appearance (Golding, 2017). In a related trial examining the different dose treatments (150, 400 and 800 Gy) showed there was little difference in overall fruit quality in treated ‘Lapin’ cherries compared to those of the untreated control fruit (Figure 50). The different dose treatments had no effect on stem browning, fruit colour, pitting, cracks, splits, bruising, rots, overall acceptability, SSC, TA nor SSC/TA ratio. The only quality parameter found to be affected by treatment was fruit firmness, where ‘Lapin’ fruit treated at the highest dose (800 Gy) resulted in significantly lower firmness. There was no difference in fruit firmness between the untreated, 150 and 400 Gy treatments (Golding, 2017). However the decrease in fruit firmness observed in both experiments were observed across a range of cultivars, but were not detected by consumers. A decrease in cherry fruit firmness with irradiation has been observed in other studies:

- Drake et al. (1994) ‘Rainier’ cherries > 600 Gy
- Drake and Neven (1998) ‘Bing’ cherries from > 300 Gy and Rainer cherries from 600 Gy
- Eaton et al. (1970) ‘Vans’ cherries at 500 Gy
- Johnson et al (1965) ‘Bing’ cherries at 600 to 800 Gy
- Kovacs et al. (1995)
- Neven and Drake (2000) ‘Bing’ cherries at 300 Gy at treatment and 7 days storage
- Thang et al. (2016) ‘Sweetheart’ cherries at 400Gy at firmness but not after storage

Whilst other reports have not shown any significant negative effect of irradiation on fruit firmness:

- Jessup (1990) ‘Bing’ and ’Lambert’ cherries up to 300 Gy for 20 days at 1 ^{o}C
- QDAFF (2012) ‘Stella’ cherries up to 1,000 Gy for 14 days at 1 ^{o}C
- Neven and Drake (2000) ‘Rainier’ cherries at 300 Gy for up to 14 days storage
- Eaton et al. (1970) ‘Lambert’ cherries up to 500 Gy and Vans cherries < 500 Gy

Overall low dose irradiation has few negative effects on fruit quality and there is generally more effect of storage time on final fruit quality.

Untreated control (0 Gy)

150 Gy

400 Gy

800 Gy

Figure 50. Effect of treatment with 0, 150, 400 and 800 Gy on appearance of ‘Lapin’ cherry fruit after treatment and two weeks storage at 0 ^{o}C with one additional day at 20 ^{o}C (unpublished from Golding, 2018).

Effects of irradiation on cherry nutritional content

In general, there are few differences in the nutritional content of cherries treated with low dose irradiation (QDAFF, 2013). However it is important to note that different cultivar tested, fruit maturity, growing conditions and management practices all affect nutritional content and care must be taken when comparing studies and treatments. An extensive report on the effects of low dose irradiation on Australian cherries was conducted in 2012 for application to FSANZ to change the food code (QDAFF, 2013). This study examined the effect of irradiation at 150, 600 and 1,000 Gy on the nutritional profile and postharvest quality of ‘Stella’ cherry and showed that low irradiation doses (150–1,000 Gy) combined with cold storage overall, did not result in significant cherry nutritional quality (including ash, energy, dietary fibre, fat profile, moisture, sodium, protein, total sugars, sugar profile, Vitamin C (ascorbic acid) and beta-carotene) and postharvest quality after treatment and after the 14-day storage period studied. These results supported the successful application to allow low dose irradiation as a market access treatment of Australian cherries.

QDAFF (2013) reported that low dose irradiation (< 1,000 Gy) did not cause any detrimental impact for all the nutritional components tested. Indeed storage treatment had a greater impact on sweet cherry nutrition than that of irradiation (QDAFF, 2013). After storage for 14 days, reduced Vitamin C (total ascorbic acid) and Vitamin A (beta-carotene) levels and increased protein and ash content and were considered senescence- related (QDAFF, 2013). After 14 days storage, only minor changes occurred as a result of irradiation, with a slight decline measured in beta-carotene levels at 600 Gy (QDAFF, 2013). Similar results were found in a previous study by Akbudak et al.

(2008), where ascorbic acid levels in untreated ‘0900 Ziraat’ cherry were no different from fruit irradiated at 300 Gy. In that study which investigated storage at six different atmosphere combinations for up to 60 days after being exposed to irradiation, the highest ascorbic acid value was recorded in fruit stored under controlled atmosphere and irradiation. Indeed Akbudak et al. (2008) showed ‘0900 Ziraat’ cherry can be stored successfully for more than 60 days under controlled atmosphere following low dose irradiation.

QDAFF (2013) also reported there were little or no changes in carbohydrates, glucose and fructose across all irradiation samples and after 14 days cold storage. Drake and Neven (1997) similarly found that carbohydrates (sucrose, glucose, fructose and sorbitol) were not influenced by irradiation treatment in ‘Rainier’ cherry, irradiated between 150 and 900 Gy. In summary, there low dose irradiation (< 1,000 Gy) has no significant negative effects on cherry fruit nutrition.

Comparison of treatment costs

There have many attempts to cost the different disinfestation alternative treatments. Nelson (1996) and Aegerter and Folwell (2000) examined the economic aspects of alternatives to methyl bromide in the postharvest and quarantine treatment of selected fresh fruits including cherries. These types of economic analysis are only useful for that time, conditions and limitations. For example these studies were very specific for that economic scenario in USA and time, with treatment assumptions and limitations at those times. Given these limitations, Aegerter and Folwell (2000) showed that methyl bromide treatment of 25,000 field bins (4082 t) of cherries had a total treatment cost of USD $40,674 or USD $9.96/t. While the irradiation treatment of the same cherry volumes had a total cost of USD $144,000 or USD $35.27/t (Aegerterand Folwell, 2000). These figures are very specific to that time, location and assumptions of the analysis and should not be used as general costs related to each treatment. However this type of research illustrates the analysis that should be done for the local industry. The Australian situation has a dedicated treatment plant in Brisbane with another facility planned for Melbourne markets in 2019. Irradiation is a commercial treatment that industry has been using for many seasons. Economic analysis of the different treatment costs need to be conducted for each treatment situation and market.

New developments and innovative postharvest treatments to maintain quality

There are a number of on-going innovations and developments to maintain the quality of cherries through the supply chain. These include; (1) the application of naturally occurring compounds, (2) edible coatings and films, (3) novel packaging (active packaging, nanotechnology, traceability etc.), (4) alternative decay control treatments and (5) new market access treatments. Each of these potential new treatments and technologies will be briefly discussed.

Application of naturally occurring compounds

Plant growth regulators have long been applied to improve the quality of cherries. For example, gibberellic acid (GA_3) has been shown, depending on the cultivar, to increase fruit weight and SSC, and delay ripening and reduce fruit cracking (Usenik et al., 2005). Indeed Australian cherry growers regularly apply GA_3 for this purpose (Dodds et al., 2017) (also see *Fruit Texture Section*). Other naturally occurring compounds have been applied to improve the shelf life of cherries. Correia et al. (2017) presented a summary of the application of calcium and growth regulators to improve cherry fruit quality (Table 3).

Salicylic acid (SA) is a naturally occurring endogenous plant growth regulator that has been found to generate a wide range of metabolic and physiological responses in plants including cherry fruit (Valero, 2013). SA as a natural and safe phenolic compound exhibits a high potential in controlling postharvest losses of horticultural crops (Asghari and Aghdam, 2010). Recently, SA and its derivative acetyl salicylic acid (ASA) have received particular attention because it is a key signal molecule for expression of multiple modes of plant stress resistance (Valero, 2013). Although the focus has been mainly on the roles of SA on biotic stresses, several studies also support major roles of salicylates in modulation of the plant response to several abiotic stresses, such as UV light, drought, salinity, chilling stress and heat shock (Ding et al., 2001; Sayyari et al., 2009, 2011). In addition salicylates delay the ripening of fruits, probably through inhibition of ethylene biosynthesis or action, and maintain postharvest quality (Srivastava and Dwivedi, 2000).

Oxalic acid (OA) is an organic acid ubiquitously occurring in various organisms, especially in plants, and plays several different roles in different living organisms. Recently, application of oxalic acid for postharvest storage of fruit has received much attention, mainly due to its important roles in disease resistance (Tian et al., 2006), chilling tolerance (Sayyari et al., 2010), and anti-senescence (Wu et al., 2011). In addition, the endogenous concentration of oxalic acid in many plant foods has been considered as a natural antioxidant by suppressing in vitro lipid peroxidation (Kayashima and Katayama, 2002).

Valero et al. (2011) showed that 'Cristalina' and 'Prime Giant' cherry cultivars treated with SA, ASA or OA delayed the postharvest ripening process, manifested by lower acidity losses, colour changes and firmness losses, and maintained quality attributes for longer periods than controls. In addition, total phenolics, anthocyanins and antioxidant activity increased in untreated fruit during the first 10 days of storage and then decreased, while in fruits of all treatments, these parameters increased continuously during storage without significant differences among treatments (Valero et al., 2011). Thus, treatments with natural compounds, such as SA, ASA or OA, could be innovative postharvest tools to extend storability of cherry with higher content of bioactive compounds and antioxidant activity as compared with controls. In addition the application of exogenous SA has also shown to reduce the decay caused by *P. expansium* in cherry fruit by stimulating the activities of antioxidant enzymes and increasing the activities of chitinase and ß-1,3-glucanase in the fruit, which might retard the development of pathogenic fungal (Xu and Tian, 2008).

Application of other novel compounds, such as β-aminobutyric acid (BABA) have also been applied to cherry fruit. BABA is known for its ability to induce plant disease resistance, as well as increased resistance to abiotic stresses. Wang et al. (2016) showed that dipping 'Hongdeng' cherries in BABA for 10 min reduced respiration rate, weight loss and increased TA levels, total phenolics, sugars and ascorbic acid during 5 days at 20 °C. Moreover, BABA-treated cherries showed higher ascorbate peroxidase, catalase, glutathione reductase, and superoxide dismutase activities (Wang et al., 2016). The use of these compounds is considered safe and environmentally friendly, resulting in extending storability of cherry with increased health-promoting properties (Valero, 2013). Currently, these postharvest treatments have only been applied at the research level, but the future is promising for application in practice. However more work in their efficacy and equally important the commercial, environmental and regulatory aspects of these treatments needs to be conducted.

