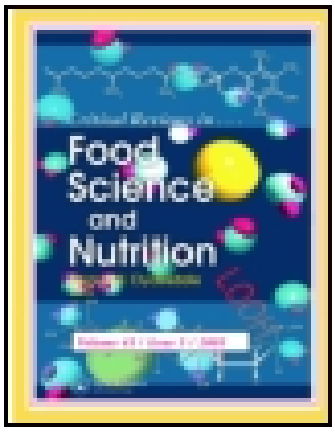

Critical Reviews in Food Science and Nutrition
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/bfsn20

Sweet Cherries from Farm to Table: A Review

Muzammil Habib[a], Mudassir Bhat[a], B. N. Dar[a] & Ali Abas Wani[a]
[a] Department of Food Technology, Islamic University of Science and Technology, Awantipora, Kashmir. J&K 192121

Accepted author version posted online: 26 Jun 2015.

To cite this article: Muzammil Habib, Mudassir Bhat, B. N. Dar & Ali Abas Wani (2015): Sweet Cherries from Farm to Table: A Review, Critical Reviews in Food Science and Nutrition, DOI: 10.1080/10408398.2015.1005831

To link to this article: http://dx.doi.org/10.1080/10408398.2015.1005831

Sweet Cherries from Farm to Table: A Review

Muzammil Habib, Mudassir Bhat, B. N. Dar and Ali Abas Wani.

Department of Food Technology, Islamic University of Science and Technology, Awantipora, Kashmir. J&K 192121

Abstract

In order to enable long-distance transportation and ensure that the fruit presents the requisite quality on arrival at markets, the cherry industry for direct consumption needs to prolong post-harvest shelf life. Sweet cherries are highly perishable, non-climacteric fruits with shelf life of 7-14 days in cold storage. Their shelf life is shortened by loss of firmness, colour and flavour, stem discoloration, desiccation and mould growth. Various factors such as harvest time, proper handling and cooling practices and above all packaging, greatly influence the shelf life of cherries. One of the areas of research that has shown promise, and had success, is modified atmosphere packaging (MAP). It is one of the fastest growing packaging technologies and has many advantages for different food products. Properly designed modified atmosphere packs can be exploited to lower respiration rates and thus ripening of fruits which results in least changes in physiochemical parameters of sweet cherries during postharvest storage. This article intended to review a broad spectrum of studies dealt with the use of MAP for preservation of sweet cherries cultivars with an interest for future research work.

Keywords: Sweet cherries, modified atmosphere packaging, firmness, colour, shelf life, storage

Correspondence author:

B. N. Dar (Asst. Prof.),

Department of Food Technology,

Islamic University of Science and Technology, Awantipora, Kashmir. J&K 192121.

1. Introduction

Cherries are members of the *Rosaceae* family and *Prunoideae* subfamily. They occupy the Cerasus subgenus within *Prunus*, being fairly distinct from their stone fruit relatives; plums, apricots, peaches and almonds. There are so many species of cherry grown throughout the world like sweet cherry (*Prunus avium*), sour, pie or tart cherry (*Prunus cerasus*), black cherry (*Prunus serotina*), West Indian cherry (*Prunus myrtifolia*) and so on (Anonymous, 2013). Cherries are cultivated mainly between 35°N and 55°S latitudes where temperature and other factors are favourable for their growth (Chadha, 2006). Cherries are harvested from June to mid-July for their optimal taste and appearance (Vursavus et al., 2006). The main characteristics for cherry quality are colour, sweetness, sourness, firmness and wealth of nutrients (Esti et al., 2002).The composition of Sweet cherry depends on cultivar, climate and maturity stage (Mozetic et al, 2006).

The total soluble solids (TSS) of Cherry ranges from 11-20 °Brix and the acidity from 0.4-1.5% (Serrano et al., 2005). The sugars in cherry fruit range from 125-265 g/kg fresh weight and organic acids range from 3.67-8.66 g/kg fresh weight (Valentina et al., 2008). Sweet cherries have been found to be a good source of polyphenols with approximately 1500 mg/kg of fresh weight, in which 60-74% of the phenols by weight consist mainly of hydroxycinnamates (Usenik et al., 2008; Jakobek et al., 2007), anthocyanins, flavan-3-ols (catechins) and flavanols (Goncalves et al., 2004). Anthocyanins, which are responsible for the colour of cherries ranges from few mg/100 g in light-coloured to about 700 mg/100 g in dark cherries (Wang et al., 1997). The major anthocyanins present in dark-coloured cherries are Cyanidin 3-rutinoside (4-44 mg/100 g) and cyanidine 3-glucoside (2-243 mg/100 g). Amongst the hydroxycinnamates,