Source/Compound	Cultivar	Effects	References
$Ca(OH)_2$	0900 Ziraat Lambert Van	Higher firmness, SSC and calcium content both in skin and flesh; Reduced fruit cracking; Decreased fruit size.	Demirsoy and Bilgener, 1998a
$CaCl_2$	Merton Glory Sue Vega	Higher SSC and phenolics content; Reduced decay and cuticular fractures; Non-significant effects on TA, color and firmness; Increased weight loss during storage.	Vangdal et al., 2008
Ethephon	Bing	Higher firmness (dehydration-related); Reduced fruit removal force and firmness.	Elfving et al., 2009
Gibberellic acid (GA_3)	Buttner's Red Lambert Van	Suppress or delay the development of the pitting symptom on bruised fruit.	Looney and Lidster, 1980; Basak et al., 1998
	0900 Ziraat Bing Lambert	Delayed harvest time.	Facteau et al., 1985; Andrews and Shulin, 1995; Demirsoy and Bilgener, 2000
	Bing Satohnishiki	Decreased the activity of PG and PME.	Andrews and Shulin, 1995; Kondo and Danjo, 2001
	Buttner's Red	Increased fruit firmness, SSC and fruit weight.	Basak et al., 1998
	0900 Ziraat Lambert Van	No significant effect on fruit firmness, SSC and fruit weight.	Demirsoy and Bilgener, 1998b
	13S-27-17 Celeste Lapins Merpet	Increased fruit firmness and TA; Decreased the activity of PG and cellulase activity; Delayed softening and fruit maturation; No significant effect on SSC and β-glucosidase activity.	Choi et al., 2002
	Bing	Higher firmness during storage.	Clayton et al., 2003
	Sweetheart	Firmer, heavier and larger fruits, better preservation of stem; No effect on color and SSC content.	Horvitz et al., 2003
	Elisa Sunburst Van	Higher yield; Increased fruit weight and SSC; Delayed process of maturity; Reduced fruit cracking.	Usenik et al., 2005
	0900 Ziraat	Firmer and larger fruits; Higher SSC.	Canli and Orhan, 2009
	Bing	Increased fruit firmness and weight; Delayed fruit maturation; Decreased fruit color.	Zhang and Whiting, 2011
	0900 Ziraat Regina Sweetheart	Increased fruit size; Retarded fruit ripening; Preserved flesh firmness; Decreased SSC, total phenolics, anthocyanins accumulation and antioxidant activity.	Ozkan et al., 2016
22S, 23S-Homobrassinolide (HBR)	Regina Summit	Increased fruit size and brightness of the red color.	Engin et al., 2016
		Increased fruit size and firmness of the flesh slightly; Better stem resistance.	
GA_3 + HBR		Increased fruit size; Higher longer fruit; Decreased SSC.	
Benzyladenine (BA) + Gibberellin (4+7)	Noir de Guben	Increased fruit size; Delayed skin color development; No significant effect on fruit firmness.	Canli et al., 2015a
Cytokinins		Increased fruit firmness, SSC and fruit weight; Decreased fruit color.	Zhang and Whiting, 2011
Auxins	Bing	Increased fruit size and total yield.	Stern et al., 2007
		Higher fruit growth rates and fruit color development (Stages I and II); No significant effect on fruit size.	Zhang and Whiting, 2011
Methyl jasmonate (MeJA)	n.d.	Reduced incidence of postharvest rot; Decreased β-1,3-glucanase, PAL and POD activities.	Yao and Tian, 2005
Salicylic acid (SA)	Sweetheart Sweet Late	Increased fruit firmness and weight; Higher concentration in total phenolics and anthocyanins; No effect on SSC and TA.	Giménez et al., 2014
Acetylsalicylic acid (ASA)		Increased fruit firmness and weight; Higher concentration of total phenolics and anthocyanins; No effect on SSC and TA.	
Oxalic acid (OA)		Increased fruit size at harvest, color and firmness; Higher concentration of total phenolics and anthocyanins; No significant effect on SSC and TA.	Martínez-Esplá et al., 2014
Methyl salicylate (MeSA)	Lapins Sweetheart Sweet Late	Increased fruit size, firmness and SSC; Higher activities of total antioxidant activity and antioxidant enzymes; Higher total phenolics and anthocyanins content; Delayed the postharvest ripening process.	Giménez et al., 2015; Valverde et al., 2015

SSC, soluble solids content; TA, titratable acidity; PAL, phenylalanine ammonia-lyase; POD, peroxidase; PG, polygalacturonase; PME, pectinmethylesterase; n.d., not defined.

Table 3. Effect of calcium and growth regulators on quality attributes of cherries *(from Correia et al., 2017).*

From: Cordia et al. (2017) Factors affecting quality and health promoting compounds during growth and postharvest life of sweet cherry (Prunus avium L.). Frontiers in Plant Science 8, Article 2166. For references in Table – see article.

Edible coatings

There is increasing consumer interest in reducing or replacing non-biodegradable food packaging which has renewed interest in the development of edible / biodegradable films or coatings. Edible films are thin layers of edible materials applied on food products that play an important role on their conservation, distribution and marketing. Some of their functions are to protect the product from mechanical damage, physical, chemical and microbiological activities. Their use in horticulture and especially on highly perishable products such as cherries, is based on some particular properties such as cost, availability, functional attributes, mechanical properties (flexibility, tension), optical properties (brightness and opacity), the barrier effect against gases flow, structural resistance to water and microorganisms and sensory acceptability.

Some beneficial effects of maintaining cherry fruit quality have been obtained with some edible coatings based on chitosan (Romanazzi et al., 2003), *Aloe vera* gel (Martínez-Romero et al., 2006), alginate (Diaz-Mula et al. 2011) and Semperfresh^{TM} (Yaman and Bayindirh, 2001; 2002) and many other composite films (Lim et al., 2011).

Chitosan Chitosan is a polysaccharide obtained from shell fish waste, possesses excellent barrier properties and provides some level of anti-microbial activity. Among alternatives that are currently under investigation to replace the use of synthetic fungicides to control postharvest diseases in fresh produce and to extend their shelf life, chitosan application has shown promising disease control, at both preharvest and postharvest stages (Romanazzi et al., 2017). Chitosan coating forms a semipermeable film on the surface of cherry fruit, thereby delaying the rate of respiration, decreasing weight loss, maintaining the overall quality, and prolonging the shelf life (Romanazzi et al., 2017). Specifically on cherries, Romanazzi et al. (2003) showed fruit immersed for a few seconds in 1% chitosan solution and stored for 14 days at 0 °C, followed by days of shelf life, showed a significant reduction in brown rot and grey mould in cherries. An additive, and at times synergistic, decay reduction has been seen by combining chitosan and hypobaric treatment (Romanazzi et al. 2003). Reduced decay development was also observed for cherries treated with 1% chitosan and stored at 25 and at 2°C (Park and Zhao 2004). Chitosan is thought is have a dual mechanism of action: it reduces the growth of decay causing fungi, and it induces resistance responses in host tissues (Romanazzi et al. 2003). Moreover, the coating can provide a substrate for incorporation of other functional food additives, such as minerals, vitamins, or other drugs or nutraceutical compounds that can be used to enhance the beneficial properties of fresh commodities or in some cases the antimicrobial activity of chitosan. Chitosan coating has been approved as GRAS substance by USFDA, and its application is safe for the consumer and the environment.

Aloe vera *Aloe vera* is a succulent plant which has been used in traditional medicine and as a food production for many years. Martınez-Romero et al (2006) showed that 'StarKing' cherry treated with *A. vera* gel significantly delayed postharvest quality losses, and storability could be extended. The sensory analyses revealed beneficial effects in terms of delaying stem browning and dehydration, maintenance of fruit visual aspect without any detrimental effect on taste, aroma or flavours (Martınez-Romero et al., 2006). Serrano et al. (2017) further showed that the increase in bioactive compounds and antioxidant activity that usually occurs during storage was delayed by aloe gel treatment, showing an effect of gel coating on delaying the normal postharvest ripening process, in accordance with previous experiments in which this treatment delayed the evolution of other nutritive and organoleptic parameters, thus making it a good candidate for future development (Serrano et al., 2017).

Alginate Alginate is a natural polysaccharide extracted from brown sea algae (Phaeophyceae), and it is composed of two uronic acids: β-D-mannuronic acid and α-L-guluronic acid. Alginate is known as a hydrophilic biopolymer that has a coating function because of its well-studied unique colloidal properties, which include its use for thickening, suspension forming, gel forming and emulsion stabilising. Sodium alginate has been effective on maintaining postharvest quality of different horticultural products, including cherry (Zapata et al., 2008; Valero et al., 2013; Diaz-Mula et al., 2012). Indeed Diaz-Mula et al. (2012) showed that 'Sweetheart' cherries treated with an edible coating based on sodium alginate at several concentrations (1, 3 or 5% w/v) showed a delay on the evolution of the parameters related to postharvest ripening, such as colour, softening and loss of acidity, and reducing respiration rate. In addition, the edible coatings showed a positive effect on maintaining higher concentration of total phenolics and total antioxidant activity, which decreased in control fruits associated with the over-ripening and senescence processes. Results from quality parameters and antioxidant activity suggested that the maximum storability period for control fruits was 8 days at 2 °C plus 2 days at 20 °C, while alginate-coated cherries could be stored with optimal quality and enhanced antioxidant activity up to 16 days at 2 °C plus 2 days at 20 °C (Diaz-Mula et al., 2012).

Biocomposite films There is a great range of potential film-forming biopolymers which include proteins (Gennadios et al., 2002) and polysaccharides (Gennadios, 2002) to create potentially functional and cheap films.

These biocomposite compounds have a unique ability to establish polymer interactions and create a continuous network responsible for the functional properties of films (Olivas and Barbosa-Canovas, 2005). Film-forming proteins such as gelatin, sodium caseinate, soy protein isolates, whey protein isolates, and polysaccharides such as carboxymethyl cellulose, methylcellulose and hydroxypropyl methylcellulose are commercially available at relatively low cost (Wang et al., 2007), and are therefore prime candidates for application on fresh fruits. We have shown the benefits of biocomposite edible coatings based on pea starch and guar gum on quality, storability and shelf life of different fresh fruit such as oranges (Saberi et al., 2018). The results showed that a pea starch and guar gum edible coatings could be a beneficial substitute to common commercial waxes for maintaining quality and storability, as well as extending shelf life of citrus fruit and potentially other fresh horticultural produce such as cherries. In cherry fruit, a shellac coating was found to be more effective in reducing the respiration rate and maintaining the quality parameters of cherries than chitosan and whey protein isolate coatings (Aday and Caner, 2010). Coating agents with higher degree of hydrophobicity were found to be more effective in maintaining fruit weight and firmness, as well as delaying deterioration. (Rojas-Argudo et al., 2005). We have also shown there is great potential to counteract moisture loss in 'Sweetheart' cherries with the use of composite films of gelatine, carboxy-methylcellulose and soy protein isolate components (Lim et al., 2011). We have also developed novel films from different starch sources such as rice (Thakur et al., 2017, 2018) and pea (Saberi et al., 2016d), with different plasticisers, emulsifiers and surfactants (Saberi et al., 2016 a,b,c, Thakur et al., 2016) to create novel films for application to horticultural produce (Saberi et al., 2018). It is critical that the development of films is done in a systematic method and focus on the commercial, safety, quality and applicability of the film.

In addition, it is also possible to add functional components into the film such as anti-browning and anti-microbial agents, nutraceuticals, volatile precursors, and colours to improve the characteristics of the film (Olivas and Barbosa-Cánovas 2005). Besides, the microbial stability, appearance, and texture of coated products can be improved by addition of other constituents, such as preservatives, antioxidants, and firming agents (Bai and Plotto 2012; Cerqueira et al. 2009).

Commercial treatments

There are a range of commercial coatings that are used in horticulture. While most coatings and films are used in citrus and apples, there are some commercial treatments available for fresh cherry fruit.

Semperfresh™ is a registered trademark of AgriCoat Industries Ltd., sold by Pace International and has been available as a coating on fruit for many years. It is composed of sucrose esters of fatty acids (E 473), sodium carboxymethylcellulose (E 466) and mono-diglycerides of fatty acids (E471) (Semperfresh™ label, 2018). It is used in some countries to maintain the quality of cherries. Yaman and Bayindirh (2002) showed Semperfresh™ coating to reduce the weight loss and increase firmness, ascorbic acid content, titratable acidity and skin colour of cherries during storage, where soluble solid content and sugar content were not affected by the coating. However, these authors showed an increase in fungal spoilage in Semperfresh™ coated cherries and fungicides should be added to avoid fungal spoilage (Yaman and Bayindirh, 2001).

Food Coat® is an edible coating composed of derivatives of fatty acids and polysaccharides in alcohol solution. The coating is produced, commercialized and distributed by DOMCA (Granada, Spain) as a concentrated liquid solution. Alonso and Alique (2004) showed Food Coat® treated cherries were shiner, more turgid and more attractive than controls after storage, although no significant effects were observed on the parameters that related to fruit quality such as colour and firmness.

Novel packaging

Active packaging

Active packaging is a system in which the product, package and environment interact to have active functions to improve quality or food safety beyond the inert passive containment and protection of the product. Active packaging systems have been developed to modify the environmental or physiological conditions within the package to either absorb (scavenger) harmful gases in the atmosphere, or release beneficial agents into the package (Table 4). Active packaging is typically found in two types of systems; (1) sachets and pads which are placed inside the headspace of the package, and (2) active ingredients that are incorporated directly into packaging materials, such as manufactured into the plastic film. With some exceptions, the commercial application of active packaging has been limited and maybe due to the hesitation of industry to use sachets which have an inherent risk of accidental ingestion by consumers and also their recycling / disposal issues in the marketplace.

Table 4. Examples of active packaging types

Packaging type	Mechanism / active agent
Absorption from atmosphere	
Ethylene	Potassium permanganate impregnated alumina pellet
	Activated carbon + metal catalyst
	Zeolite
Oxygen	Iron based
	Ascorbate
	Catechol
Water	Absorbent pads
Releasing agents	
Sulphur dioxide	Sodium metabisulphate

1. Absorption of undesirable compounds from the package

Ethylene. Ethylene is a hormone promoting fruit ripening and can influence postharvest life of both climacteric and non-climacteric fruits by influencing their quality attributes and the development of physiological disorders and postharvest diseases (Kader, 1985). Exogenous ethylene has been shown to have no effect on respiration rate and firmness loss during cherry fruit ripening (Li et al., 1994), but Gong et al. (2002) showed that exogenous ethylene accelerated the development of stem browning in sweet cherry cultivars, even though 1-MCP had been applied. While ethylene is generally not known to have any negative effects on cherry fruit quality, its effect at low levels during long term storage are not known, and work with other commodities have shown negative effects of ethylene on both climacteric and nonclimacteric fruit during storage (Wills et al., 2014; Li et al., 2017; Li et al., 2018). Ethylene can be scrubbed from the package atmosphere with the use of many different substances such as; activated carbon (charcoal), clay materials such as zeolite, and potassium permanganate in sachets. There are numerous commercial products which use these different absorption and oxidation mechanisms. For example, PacLife™ are a packaging company in Chile which sells cherry MA bags with zeolite nano-particles (www.envasespaclife.com).

Oxygen. There are a number of commercial treatments which absorb oxygen from packages. Often the oxygen absorber or scavenger is enclosed in a porous sachet or packet but it can also be part of packaging films and structures. Many oxygen scavengers use a mixture of iron powder and sodium chloride. Whilst non-ferrous non-ferrous variants, such as ascorbate, catechol based sachets are also available.

Other scavenging systems. There are various CO_2 absorbers (such as calcium hydroxide) and water absorbers (such as clays and silica gels) which are available. However most horticultural products require high humidity and can generally tolerate low CO_2 levels, and therefore these absorbers are not generally used in packaging. But some humidity management is commonly used with absorbent pads, which was discussed in the *Minimising Water Loss Section*.

2. Releasing beneficial agents

Sulphur dioxide. Sulphur dioxide (SO_2) is widely used to control postharvest decay (*Botrytis*) in tablegrapes during storage however it is not currently used in cherries. However care must be taken to ensure there are no chemical residue issues associated with its use, which may compromise fruit safety. In addition, micro-cracks in the fruit around the stem offers an entry point for SO_2 and can cause bleaching and discolouration of the berry. Ekman (2011) showed inconsistent results on the effects of SO_2 treatment on the development of rots in cherry fruit during storage and fruit quality following treatment and storage. However Golding (2010) showed of SO_2 treatment as a postharvest disinfestation treatment had some promise with *in vitro* tests against Queensland fruit fly larvae, but the results in the *in vivo* trial in 'Sweetheart' cherry fruit were less encouraging.

There are also a range of experimental chemicals and treatments which have significant potential for development as commercial beneficial releasing agents into packages. These treatments include; essential oils which have postharvest antimicrobial and antifungal activities, ethanol and other generally regarded as safe (GRAS) compounds which have antifungal and potential insect disinfestation capabilities. For example Serrano et al. (2005) tested the addition of eugenol, thymol, menthol or eucalyptol (pure essential oils) in polypropylene bags to generate a modified atmosphere. They showed a steady-state atmosphere was reached after 9 days of cold storage with 2-3% CO_2 and 11-12% O_2 with no significant differences between treated and control, with the exception of eucalyptol, in which significant increases in CO_2 and decreases of O_2 were obtained. Those cherries under active packaging showed benefits in terms of reduced weight loss, delayed colour changes and maintenance of fruit firmness during 16 days of storage. In addition, stems remained green in treated cherries while they became brown in control and reduced moulds and yeasts and total aerobics mesophilic (Serrano et al., 2005). In addition, the addition of eugenol to MAP led to higher increases in both total phenolics and antioxidant activity, which were attributed to the phenolic nature of this essential oil.

These treatments are being developed and commercialised. However significant health and consumer regulations need to be overcome before these are commercially available.

Intelligent packaging

Intelligent (or smart) packaging involves the ability to sense or measure an attribute of the product inside the package and trigger active packaging functions or communicate this information to users. This intelligent packaging can carry out a range of functions such as detecting, sensing, recording, tracing, communicating, and applying scientific logic to facilitate decision making to maintain quality and food safety. A variety of sensors have been developed based on chemical, enzymatic, immunochemical, or mechanical reactions to determine the quality (including food safety attributes) of the produce within the package. These can be used to detect and communicate such information as time/temperature conditions and history, oxygen and carbon dioxide levels, package leakage or spoilage, commodity ripeness and freshness, microbial growth, and specific foodborne human pathogen identification. A good example of the concept of intelligent packaging is the use of an antimicrobial active packaging material which can be made by incorporating and immobilising antimicrobial agents into food packaging material and applying a bio-switch concept. In a bio-switch system, an antimicrobial agent is released as required when there is microbial growth. The basic concept is that a change in the environment such as pH, UV light, or temperature occurs and the antimicrobial agent responds accordingly. This has widespread application to the storage of fruit and vegetables but has yet to be fully explored. Central to the development of intelligent packaging has been the rapid and evolution of nanotechnology and its application to packaging science.

Nanotechnology

Nanotechnology is the manipulation of matter on an atomic, molecular, and supramolecular scale and has the potential to revolutionise packaging. Rapid advances in nanotechnology during the last 10 years have led to significant applications of nanotechnology in food packaging, including horticultural produce. Already the global nontechnology packaging industry is huge with a 2013 market value of US$6.5 billion. However this is expected to grow at 12.7% to increase to US$15 billion in 2020 (Persistence Market Research, 2014).There are several excellent reviews of the applications of nanotechnology in packaging (Duncan, 2011; Cushen et al., 2012). However due to the rapidly development science and technology around nanotechnology, the consumer and environmental regulations have not kept up in most countries around the world (Cushen et al., 2012). The enormous potential benefits offered by nanotechnology must be weighed against the potential risks of use and abuse of nanomaterials, and in large part these risks are still being evaluated (Duncan, 2011). In addition, public perception of the various applications of nanotechnologies will be a major factor determining the commercial success of this technology.

Polymer nanocomposites are created by dispersing an inert, nanoscale filler throughout a polymeric matrix / film. Filler materials can include clay and silicate nanoplatelets, silica nanoparticles, carbon nanotubes, graphene, starch nanocrystals, cellulose-based nanofibers or nanowhiskers, chitin or chitosan nanoparticles and other inorganics (Duncan, 2011).This range of polymer nanocomposites can enhance traditional packaging by increasing strength, improved barrier properties, alterations in surface wettability and hydrophobicity etc. Polymer nanocomposites can be cheaper compared to other packaging techniques, such as multilayer films and polymer blending, owing to the use of fillers that are less expensive and have enhanced tensile and compressive strengths compared to the polymers. Duncan (2011) also reports that nanocomposites may even offer environmental advantages over conventional plastics: when a nanofiller is dispersed within the bio-compatible polymer polylactic acid (PLA), the PLA bio-nanocomposite actually has a faster rate of biodegradation than PLA containing no such additives. While polymer nanocomposites may represent the next revolution in food packaging technology, there are still steps that need to be taken in order to ensure that consumers are protected from any potential hazards these materials pose (Duncan 2011).

Nanoparticle-based antimicrobials have been actively researched and developed. Silver based nanoparticles are potent broad spectrum antimicrobials which have been tested against a range of organisms. Although there are commercial packaging products in some countries which use silver nanoparticles for the storage of produce, the nanoscale silver on human health and the environment is unclear (Duncan, 2011). On-going research and reviews will assist authorities regulate their use and protect consumers and the environment.