neochlorogenic acid and p-coumarylquinic acid have been found to be in good quantity (Kim et al., 2005) while as small amounts of chlorogenic acid and ferulic acid have also been found. (Matilla et al., 2006). Hydroxybenzoic acids are found in sweet cherries only in small amounts (Matilla et al., 2006).

Cherries are known for various health benefits, especially in aiding the weight loss campaign. The consumption of cherries (containing phenolic antioxidants) have been found to reduce the risk of cancer (Kang et al., 2003), pain from arthritis and inflammation (Jacob et al., 2003; Seeram et al., 2002; Mamani-Matsuda et al., 2006; Garcia-Closas et al., 1999; Kroon and Williamson, 1999), symptoms of exercise induced muscle damage (Connolly et al., 2006), oxidative stress in older people (Traustadtir et al., 2009), and offer protection against neurodegenerative diseases (Kim et al., 2005; Usenik et al., 2008). Moreover, cherry contains perillyl alcohol (Kris-Etherton et al., 2002), a hydroxylated monocyclic monoterpene, efficient against the formation and progression of a variety of cancers (James et al., 1998).

Sweet cherries are extremely difficult to handle after harvest and are highly perishable (shelf life of 7-14 days) (Padilla-Zakour et al., 2007) mainly due to little stored carbohydrate (starch) and are very susceptible to bruising which leads to softening, changes in the sugar-acid balance, desiccation and browning of the stem (Alique et al., 2005; Bernalte et al., 2003; Petracek et al., 2002). Sweet cherry is characterized by high transpiration rate, susceptibility to fungal rots and vulnerability to physiological disorders such as pitting and bruising, all of which limit their market life (Alique et al., 2005). Other physiological and biochemical processes in the fruit, like loss of cell compartment and acid degradation are more crucial than anthocyanin content for colour changes of cherries (Bernalte et al., 2003; Esti et al., 2001; Zhang et al., 2000).

Number of technologies has been developed for extending the shelf life of sweet cherries like to design and optimise processing, storage, and transport conditions and methodologies (Remon et al., 2003). However, there is an increased awareness among consumers that many of the chemical treatments applied to fruits are potentially harmful to humans and irradiation application is quite limited for the same reason. For sweet cherries, cold storage appeared to be a reliable way to stop fruit deterioration (Bernalte et al., 2003). In addition, the use of modified atmosphere packaging (MAP) has been reported to be effective in delaying the physico-chemical changes related to quality loss (Tian et al., 2004; Spotts et al., 2002; Petracek et al., 2002; Remón et al., 2000).

2. Production

Sweet cherries, grown in temperate climate are commercially cultivated in more than 40 countries worldwide. The production has rapidly increased due to high consumer demands resulting in increased cultivation throughout the world. The leading sweet cherry producing countries are Turkey, US, Iran, Italy, Spain and Austria (FAO 2011). The world's sweet cherry production was estimated to be 2.185.881 metric tons in 2009 and Global cherry production in 2011/12 is forecast at 1.9 million metric tons (MMT), down 7 percent from last year as Turkey's output plunges 40 percent. Cold and excessively wet spring weather conditions in Turkey hindered the bloom, pollination, and growth (USDA FAS 2011). World production of cherries has been estimated 2005095 Metric Tons (FAO 2011). The causes of this decline would be the conditions of humidity and cold that affected the U.S. production and of the 27 countries of the European Union, causing problems for pollination, flowering and growth (Braga, 2010) .Turkey is the largest sweet cherry producer in the world contributing 310,254 tonnes to the world