Sensors that monitor changes in packaging conditions have great potential and application for packaging of cherries. A range of technologies have been assessed and applied to measure gases within MA packaging. Duncan (2011) reports of measuring CO_2 content in MA packaging using luminescent dyes standardised by fluorophore-encapsulated polymer nanobeads, where the CO_2 sensor has a detection range of 0.8–100%, a resolution of 1%, and only 0.6% cross-sensitivity with O_2. Other examples of gas sensing technology include a series of electronic sensors which utilise ZnO– TiO_2 nanocomposites or SnO 'nanobelts' to detect the presence of volatile organics, including acetone, ethanol and carbon monoxide which may be useful in detecting if the package had been exposed to anaerobic conditions. While the use of WO_3-SnO_2 nanocomposites have been shown to detect the presence of ethylene inside packages (Duncan, 2011).

Some of this technology is already commercially available, where colour sensitive indicators have been developed and commercialised for some horticultural produce such as pears. A commercial company, ripeSense® has successfully commercialised this technology which is a ripeness indicator label developed to detect volatile aroma compounds associated with the ripening of pears (ripeSense®, 2016) (Figure 51). The sensor label works by reacting to aromas released by pears as they ripen and changes colour upon detection of ripening the aroma volatiles. The sensor is initially red and graduates to orange and finally yellow. Consumers can match the colour of the sensor label with their eating preferences, accurately choosing and consuming pears according to their firmness/ripeness preferences. Damage and shrinkage can be reduced as this indicator significantly reduces damage by consumers as they inspect fruit before purchase. This indicator has been developed for a variety of fruit such as pears, kiwifruit, melon, mango, avocado, peaches and nectarines (ripeSense, 2016), but there have been no developments for cherries.

Figure 51. Example of intelligent packaging. Ripeness indicators for fresh pears (ripeSense®).
(Photos from ripeSense® www.ripesense.co.nz. Accessed 20 January 2018)

Time-temperature indicators (TTI) are small measuring devices capable of showing a time-temperature-dependent relationship as an irreversible colour change. Different TTI are based on different technologies and mechanisms. For example, one technology is based on the polymerisation of diacetylenic monomers, whose rate is dependent on temperature. As the environmental temperature rises, diacetylenic monomers polymerise and change to a darkened material.

OnVu™ have commercialised a TTI which uses temperature-sensitive ink that is printed in the shape of a thermometer directly onto the package primarily for chilled meat, but could be applied to horticultural cool chains. The indicator is started by exposing it to UV light on the packingline, causing it to turn dark-blue. From that moment on, the indicator monitors the cool chain. As time passes and/or if the cold chain is interrupted, the colour pales. At higher temperatures, the discolouration happens faster. If the product is stored or transported at an excessive temperature for too long, the colour in the middle of the thermometer gets lighter (Figure 52). The speed and temperatures at which the colour changes can be customised according to the product or application needs (OnVu, 2015).

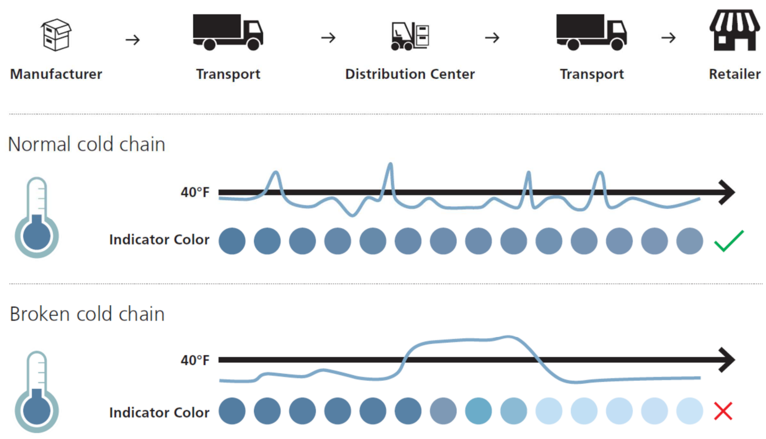


Figure 52. OnVu™ labels are attached to fruit boxes at the packinghouse where anyone along the supply chain can check the indicator at-a-glance and in real time. The OnVu™ labels are based on a temperature-sensitive ink technology. *(Figure from OnVu™ www.onvu.de. Accessed 20 January 2018)*

In addition to general sensors which determine the quality of produce inside packages, the application of sensors / assays that detect contaminants are being developed and have great potential for packaging. The need to rapidly and accurately detect small amounts of pathogen or toxins in food is an essential step in keeping the consumer safe. A range of different nanotechnology applications are being developed to assess food borne pathogens. For example, several biosensors have been designed for the detection of most common food pathogens e.g. *Listeria monocytogenes*, *E. coli* and *Salmonella* sp. as well as mycotoxins in food. These technologies show great potential for the future of packaging.

Traceability

Food traceability is becoming increasing important and is a growing and important attribute of packaging. The use of radio frequency identification (RFID) have been used in many non-horticultural supply chains for many years, where RFID tags can incorporate data such as details of product and the producer. This can also be incorporated into horticultural supply chains to improve traceability where the history of the packed produce can be recalled at any time. In addition some RFID can also transmit measured environmental factors such as temperature and relative humidity. This has tremendous potential for horticultural produce packaging, including cherries and traceability as labels can be made via high quality screen printing and lamination technologies on low cost foils in combination with pick-and-place technology (Smits et al., 2012). For example there are commercial semi-active RFID tags that can measure temperature of the product in the supply chain can then integrate this over time to estimate the shelf life of the produce, which can then be remotely communicated to a reader. RFID technology has also been used in monitoring the ripening of climacteric fruits during transportation and vending. Kumar et al. (2009) reviews work that developed a prototype of an RFID system with metal oxide sensors on-board the reader for monitoring the ripening of apples. The development and application of technology to integrate RFID tags with sensors for monitoring produce quality or the detection of pathogens offer great potential for packaging and safe horticultural supply chains. However as with all technology, its application must be economic for commercial application.

Food fraud is becoming a very important issue in the marketing of cherries in export markets. It is estimated that food fraud costs the global food industry over $15 billion annually and the cost is rapidly rising. Being able to ascertain the origin of cherries and their attributes from the orchard through the packingline to retail and food service, and into the home is growing in importance. In addition, public health concerns are demanding traceability. While the use of unique packaging and QR codes are excellent options to minimise counterfeiting of cherries (Figure 53), unfortunately fraud can still continue to occur and jeopardises cherry exports, particularly to China (Hawthorne and Lynch, 2015). In addition, consumers are becoming increasingly aware of food fraud and while there are continual improvements in packaging technologies which are helping to combat fraud, the measures to overcome fraud must be economic. Although cherries are a relatively high value crop, the cost to securely identify and prevent fraud and tampering must be kept to a minimum.

Figure 53. Mechanisms to prevent counterfeit cherry fruit; (1) specialist high quality box stickers and cartons, (2) unique printed plastic liners and (3) single QR codes to verify the authenticity of the cherries.
(Photo from Reid Fruits, Tasmania - with permission)

An option of labelling the fruit with non-visible, safe technology is becoming available with DNATrax® technology. SafeTraces® is a company that manufactures biological tracers which are invisible, edible, odourless, and tasteless barcodes for food producers to directly can apply directly to their food, including horticultural produce (Figure 54). SafeTraces® is based on DNATrax® technology which is itself based on food-based FDA-approved sugars, and a unique non-biological DNA tag (Zografos and Farquar, 2015). Food processors and other people in the supply chain can spray SafeTraces® DNA tag on fruit so that their provenance and qualities can be traced and verified throughout the supply chain. The DNA bar code has 64 bits of information identifying a grower or any information required such as orchard, harvest date, packing time etc. The micro particle can be sprayed directly onto the product or mixed with a coating and will adhere to the fruit. The markers can then be read with specific barcode readers, providing a traceability tool. So far the technology is being used by a handful of food and farming customers across varying industries from apples to chocolate (Safetraces, 2018). The invisible tagging system makes the tags themselves virtually tamper-proof and the tags can serve as verification for various qualities like geographical provenance, organic status, sustainable sourcing, or varietal. SafeTracers (2018) report that the cost of their technology starts at about USD $2 per tonne which seems acceptable, however issues with market acceptability and regulatory approval need to be resolved. However the US FDA has affirmed the technology as generally regard as safe (SafeTraces, 2018).

Figure 54. SafeTraces® application on horticultural produce.
(Photos from SafeTraces® www.safetraces.com Accessed 5 January 2018)

Bio-based films

Most current plastics used in packaging are sourced from petroleum sources and concerns for about their production, disposal and recycling are leading to the development and use of alternatives such as bio-based polymers. Indeed the UK is planning to eliminate all avoidable plastic waste by 2042, where plastics such as carrier bags and food packaging will be eliminated. The European Commission has proposed that by 2025 at least 55 per cent of all plastic packaging should be recycled. This regulatory drive has led to increased interest in non-petroleum plastics. Bio-based polymers are plastics derived from renewable biomass sources and can be composed of starches, cellulose, biopolymers and a variety of other materials. Although bio-based polymers currently share less than 1% of the total market, interest in their development and application is growing. It is expected that by 2020 the share of bio-based and biodegradable plastics will increase to 2.5% of fossil plastics production (van den Oever et al., 2017).

The first generation of bio-based polymers had focused on deriving polymers from agricultural feedstocks such as corn, potatoes, and other carbohydrate feedstocks. However, the focus has shifted in recent years due to a desire to move away from food-based resources and significant breakthroughs in biotechnology. Bio-based polymers similar to conventional polymers are produced by bacterial fermentation processes by synthesising the building blocks (monomers) from renewable resources, including lignocellulosic biomass (starch and cellulose), fatty acids, and organic waste (Babu et al., 2013).

There are many different biobased polymers on the market including; starch, cellulose, polylactic acid, and polyhydroxyalkanoates (PHAs) and bio-polyethylene.

• Starch is a natural carbohydrate based polymer that is abundantly available in nature from various sources including wheat, rice, corn and potato. It is used in a wide range of applications such as in plasticised starch blends and thermoplastic starch polymers.

• Cellulose biopolymers are mainly cellulose esters (including cellulose acetate and nitrocellulose) and their derivatives which are generally derived from cotton fibres and wood.

• Polylactic acid is widely used in many day-to-day applications and is becoming a growing alternative as a green packaging materials as it can performs better than synthetic films.

• Polyhydroxyalkanoates (PHAs) are a family of polyesters produced by bacterial fermentation with the potential to replace conventional hydrocarbon-based polymers. PHAs occur naturally in a variety of organisms, but microorganisms can be employed to tailor their production in cells. Until now, the PHA polymer was a very expensive as it was commercially available in very limited quantities.

• Bio-polyethylene (also known as renewable polyethylene) is polyethylene made out of ethanol, which becomes ethylene after a dehydration process. It can be made from various plant sources such as sugar cane, sugar beet and wheat grain. Bio-derived polyethylene is chemically and physically identical to traditional polyethylene, and as with traditional polyethylene it is not biodegradable but can be recycled.

There are a range of other bio-based natural polymers such as chitin, and various polysaccharides and proteins. These materials and their derivatives offer a wide range of properties and application and are discussed by Babu et al. (2013) and van den Oever et al. (2017).

Availability and costs

For most of the bio-based and biodegradable plastics there are several suppliers and most plastics are readily available. In general, bio-based and biodegradable plastics are more expensive than fossil-based plastics on a weight basis (van den Oever et al., 2017). However, specific material properties can allow costs reductions in the use or end-of-life phase. There are several examples of bio-based and/or biodegradable plastic products being cost competitive already today. Further, the price of fossil-based plastics is depending on oil prices and fluctuates with oil prices while in general the prices of bio-based plastics depend on biomass prices that are more stable. When the economy-of-scale of production, conversion into products and logistics becomes more favourable it is expected that the prices of bio-based plastics will come down (van den Oever et al., 2017).

Environmental considerations of packaging

Sustainable packaging is the development and use of packaging which results in improved sustainability and it not just focused on recycling. Whilst recycling is an integral part of sustainability, additional approaches are needed. This includes the increased use of life cycle inventory and life cycle assessment to help guide the use of packaging which reduces the environmental impact and ecological footprint. This approach looks at the whole of the supply chain: from basic function, to marketing, and then through to end of life and rebirth (Álvarez-Chávez et al., 2012). As mentioned previously, the use of returnable plastic crates have significant environmental benefits as compared to single use boxes or cartons and these are becoming more widely used. While the use of bioplastics, recycling and biodegradable plastics are improving the sustainability of packaging, some studies have concluded that none of bio-based plastics currently in commercial use or under development are fully sustainable (Álvarez-Chávez et al., 2012). However there is considerable scope to improve the global packaging industry. The sustainability of packaging in the Australian horticultural industries, including the cherry industry will be coming under greater focus with growing consumer and regulatory attention. Horticulture should to be proactive in addressing and managing these issues.

Alternative decay control

Postharvest decay during storage and marketing is a major loss of quality. Postharvest pathogens are currently controlled with the use of synthetic pre- and postharvest fungicides, but there is a growing consumer and regulatory resistance to their continued use. Alternatives to the use of synthetic fungicides are needed for postharvest applications. Compared to synthetic fungicides, alternative methods might also have the benefits of lower risk of the development of fungal resistance, lower cost, and application close to the harvest. Moreover, they have the potential to reduce the impact of agriculture on the environment and on human health. Several options are research areas are discussed:

Biocontrol options

Biological control (or biocontrol) has been extensively studied in the last 30 years to maintain fruit quality where use microbial antagonists (either existing microorganisms on the produce itself, or from other sources) to control postharvest decay (Lima et al., 2015; Sharma et al., 2009). Many studies showed promising results of using antagonists to control pathogenic decay in a range of horticultural crops (Jamalizadeh et al., 2011; Lima et al., 2015; Sharma et al., 2009). Microbial antagonists work through various modes of actions, including competition, antibiosis, parasitism, induced resistance in the host tissue, and production of volatile metabolites. The details of action mechanisms, traits of desirable microbial antagonists, and the use of microbial antagonists have been reviewed (Jamalizadeh et al., 2011; Sharma et al., 2009). To be effective, antagonists need to be introduced onto the surface or the wound sites of the fruits before the arrival of pathogens, so that they can compete for nutrients and niche exclusion.

The use of yeast antagonists to control diseases and decay from these pathogens has been examined before and after harvest on cherries, where several antagonists were reported to be effective (Oro et al., 2014; Tian et al., 2004). For example the application of the biological control agents, *Aureobasidium pullulans* and *Epicoccum purpurascens* to cherry blossoms reduced the number of latent infections by *M. laxa* in immature fruits (Wittig et al. 1997). Whilst Ippolito et al. (2005) showed that application of *A. pullulans* and salts applied alone and in combination, one week before harvest, were as effective as the fungicide tebuconazole in controlling postharvest rots in cherry fruit.

Enhancement of the efficacies of yeast antagonists can be achieved when used in combination with cold storage and/or other postharvest treatments, such as antimicrobial compounds (sodium bicarbonate, potassium sorbate, salicylic acid, and ammonium molybdate) and controlled atmosphere storage (Karabulut et al., 2001; Tian et al., 2004). For example, Ippolito et al. (2005) showed *Aureobasidium pullulans* in combination with calcium chloride or sodium bicarbonate was found to be effective against postharvest pathogens on cherries. In addition, Delgado-Adámez et al. (2017) showed the combination of microbial antagonists (*Hanseniaspora uvarum*, *Cryptococcus laurentii* and *Pichia guillermondii*) and sodium bicarbonate were capable of reducing the percentage of infected wounds of the main postharvest pathogens (*M. laxa, A. niger* and *B. cinerea*) on cherries at 25°C. However the addition of controlled atmosphere storage does not always give positive effects on the survival and persistence of biological control agents where their growth might be suppressed under low O_2 and high CO_2 storage (Qin et al., 2004). Furthermore, research has also suggested that induction of defense response against pathogen-induced oxidative stress may be the main mechanism of the yeast antagonists (Xu and Tian, 2008).

Commercial considerations. It is important to recognize the handling and processing of cherry fruit when applying these alternative treatments. As cherries are precooled by hydrocoolers it is important to show these treatments can be commercially applied and are effective. Karabulut et al. (2005) showed postharvest diseases of cherries can be controlled by drenching the fruit with yeast antagonists *M. fructicola* and *K. apiculata* or sodium bicarbonate as stand-alone treatments however combining the yeast antagonists with the sodium bicarbonate did not improve the efficacy of the yeast antagonists and suggest that the yeast antagonists and sodium bicarbonate treatments can be best implemented in the field or in the packinghouse when the fruit are hydrocooled.

Natural compounds

The control of postharvest decay with natural antifungal compounds has been widely studied (Spadoni et al., 2015). Approximately 10,000 secondary plant metabolites have been chemically defined for their antimicrobial activity, but the number of available plant active substances is considered much higher. Natural compounds of plant origin with well documented antimicrobial activity include volatile organic compounds, isothiocyanates, trans-2-hexal, carvacrol, thymol, citral, trans-cinnamaldehyde and essential oils (Spadoni et al., 2015). Postharvest fumigation with carvacrol or thymol was effective in controlling *B. cinerea* and *M. fructicola* on cherries (Tsao and Zhou, 2000). However these volatiles have been reported to cause phytotoxic symptoms and off-flavours in cherries (Tsao and Zhou, 2000). However Zapata et al. (2017) incorporated essential oils into alginate edible films and did not report any phytotoxic effects; indeed treated fruit had better storage life than untreated fruit.

The control of postharvest rots on the sweet cherry by sodium bicarbonate and potassium sorbate has been demonstrated (Ippolito et al., 2005; Karabulut et al., 2001, 2005; Feliziani et al., 2013) with some phytotoxic limits observed in some cultivars (Karabulut et al., 2005; Feliziani et al., 2013). However in these experiments, the salt solutions were not washed off but in commercial practice cherry handling uses water flumes and washing and therefore this should prevent any phytotoxic effects. These compounds have been demonstrated to be effective in controlling rots and are commercially used in other industries, such as citrus. These should be looked at more detail for cherries.

As discussed in the *Edible Films Section* (above), salicylic acid is an endogenous hormone having a key role in various species of plant growth. Positive salicylic acid effects have been reported for control of *P. expansum* in cherry (Xu and Tian, 2008). A stimulation of the antioxidant enzyme activities reported in cherry treated with salicylic acid suggested that the activation of antioxidant defense plays the main role in resistance against *P. expansum* (Xu and Tian, 2008). However, the disease reduction obtained in treated fruit was very low (<15%) and salicylic acid cannot be considered satisfactory and recommended for inclusion in postharvest decay management programs for fruit packing houses.

In addition to direct fungistatic action of natural compounds, many compounds can induce resistance to postharvest pathogens. The chemicals can elicit defense mechanisms in the fruit to increase their resistance to postharvest fungal attack. Feliziani et al. (2013) examined a range of chemicals such as oligosaccharides, benzothiadiazole, chitosan, calcium plus organic acids, and nettle macerate and showed they reduced the growth of major cherry decay causing fungi, *Monilinia laxa*, *Botrytis cinerea* and *Rhizopus stolonifer*. Treatment of cherries three days before harvest or soon after harvest with oligosaccharides, benzothiadiazole, chitosan, calcium plus organic acids, nettle extract, fir extract, laminarin, or potassium bicarbonate reduced brown rot, grey mold, *Rhizopus* rot, *Alternaria* rot, blue mold and green rot of cherries kept for 10 days at 20 $^{\circ}$C, or 14 days at 0.5 $^{\circ}$C. Among these resistance inducers, when applied either preharvest or postharvest, chitosan was one of the most effective in reducing storage decay and its antimicrobial activity *in vitro* and in field trials was comparable to that of the synthetic fungicide fenhexamid (Teldor®). Benzothiadiazole was more effective when applied postharvest than with preharvest spraying, as it was not sufficient to control brown rot (Feliziani et al., 2013). Benzothiadiazole mimics the effects of salicylic acid, which is involved in plant signal transduction systems and is needed to activate the formation of defense compounds, such as polyphenols and pathogenesis-related proteins. As mentioned previously, among alternatives that are currently under investigation to replace the use of synthetic fungicides to control postharvest diseases in fresh produce and to extend their shelf life, chitosan application has shown promising disease control, at both preharvest and postharvest stages (Romanazzi et al., 2017). These resistance inducers could represent good options for organic growers and food companies, or they can complement the use of synthetic fungicides in an integrated disease management strategy. However, further studies on the impact of the treatments with these resistance inducers on the flavour and quality characteristics are needed.

We have assessed different organic compounds such as potassium bicarbonate (Ecocarb®), rhamnolipids and fatty acid soap (Eco-protector®) against the standard fungicide treatment for the control of *Monilinia fructicola* (cause of brown rot) and *Botrytis cinerea* (cause of grey mould) on 'Regina' cherries (unpublished)(Figure 55). In summary the commercial fungicide treatment (fludioxonil) provided the best protection against brown rot and grey mould however some of the other organic treatments were better than the water control. In addition some treatments had detrimental effects on final fruit quality. The use of organic postharvest treatments should be further explored in terms of decay control and fruit quality.

Figure 55. Assessment of postharvest organic treatments to control brown rot and grey mould at NSW DPI.
(Photos - John Golding, NSW Department of Primary Industries)

The use of other natural compounds such as pomegranate extract (Nicosia et al., 2016) have also been shown to be effective in reducing natural rots under semi-commercial conditions on cherry fruit, where *Monilinia laxa* and *B. cinerea* rots were reduced by 61% (cv. 'Bigarreau Moreau') and 96% (cv. 'Giorgia'), respectively. However, the practical application of plant extracts to control postharvest decay represents the early stage of process geared to the development of commercially viable products. There are still major obstacles in large scale use of plant extracts for controlling postharvest pathogens. These include the reduced and inconsistent efficacy as a result of fruit physiology and environment, low residual activity, lack of curative effect and limited range of activity against different fungal pathogens (Bautista-Baños, 2014).