production (Kalyoncu et al., 2009). In Turkey, approximately 12,800 tons of cornelian cherries are produced per annum. Sweet cherries are grown almost everywhere in Europe which contributes about 40% to the total cherry production (Kallayne, 2003). The major commercial cherry orchards in Europe extend from the Iberian Peninsula east to Anatolia, and to a smaller extent are also grown in the Baltic States and southern Scandinavia. Portugal produces more than 15,000 tons of cherries per year (Serra et al., 2010) and it is in the northeast of the country, namely “Beira Interior”, where this fruit is more cultivated. The sweet cherry production in US has been estimated around 315,400 tons in the year 2010 (National Agricultural Statistics Service, 2010) which is about 27% less than 2009 cherry production. Washington produces about 40% of the USA’s sweet cherries and ranks first in the nation for sweet cherry production. The Lambert variety is also grown on the eastern side of the Pacific. Northwest which produces 87% of the sweet cherries in the U.S., and exports approximately 30% of its crop to Japan? Michigan sweet cherry production in 2009 was 28,700 tons (Michigan Farm Bureau, 2010). Australia is also famous for the production of sweet cherry varieties like "Montmorency", "Morello", "North Star", "Early Richmond", "Titans", and "Lamberts". South Australia produces over 860 tonnes of fresh cherries annually, about 9% of Australia's cherry production. The main cherry varieties grown in South Australia are Stella and Lapin. The main production areas for cherries in South Australia include: the Adelaide Hills (Cherryville, Summertown, Uraidla, Lenswood, Forest Range, Gumeracha), the Riverland (Renmark, Barmera) and the Limestone Coast (Glencoe, Mt Gambier, Mingbool). India produces all deciduous fruits including pome fruits (apple and pear) and stone fruits (peach, plum, apricot and cherry) in considerable quantity. The sweet cherry cultivars grown in different states of India include Bigarreau Napoleon, Black

Heart, Guigne Noir for Jammu & Kashmir and cultivars like Black Tartarian Bing, Napoleon (white) Sam, Sue (White), Shella for Himachal Pradesh. For warmer climate, cultivars like Summit, Sunburst, Lapins, Compacat and Stella have also been found. The cherry output produced in Himachal Pradesh in 2007-08 was 698 tonnes and was around 900 tonnes in the year 2010 (Indian Society of Agribusiness Professionals, 2010, The Indian Express 2010).

3. Shelf Life

Fresh produce continue to actively metabolize during postharvest phases. During the movement of fresh products to market, wholesalers and retailers frequently do not have enough facilities set to the optimum conditions for each commodity. Inventory management and marketing largely determines how a product will be handled. Fresh produce probably receive the greatest temperature abuse at the retail level. Consequently temperature management is critical. Rapid decrease in temperature and close temperature control are required if fruit is to be shipped to distant markets. Several factors affecting the shelf life are:

3.1 Type/variety

Despite the efforts of agricultural production, classification and packaging, one of the main problems in cherry production is the uncontrollable effect of the natural product variability. Selection of cultivars with the quality attributes required and optimum maturity should be attempted to produce high quality products. Cultivar selection is a major factor in quality as the genetic make-up of the plant determines the structural and chemical features of the product (Powrie and Skura, 1991). Increasing the plant density may lead to reduction in fruit size and quality, especially TSS, indicating a progressive competition between trees (Eccher and Granelli, 2006). For a specific cultivar, the fruit to leaf area ratio of the current season is the most

important factor affecting fruit weight (Flore and Layne, 1999; Proebsting, 1990). In another observation by Kappel et al. (1996), cultivars should be carefully chosen, especially with regard to fruit size. Irrigation and nutrition should be balanced according to demands to avoid firmness and TSS reductions (Crisosto et al., 1995).

3.2 Harvest Time

Sweet cherry fruits exhibit important biochemical and morphological changes during maturation, including increase in colour depth and sugar content (Tudela et al., 2005) which are the main indicators of maturity. However, it needs to be taken in account that maturity of fruit varies within and between tress. Fruit colour and TSS levels decrease with delay in flower anthesis and fruit location progressing from the top to the base of plant (Patten et al., 1986). Cherries harvested before they reach 14% TSS are less acceptable by the consumers. The higher the TSS content, the greater is the perception of quality. A significant quality loss was observed in cherries when harvested one week later (Padilla-Zakour et al., 2007). For efficient mechanical harvesting of sweet cherries, the fruit removal force (the force required to pull the fruit from the stem) must be lower than 300 g. Fruit removal force can be measured by the use of a mechanical force gauge (Ametek, Inc., Hatfield.PA).