Other potential treatments

Physical treatments. The use of physical treatments to reduce the incidence of postharvest rots includes MA packaging, irradiation, low pressure treatments, energy treatments. These will be briefly reviewed with special reference for the control of postharvest cherry pathogens:

Atmosphere. The role of MA in reducing postharvest decay has previously been described in the *Modified Atmosphere* section, in summary high CO_2 and low O_2 generated within the MA has been shown to reduce the incidence of postharvest decay (Wani et al., 2014). For example, Seradilla et al. (2013) showed that controlled atmospheres with 5% O_2 + 10% CO_2 and 8% O_2 + 10% CO_2 were highly effective to control the growth of mesophilic aerobic bacteria, psychrotrophs, *Pseudomonas* spp., yeasts, and moulds after 15 days of storage, showing, in the case of yeasts and moulds, counts that ranged between < 1 and 1.75 log CFU/g.

Mozetič et al. (2006) reported that exposure of 'Lambert Compact' cherries to the inhibitor of ethylene action, 1-MCP at 360 nL L^{-1} significantly reduced rot development from 14% in control fruits to 6% in 1-MCP-treated fruit after 12 days of storage at 4 ^{o}C. Li et al. (2016) also reported that exposure of 'Sweetheart' cherries to 1-MCP at concentrations between 0.5 and 2.0 mL L^{-1} reduced decay development by 47–73 % compared with control untreated fruits, however further data was not provided. While exposure to 1-MCP may enhance oxidative stress tolerance and maintains cell membrane integrity during storage of cherry fruits (Sharma et al., 2010; Yang et al., 2011), its commercial outcomes is limited. In limited experiments at NSW DPI, the application of 1-MCP did not significantly benefit the storage of cherries (unpublished data).

Energy treatments. The use of energy treatments such as UV-C irradiation and cold plasma show some promise in controlling postharvest decay and improve food safety.

Ultraviolet light has mainly been used for surface disinfestation due to its direct effect on the pathogens because of DNA damage and it can also induce resistance mechanisms in different fruits against pathogens (Nigro et al., 1998). Treatment with UV-C irradiation (180 -280 nm) has been shown to be effective in reducing pathogen growth in many fruits (Guerrero-Beltrán and Barbosa-Cánovas, 2004) but Marquenie et al. (2002) showed there was no effect on the incidence of rot in cherry fruit exposed to 10 kJm^{-2} UV-C followed by storage at 12 °C for 10 days. However we have recently shown that UV-C treatment at five different intensities (0, 2.1, 9.7, 25.3, 50.8 kJm^{-2}) on 'Sweetheart' and 'Lapin' cherries significantly reduced the development of rots in both cultivars were stored at 20 °C for 9 days, but this effect was not obvious for longer storage periods at low temperature (Figure 56) (Pristijono et al., 2018c). This treatment shows some potential and could possibly be incorporated into current handling systems (Figure 56).

Figure 56. Prototype custom made semi-commercial in-line UV-C treatment at NSW DPI, Ourimbah (left). Results of treatment of 'Sweetheart' cherry fruit with UV-C light stored at 20 ^{o}C – untreated control (middle) and 50.8 kJm^{-2} UV-C treatment (right) (*from Pristijono et al., 2018c). (Photos – Penta Pristijono University of Newcastle)*

Cold plasma. Cold plasma is an ionised gas containing reactive oxidising species and UV radiation which have strong biocidal properties against a broad range of microbes such as bacteria, fungi, yeast and viruses (Niemira, 2012). Short-time exposure to the cold plasma can effectively kill, inactivate or reduce human and plant pathogens, and even insect-pests on horticultural produce (Niemira, 2012). Unlike other treatments, effective treatment times are short varying from a few seconds to minutes. Cold plasma has gained significant attention and interest because of their strong antimicrobial effects at relatively low gas temperatures. Hort Innovation and NSW Department of Primary Industries have co-invested in a new research project to examine the potential of cold plasma for Australian horticulture (HN15000). There may be potential for the application of cold plasma to kill postharvest decay and human pathogens, such as *E. Coli*, on the surface of cherries in the sorting and packingline. Cold plasma may also find a place as a technology in sanitation.

Low dose irradiation. The use of low dose gamma or X-ray irradiation (< 1,000 Gy) can be used as a market access treatment for some export markets, such as Indonesia, for the management of quarantine insect pests, such as Queensland fruit fly. Irradiation treatment has also been shown to help prolong the shelf life of cherries by inhibiting the growth of fungi and delaying senescence (Wilkinson and Gould, 1998). However higher doses of irradiation (> 2,000 Gy) are generally required to control postharvest decay. Recent unpublished fruit quality work with different low dose irradiation treatments (up to 800 Gy) at NSW DPI has shown no beneficial effect on postharvest decay development in 'Lapin' cherry fruit during storage and shelf life at 20 ^{o}C (Golding, 2017).

Low pressure treatment. Low pressure storage technology has been around for many years but it has recently re- emerged as a technique which can rapidly remove the heat, reduce the oxygen level and rapidly remove and manage the storage atmosphere (Wang et al., 2001). While low pressure treatments have been shown to delay the ripening of many fruits (Burg and Burg, 1966), there is little in the literature about the influence of hypobaric treatments on the development of postharvest diseases. In comparing different low pressure treatments, Romanazzi et al. (2001) showed cherries exposed to a low a low pressure atmosphere of (0.50 atmosphere) for 4 hours had the lowest incidence of grey mould, brown rot and total rots. In a recent Hort Innovation project for AusVeg, we recently showed low pressure storage could maintain quality and reduce the level of postharvest rots in zucchini and capsicum fruit (Pristijono et al., 2018a, b). This has been further confirmed *in vitro* and *in vivo* in other fruit (unpublished). Low pressure treatment and storage is becoming more practical with the development of shipping containers (Figure 57).

Figure 57. Experimental low pressure chambers for postharvest storage and disinfestation research at NSW DPI, Ourimbah (left). Commercial low pressure shipping container(right) – VivaFresh^{TM} (USA).

(Photos – John Golding NSW DPI (left) and VivaFresh^{TM} www.vivafresh.net. Accessed 5 February 2018)

Alternative end-point market access treatments

While cold treatment, methyl bromide fumigation and irradiation are accepted market access protocols for the export of Australian cherries, there are a number of trial end-point treatments which have been assessed with cherries.

Fumigants

A range of fumigants such as chloropicrin, dichlorvos, dimethyl disulphide, ethane dinitrile, ethyl formate, ethylene oxide, hydrogen cyanide, methyl bromide, methyl iodide, methyl isothiocyanate, nitric oxide, ozone, phosphine, sulphuryl fluoride etc. have been trialled on fresh fruit and vegetables, with few reports specifically on cherries.

Phosphine Phosphine gas is routinely used for the disinfestation of stored dried-product industries such as grains. The use of pure (99.3%) cylinderised phosphine was developed by BOC Australia under the name, VAPORPH$_3$OS® and is registered for use on cut-flowers. While phosphine has been shown to cause phytotoxic damage to some fruit, Soma et al. (2007b) reported no injury to 'Satonishiki' cherry fruit at phosphine concentrations up to 1,426 ppm for 24 hours at 15 °C.

GRAS or 'Generally Recognised As Safe' compounds are considered safe for use with human food (USFDA 2013) and have been assessed against cherry fruit. These compounds are ideal potential treatments but they generally have low efficacy and penetration into the fruit for treatment against internal pests.

Ethyl formate Ethyl formate is a natural plant volatile that is a GRAS compound that is registered for postharvest fumigation use for the control of surface pests such as mealybugs, thrips and mites. It is registered by many companies including as VAPORMATE® (BOC Gases Limited, Sydney) containing 16.7% ethyl formate in 83.3% carbon dioxide (w/w). A major issue with ethyl formate is that it does not penetrate readily through fruit surfaces to control internal pests such as fruit flies. Golding (2012a) showed that fumigations of 'Sweetheart' cherry fruit infested first instar Queensland fruit fly using 240 or 420 g/m^3 VAPORMATE™ (40 or 70 g ethyl formate /m^3 in CO_2) at 3 °C or 15 °C for 4 hours showed no clear difference between the treatments and controls, although ethyl formate showed increase mortality with short-term assessment with no cold treatment (Golding 2012a).

Ethanol Ethanol vapour treatment is a potential postharvest treatment with the potential to maintain cherry stem condition during storage, but also improve the efficacy of cold disinfestation. Ethanol is a GRAS compound and has shown that to kill quarantine pests on the surface when the larvae are inside the fruit; the effectiveness of the ethanol vapours is significantly reduced. Ethanol vapours were trialled on a range of cherry varieties to reduce the time in cold disinfestation for Queensland fruit fly and maintain cherry stem quality in a previous Horticulture Australia Limited project (CY07011) (Golding, 2008). Ethanol was applied as a vapour via ethanol treated paper pads placed into the top of sealed cherry boxes. Although ethanol treatment did not adversely affect fruit quality, the treatment was not effective in enhancing the mortality of the cold treatment in killing QFF first instar larvae in cherry fruit.

Heat treatments

Heat treatments are used for the disinfestation of tropical and subtropical fruits (Neven 2000). Heat is applied to increase temperature of the host commodity above the thermal limits for pest survival. Heat treatments can be applied as hot water or hot air. Hot air treatments can be applied as a high relative humidity ('vapour heat') or low relative humidity heat treatment (high-temperature forced air). Temperatures applied range from 40 °C to 50 °C for durations from minutes to hours. Heat treatments are usually required to bring core temperature of the largest fruit in the coolest part of the treatment chamber to a specified temperature and hold it there for the required time. Temperature, duration and application method must be precise and uniform to kill pests without damaging the commodity. Armstrong and Mangan (2007) reviewed the use of heat treatment research and commercial heat treatments. However these treatments are not recommended to cherry fruit due their perishable nature which require the fruit to be kept as cool as possible.

Controlled atmosphere treatments

Controlled atmosphere (CA) treatments are an attractive alternative for postharvest insect control in cherries where levels of CO_2 and O_2 are generally moderate around 3 %CO_2 and 2% O_2. CA provides a non-chemical treatment that leaves no residues in the commodity. This treatment avenue is important for timely marketing, as many of the CA treatments have been shown to require only several days for efficacy against target pests. The use of ambient and higher temperature CA treatments is not feasible for cherries as they are perishable with relatively short shelf life. While MA can be effective in killing insects from fresh fruit several issues such as lengthy treatment durations and very low oxygen concentrations are needed to kill insects.