3.3 Temperature and Relative Humidity (RH)

The two main external factors affecting sweet cherry during its post harvest conditions are temperature and RH of the environment (Yaman and Bayoindirli, 2006). In many storage studies, temperature is controlled but RH is not. There are practical difficulties in maintaining RH in large storage rooms within a narrow range at high relative humidities. At high RH, a small

fluctuation in temperature (<0.5°C) can result in condensation on cool surfaces. Fibreboard and wood absorbs water and may decrease RH in a room. High RH will not prevent moisture loss if the product temperature is not near the air temperature. The nature of the commodity evaporative surface is determined by commodity type and cultivar and both have a major influence on the rate of evaporation. The optimum temperature for harvest and handling of sweet cherries is 10-20°C, while the optimum storage temperature is 0°C with a RH range of 90-95% (Bernalte et al., 1999). These two factors including the composition of the atmosphere influence the postharvest quality of fruits and also influence the growth of microorganisms present on the fruit. Storage temperature is one of the main factors that affect post-ripening and qualities such as respiration, transpiration, senescence and other physiological actions. In addition, temperature fluctuation during storage is another key factor which can make many kinds of oxidases active and hence speed up the post-ripening of stored sweet cherries (Romano et al., 2006).

3.4 Respiration Rate

Fresh produce are biologically living tissue with biochemical metabolic activity: respiration, senescence, ethylene production, and organ development. While some of these activities are desirable and essential, most of them consume nutrients and energy sources with loss of freshness (Mozetic et al., 2004). Some degree of respiratory activity should be maintained for vitality of the fresh produce, but highly elevated respiration spends up the reserved energy and accelerates the process of senescence resulting in reduced sweetness and freshness. With progression of metabolic processes, fresh produce becomes soft and labile to bacterial and fungal infections in longer storage. Cherries are highly perishable fruits with a respiration rate of 10-20 mg CO_2 /kg/h at 5°C and highly prone to surface pitting that leads to fruit rot during cold storage

(Crisosto et al., 1993). Sweet cherries decay rapidly after harvest as a consequence of their high respiratory rate, which constitutes the main problem for successful transport and marketing (Mozetic et al., 2006). Even different varieties of the same product can exhibit different respiration rates. Care is necessary when packing in MAP due to alterations of respiration rate over time that are not normally considered in MAP design (Golias et al., 2007).

3.5 Storage and Handling

Sweet cherry fruits deteriorate rapidly after harvest with a reduced shelf life and sometimes do not reach the consumer at optimal quality after transport and marketing. The main causes of sweet cherry deterioration are weight loss, colour changes, softening, surface pitting, stem browning and loss of acidity (Bernalte et al., 2003). Fruit is also infected by rain splits or wounds occurring at harvest or during packing (Mattheis, 1998). The main responsible factors for the decay of sweet cherries are the post-harvest rots from several fungi which cause considerable economic losses and thereafter a fermentative metabolism with generation of off-flavours due to ethanol and acetaldehyde (Esti et al., 2002), during storage or transportation. The principal means of reducing transpiration and respiration of sweet cherries and prolonging their shelf life are rapid elimination of field heat and strict temperature control during the storage (Petracek et al., 2002). The characteristic most often associated with storability of sweet cherries is flesh firmness. However, recent studies have shown that firmness is not always directly related to shelf life (Long, 2007). A number of diseases, insects, animal pests and environmental conditions cause heavy sweet cherry losses. The most serious disease is bacterial canker caused by *Pseudomonas syringae* (Bright and Marte, 2004). The fungal spoilage is mainly due to species of genera *Penicillium, Botrytis* and *Monilinia,* responsible for blue rot, gray mold and brown rot,