CA is generally used either in combination with low temperature to enable long treatment times without reduction in fruit quality; in combination with high temperatures to reduce treatment times; and/or followed by cold storage to provide an additive mortality effect. However short-term high CO_2 combined with low temperature treatments have potential to be used for control of pests on a range of fruits, including cherry.

High CO_2 treatment High CO_2 treatment has been shown to be an effective alternative or complement to other disinfestations treatments. Alonso et al. (2005) showed that a short term high CO_2 treatment reduced the lethal times in cold storage of Mediterranean fruit fly larvae in citrus. We have also demonstrated that this combination treatment (high CO_2 treatment and cold) at both 0 ^{o}C and 3 ^{o}C the beginning of the cold disinfestation period significantly reduced the time to kill first instar Queensland fruit fly in 'Rons seedling' cherries. The storage trials with these treatments on a range of cultivars, such as 'Lapins',' Rons seedling', 'Stella' and 'Bing' also showed that there were no adverse effects of the high CO_2 treatment on fruit quality across a range of treatment times and cultivars (Golding et al., 2010; Golding et al., 2012). Thus it is possible that a short-term high CO_2 treatment in combination with cold could be used to reduce the time in cold disinfestation without detriment to fruit quality during storage. Indeed in a recent trial for the PBCRC, we showed that high CO_2 combination treatment of a total of 8 days at 3 ^{o}C in 'Sweet Georgia' cherries resulted in 3 survivors in an estimated 76,766 insects, where the percentage mortality was 99.9963% which equated to probit 9 of 8.94. Further refining this treatment may allow an on-shore cold-combination disinfestation treatment before airfreight to export markets.

CATTS A special example of combined treatments is controlled atmosphere: temperature treatment system (CATTS) developed by Neven and Mitcham (1996). CATTS has been successful in reducing the amount of treatment time required to eliminate target insects life stages when compared with either heat treatments or controlled atmospheres alone. This is a great advantage over traditional hot air and hot water dips, because the reduced treatment times help preserve fruit quality. Neven and Drake (2000) compared the effects of controlled atmosphere heat treatments (CATTS), irradiation and fumigation with methyl bromide. They showed that irradiated cherries had overall quality better than methyl bromide-treated cherries. CATTS-treated 'Rainier' cherries, but not 'Bing', had more pitting and bruising after 14 days of storage than fruit from other treatments. Both cultivars treated with methyl bromide had poorer stem quality than controls. CATTS-treated 'Bing' fruits had poorer stem quality after 7 and 14 days of storage than the controls.

Energy treatments

Radio-frequency (RF) and microwave energy are sources of heat that involve application of electromagnetic energy at 10 – 30,000 MHz. Because of the congested bands of radio-frequency and microwaves already being used for communication purposes, regulatory bodies have allocated five frequencies for industrial, scientific and medical applications: 13.56, 27.12, 40.68 MHz on the RF range and 915 and 2,450 MHz in the microwave range.

At some wavelengths being studied, insects can be selectively heated without adversely heating the product (Schneider et al., 2003). Radio frequency energy provides a potential method to rapidly heat cherry fruit and insect larvae, resulting in short heat treatments that may provide insect mortality with less effect on fruit quality. Radio frequency heating involves the direct interaction between RF wavelengths of energy and the dielectric properties of any water based body. As a consequence, there is molecular agitation and this movement generates heat within the fruit and the insects simultaneously. For internal pests such as Queensland fruit fly, radio-frequency has been used in combination with water immersion to obtain uniform temperature increases in both the core and surface of the commodity. Ekman (2005) showed dielectric disinfestation in combination with cold treatment was possible with cherries, but there were high levels of variability with this technology. Monzón et al. (2005) showed with 'Bing' cherry fruit that stem browning and fruit pitting were affected by radio frequency heating. The quality of the cherries following these treatments was only acceptable when fruit were stored for a short period, but this maybe adequate for air shipments (Monzón et al., 2005). Microwave treatments have also been assessed against codling moth disinfestation in 'Bing' cherries (Ikediala et al., 1999). In general, microwave treatments at 45°C and 50 °C appear more promising because they affected fruit quality only slightly. But, microwave treatment at 45 °C had lower insect mortality, and thus may require prolonged holding to achieve desired mortality (Ikediala et al., 1999).

Other treatments

There are a range of other physical treatments such as high pressure, vacuum, metabolic stress disinfestation and disinfection (MSDD), pulsed electrical field, electrical energy (ohmic or joule) heating, infrared and cold plasma but these are beyond the scope of this review.

New Technology

Non-destructive quality assessment use of near infrared spectroscopy (NIR)

Near infrared spectroscopy (NIR) is a spectroscopic method which uses the near infrared region of the electromagnetic spectrum (from about 800 nm to 2,500 nm). In NIR spectroscopy, the fruit is irradiated with NIR radiation, and the reflected or transmitted radiation is measured. While the radiation penetrates the fruit, its spectral characteristics change through wavelength dependent scattering and absorption processes. This change depends on the chemical composition of the product, as well as on its light scattering properties which are related to the microstructure (Nicolai et al., 2007). Advanced multivariate statistical techniques, such as partial least squares regression is then applied to extract the required information from the usually convoluted spectra (Nicolai et al., 2007). This technology is available in the laboratory, in the orchard as a hand-held instrument and on in-line commercial packing lines for sorting fruit. Indeed NIR cameras are used in modern cherry graders such as GP Graders systems electronic AirJet® grader (*See Packing and Sorting Section*).

The development of portable in-field use of NIR spectroscopy to assess fruit SSC accurately and rapidly is now available (Nicolai et al., 2007; Walsh et al., 2007) and has been assessed for cherry fruit (Carlini et al. 2000, Lu, 2001). This technique allows the non-destructive measurement of fruit SSC in the orchard during fruit growth and development, or in the market place. Lu (2001) showed the potential of near–infrared (NIR) reflectance spectroscopy as a means for nondestructive measurement of the firmness and sugar content of cherries. He developed models to predict the sugar content and even showed gave relatively good predictions of the firmness. However this was only on two cultivars (‘Hedelfinger’ and ‘Sam’) in one season.

Toivonen et al. recently developed models with high accuracy of predicting dry matter (with a resolution of 0.5% dry matter content) on three different cherry cultivars (‘Staccato™’, ‘Sentennial™’, and ‘Sovereign™’) which showed dry matter in cherries can be predicted accurately and non-destructively using visible/near-infrared spectroscopy Figure 58). As discussed previously (*see Nutrition Section*), total dry matter content and soluble solids make up 80% of the dry matter content of the fruit. Therefore, dry matter content can be considered to be mostly consisting of sugars but also includes cell wall residues (dietary fiber), acids, and a very small amount of protein. It has been found that while NIR spectroscopy can be used to measure sugars and dry matter at harvest with other fruits such as apples, dry matter measures appear to provide a more consistent prediction of post-storage quality (Palmer et al., 2010; Kumar et al., 2015). While this aspect has yet to be fully assessed in cherries, very preliminary data suggests that very high dry matter is not good for post-storage quality (Peter Toivonen *personal communication*).

Escribano et al. (2017) also showed that NIR could be used to predict SSC and dry matter content of external ‘Chelan’ and ‘Bing’ cherries; R^2 values for SSC ranged from 0.73 to 0.89 and for dry matter content from 0.67 to 0.723 between the predicted and the observed values in the external validation set, respectively. However of more interest, consumer preference evaluation for ‘Bing’ and ‘Chelan’ cherries with differing SSC (16.4 – 28.5 % Brix) and dry matter content (17.7 – 31.6%) showed higher acceptance by consumers for cherries with high dry matter content as well as for cherries with high SSC. Indeed dry matter content was equal to or superior to SSC for predicting flavour intensity and balance of sweet to sour taste as assessed by consumers (Escribano et al., 2017). Considering the revealed importance in sensory evaluation of dry matter content, as well as SSC, in the eating quality of sweet cherry, Escribano et al. (2017) suggests that the use of handheld NIR devices, which are rapid, lightweight and user-friendly should be considered for routine, non-destructive analysis of cherry quality.

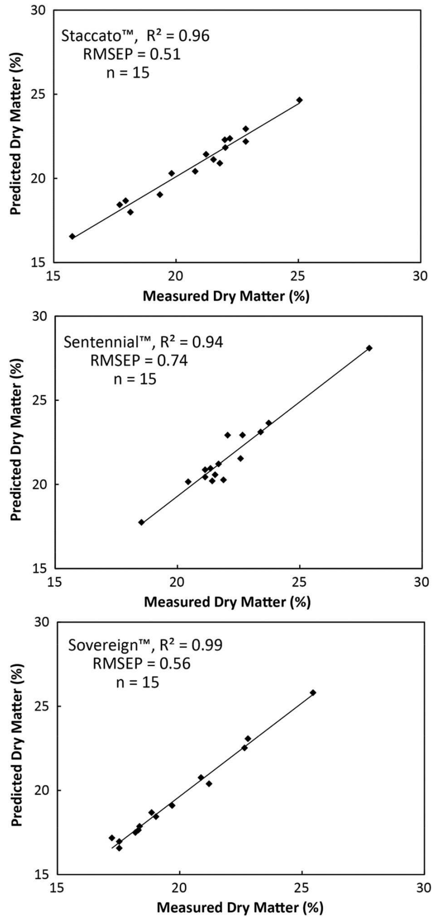


Figure 58. Measured versus predicted values of the dry matter content (%) in Staccato™, Sentennial™, and Sovereign™ sweet cherries using a model developed for 'Lapins'. The high R 2 values for all three cultivars indicates that the prediction value of the model is quite high, and the root mean square error of prediction (RMSEP) provides an indication of the robustness of the model for these cultivars when compared against the root mean square error of cross validation (RMSECV).

Figure from: Toivonen P.M.A, Batista A. and Lannard B. (2017) Development of a predictive model for 'Lapins' sweet cherry dry matter content using a visible/near-infrared spectrometer and its potential application to other cultivars. Canadian Journal of Plant Science 97, 1030-1035.

Nondestructive sensors which use NIR or other spectrometry are becoming user-friendly and cheaper. There are a number of instruments on the market:

- Felix 750 Produce meter is a hand-held NIR instrument which has been used on many cherry fruit maturity and quality studies as described above (Escribano et al., 2017; Toivonen et al, 2017) (www.felixinstruments.com) (Figure 59).
- SCIO is a small pocket sized spectrometer which has been developed with potential for use in the food and horticulture industries (Figure 59). It uses new generation LEDs for the sensor source which makes it more affordable. (Consumer Physics) (https://www.consumerphysics.com).
- DA cherry meter is a handheld device which non-destructively measures the difference of absorbance between 670 and 720 nm (Figure 59). The IAD value correlates with the chlorophyll content in the flesh of the fruit and can be used as maturity indicator of apples or peaches. This is good for fruit where chlorophyll is an indicator of maturity, but less important with cherry fruit. However the DA cherry meter can measure within the fruit and provides an alternative the colour plates for assessing maturity where the cherry flesh continues to darken as the fruit ripens which can't be visually discerned (www.trturoni.com/en/fruit-veg-ripeness-quality-control/da-meter/cherry-meter.7.html).

Nagpala et al. (2017) examined the relationship between the IAD index and some quality traits such as chroma (skin colour intensity), fruit anthocyanin content and SSC in 'Lala Star' cherry fruit and showed some correlation of IAD with fruit colour and anthocyanin (which can also be done with colour charts), but the relationship with SSC was less strong ($r^2 = 0.55$).

Figure 59. Use of Felix 750 hand held NIR instrument for laboratory testing of cherries (top left) and field / orchard (top right), DA cherry meter (bottom left) and SCIO pocket spectrometer (bottom right).
Photos from Peter Toivonen Agriculture and Agri-Food Canada) (top and bottom left); Felix Instruments (top right) (www.felixinstruments.com); and SCIO Consumer Physics (bottom right) (www.consumerphysics.com).

Conclusions

The future success of the Australian cherry industry will be driven by the need to consistently deliver high quality fruit to the consumer. Indeed the Australian Cherry Strategic Investment Plan identified that there is a very high possibility that unless there is an effective intervention of improved quality and consumption, prices on the domestic market will decline further to the point of negative returns for many businesses (Cherry SIP 2017-22). It is therefore essential to take advantage of the growing demand for cherries in nearby export markets by consistently delivering high quality cherries.

This review identified the key pre- and postharvest management practices to consistently deliver high quality fruit to the consumer. Preharvest factors determine the quality of harvested fruit. It is critical to optimise fruit quality at harvest with genetics and orchard management to improve fruit size, firmness and taste. While many of these management factors (such as calcium and GA sprays) are regularly conducted by growers, there is little information on their actual benefit on final postharvest quality, storage behaviour and consumer acceptability.

Postharvest handling and storage are critical components of maintaining and delivering high quality cherry fruit to the consumer. It is critical that cherry fruit are carefully harvested and handled. Cherry fruit are relatively delicate where pitting and bruising damage can easily occur during handling and packing. These disorders are insidious as they do not immediately appear during handling but are expressed during storage in the supply chain. It is critical that growers and packers continually manage their packing operations to prevent these disorders. In addition, the control of postharvest decay needs to be actively managed. While the current use of postharvest fungicides are widely used and effective, there is a need to work towards low MRL or alternative treatments to manage postharvest decay. This will provide a marketing advantage of Australian cherries in export markets. In addition the effective management of stem freshness, i.e. maintaining the green colour of the stem is critical to maintain overall fruit acceptability and consumer acceptability. While cosmetic in appearance, stem condition is critical and green fresh looking stems need to be maintained from harvest through to the consumer.

The most important aspect of cherry postharvest management is the cool chain. Cherry fruit are very perishable and storage or handling at higher than recommended temperatures reduces quality and storage life. It is essential to maintain correct handling and storage temperatures from the orchard to the consumer. While the cool chain can be directly managed on farm and in the cool room, it is essential to work with the entire supply chain, including trucking companies and the retailers, to maintain the cool chain and fruit quality through to the consumer. This requires a collaborative approach. It is in everyone's best interest to consistently present high quality safe fruit to the consumer. However there maybe opportunities to provide more education and targeted interventions which will improve cool chain practices through the supply chain.

The increased competition from other southern hemisphere competitors such as Chile, into important exports markets, reinforce the need to improve fruit quality and market differentiation. Cherries are a fruit with high growing, harvesting and packing costs. It is critical that the Australian cherries transition as a premium product with higher quality, larger fruit with better flavour and nutrition. To capitalise on improved quality, it is essential that the postharvest handling and presentation of fruit to the consumer is improved. If Australian cherries are premium quality, then consumers must feel justified in paying premium prices and this can be justified with premium packaging. Packaging is an important part of protecting the cherry fruit against damage, reducing waste, maintaining food safety, marketing and product differentiation. High quality packaging of premium fruit can justify premium returns to the grower and packer. As production and handling costs rise, improved packaging and marketing can assist justify the increased returns to growers. The future success of the Australian cherry industry will depend on the application of international best practice for the management of cherries both for the domestic and export markets. While there are numerous innovations and developments in postharvest technologies and packaging, the ultimate use of any technology or packaging is the one which provides optimum performance at the lowest economic and environmental cost.

Recommendations

Summary of recommendations on key technologies / research themes for future investments in postharvest R&D:

1. **Implement postharvest best practice and skills development**
   - Develop and implement postharvest best practice (including food safety)
   - Improve postharvest skills and practice for Australian cherry industry

2. **Postharvest innovations to support export market development**
   - Develop predictive models to deliver high quality fruit to export markets
   - R&D to support pre- and postharvest recommendations of key export varieties
   - Export simulations to evaluate innovations in postharvest treatments and packaging

3. **Improving the delivery and safety of high quality fruit for domestic consumers**
   - Improving domestic cold chain
   - Selection and tailoring packaging design and materials to optimize final product quality and reduce waste

1. Implement postharvest best practice and skills development

Develop and implement postharvest best practice

A key recommendation is to develop postharvest best practice guide based on the outcomes and key findings of this review. This could be in the form of a separate postharvest best practice guide, or integrated into current production guides such as 'Australian Cherry Production Guide' or the 'Cherry Export Manual'. It is critical that best practice food safety practices and monitoring program are integrated into this guide. Food safety is a non-negotiable attribute for the Australian cherry industry. While Australia currently enjoys a good reputation of delivering safe healthy cherries with good practices and QA systems, it is critical to remain pro-active and instill best food safety monitoring and best practice into industry. As part of the delivery of the postharvest best practice it is essential that this is supported with development and extension of training resources package to supplement the guide. A key component of the uptake and implementation is the demonstration of the key practices to growers and packers. This should be delivered through a series of national and regional postharvest workshops on current postharvest topics and issues. Topics for workshops should include; the management of the cool chain, effective use of sanitisers and fungicides, postharvest handling to prevent pitting and bruising, packaging technology etc.

Improve postharvest skills and practice

The current level of postharvest knowledge within the industry is variable, while many growers are very good packers and exporters, some other growers have limited knowledge and skills. To build upon the best practice, it is critically important to improve the postharvest knowledge and skills within the industry and to give the technical innovation skills to growers / packers required to continually develop their own best practice. It is recommended to develop and deliver a pilot two day intensive Master class in the fundamentals and applied aspects of cherry postharvest science and technology (e.g. sanitiser and fungicide use, supply chain and temperature management etc.). The aim will be to improve the postharvest knowledge of key operators within the packinghouse and supply chain (such as QA managers) to ensure optimal practices are adopted and maintained. This course could align with a unit of competency AHCPT303 'Implement a Post-harvest Program' and contribute to a nationally recognised qualification in production horticulture.

2. Postharvest innovations to support export market development

Develop predictive models to deliver high quality fruit to export consumers

Industry needs to focus on the final fruit quality eaten by consumer, rather than the initial quality put into the box. While growers and exporters have a good idea on which cultivars are suitable for export, beyond cultivar there is little information on the numerous pre and postharvest parameters which combine to affect final product quality. As a starting point, research is required to work toward a practical and functional matrix of fruit quality parameters (e.g. firmness, TSS, TA, colour etc.) that predict the storage potential and eating quality on key export markets. Due to the long shipping times, Chile has been working in this area several years where it has developed a working model to predict storage potential for their cultivars and growing conditions. The model also has correction factors in term of decay, size distribution, crop load, and colour. While there are a lot of unknowns in this area (such as seasonal differences, preharvest factors affecting storage life etc.), the development of Australian fruit quality export models needs to be developed and applied.

R&D to support pre and postharvest recommendations of key export cultivars

Specific recommendations, rather than general postharvest practices for specific cultivars will refine and optimize postharvest management and final fruit quality for important cultivars. The review identified specific differences between major export cherry cultivars in their behaviour to postharvest handling and storage. Key research and development in pre-harvest, postharvest maturity, storage behaviour and consumer acceptability to deliver high quality fruit from key export cultivars need to be completed. This should also include re-examination current treatments on final consumer quality, rather than harvest quality only. Consumer focused research is also required to identify the drivers of consumer preferences different export markets, particularly in Asia. This research will also deliver insights into current export programs and drive pre and postharvest changes to meet these consumer preferences.

Export simulations to evaluate innovations in postharvest treatments and packaging

New approaches to delivering high quality safe cherries to export market should be conducted with extensive assessments in simulated export conditions. Innovations identified in the review such as innovative preharvest treatments such as chitosan, alternate low chemical decay control technologies, smart eco-friendly packaging, and new technologies such as NIR which may have predictive role in consumer preferences. These technologies are at different levels of commercial application, but applied local R&D in Australia would assess their potential for adoption. The research must include export simulation trials and full quality and economic analysis.

3. Improving fruit quality to domestic consumers

Improving the domestic cold chain

The current cherry cold chain on the domestic market needs improvement. It is essential that the entire supply chain from the grower, trucking company, wholesaler, retailer work together to maintain the quality of cherry fruit to the consumer. The first recommendation is to develop practical guides (information packages) for all stakeholders in the supply chain to maintain and monitor optimal temperatures and handling, and ensure that these recommendations are implemented to ensure the cold chain to maintain fruit quality. This should also include the assessment and implementation of new real-time technologies such as 'Sendum™' to monitor cold chain would improve confidence in the current cold chain.

The review also noted a particular impediment to the fruit quality presented at the retail level. It is recommended that the industry work with the major retailers (particularly category managers) to improve quality and retail displays of Australian cherries. Poor retail displays in the retail market, slow fruit sales which further deteriorates fruit quality. The second recommendation for this section is the development of a practical information package for cherry retailing best practice for retail store workers which can be delivered as part of their internal training at the start of the cherry season. It will be important to work with the category managers to ensure the fruit are maintained at optimal quality through to purchase.

Selection and tailoring packaging design and materials to optimize final product quality and reduce waste

In line with global and domestic trends in packaging and consumer expectations, industry must invest in smart eco-friendly packaging to deliver high quality fruit through the domestic supply chain and at the same time reduce waste. As production and handling costs rise, improved packaging and marketing can reduce waste and assist justify the increased returns to growers. It is recommended to evaluate new materials and designs and potential of eco-friendly edible coatings which maintain fruit quality through the supply chain and to reduce the levels of waste. Of particular importance is the need to assess and identify retail and packaging innovations in short term unrefrigerated displays. This type of display is a reality in the commercial retailing of Australian cherries, and packaging solutions need to be developed and optimised to maintain quality in these short-term non-ideal retail environments.

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