respectively (Venturini et al., 2002). The occurrence of these rots and their influence on cherry quality is dependent on cultivar (Kappel et al., 2002) and ripening stage at harvest (Drake and Elfving, 2002). Fruits like sweet cherries are infected by different pathogens, both in the field and even more so during post harvest storage. The main decay is gray mold caused by *Botrytis cinerea* Pers. infecting fruits and Rhizopus rot induced by *Rhizopus stolonifer* (Rommanazi, 2009), which attacks sweet cherries (Maas, 1998). Rhizopus soft rot of cherries occurs throughout the world on harvested fleshy organs of the fruit during storage, transit, and marketing (Odeh, 2006). Moreover, sweet cherries suffer heavy losses mainly by brown rot, caused by three different species of the genus Monilinia (*M.laxa*, *M.frutigena* and *M.fructicola*) and also to a lesser account, by blue mold caused by *Pencillium expansum*, Alternaria rot caused by *Alternaria alternata* and Cladosporium rot caused by *Cladosporium* sp. (Rommanazi, 2009). *Penicillium expansum* produces the mycotoxin patulin, which rise to unacceptable levels and thus affect the quality of the fruit (Odeh, 2006). Cherry leaf spot is the another fungal disease caused by the fungus *Blumeriella jaapii* and is a potentially devastating disease of sour and sweet cherries and plums. Besides a direct loss in yield and quality of fruit, premature defoliation weakens trees and makes them less winter-hardy. Sweet cherry fruit is unique with higher tolerance to elevated CO_2 concentrations than most stone fruits (Porritt and Mason, 1965). High levels of CO_2 were used to reduce losses from decay by many fungi in the fruit (De Vries et al., 1991).

4. Quality Parameters

Sweet cherry is one of the most popular of the temperate fruits. The main quality attributes which influence consumer acceptance of sweet cherries are sweetness, sourness, skin

colour, fruit firmness and fruit weight of cherry cultivars (Ferretti et al., 2010**;** Muskovics et al., 2005; Crisosto et al., 2003). Skin colour is the most important indicator of quality and maturity of fresh cherry, and depends on the anthocyanin content (Esti et al., 2002) which ranges from few mg/100 g in light-coloured to about 700 mg/100 g in dark cherries (Wang et al., 1997). As skin colour of the fruit darkens, postharvest life decreases (Crisosto et al., 1997). Fruit weight and size are very important characteristics for commercial market value of sweet cherries (Martino et al., 2008) and sweet cherries with large fruit size are distinctly preferred by most consumers as they have greater visual appeal, better taste and possess more flesh (Blazkova et al., 2002; Looney et al., 1996). Increase in fruit size and weight of sweet cherries takes place just before harvest as ripening occurs. As much as 25% of final fruit weight is added in the last week of growth prior to harvesting (Blazkova et al., 2002). Fresh cherries are rich in sugar, anthocyanins, organic acids and tannins (Seeram et al., 2002) and contain twice as much ascorbic acid (vitamin C) as oranges (Yilmaz et al., 2008). The antioxidant capacity of cherries is due to the presence of phenolics , anthocyanins, and melatonin (Seeram et al., 2002; Vinson et al., 2001; Burkhardt et al., 2001) and it is because of these phenolics, cherries rank first followed by other 19 fruits when comparing their antioxidant capacity (Vinson et al., 2001). Phenolic antioxidants have various positive effects on the human health like anti-inflammatory and anticarcinogenic effects and are important in the human nutrition (Usenik et al., 2008). Fruit firmness is also an important quality attribute and is directly related to enhance the storability potential and to induce greater resistance to decay and mechanical damage (Esti et al., 2002; Girard and Kopp, 1998). Considerable genotypic differences in fruit firmness are found in sweet cherries (Esti et al., 2002). Late cultivars of sweet cherry are firm as compared to early cultivar

which are generally much softer. The cultivars having TSS above 15 °Brix is considered to be acceptable for sweet cherry (Kappel et al., 1996). Sugar concentration of sweet cherries increase as the fruit ripens while acids remain relatively constant (Blazkova et al., 2002). The presence of glucose and fructose are mainly responsible for the sweetness of sweet cherries (Serrano et al., 2005) and sourness is mainly due to the presence of organic acid (malic acid) (Bernalte et al., 2003; Esti et al., 2002). TSS and titratable acidity (TA) are related to flavour intensity, with higher TSS and TA accounting for better acceptability (Martino et al., 2008; Crisosto et al., 2003) and the ratio TSS/TA is related to the perception of sweetness, sourness or cherry flavour (Crisosto et al., 2002). TA also depends on cultivar, with levels of 0.4–1.5%, the main organic acid being malic acid (Bernalte et al., 2003; Esti et al., 2002; Bernalteet al., 1999). The TSS/TA ratio at harvest is a predominant parameter for consumer acceptance together with the absence of stem browning (Crisosto et al., 2003).

4.1 Compositional Changes during pre-harvest

Sweet cherry composition depends on cultivar, climate and maturity stage (Mozetic et al., 2006; Goncalves et al., 2004a,b). There are many physical factors affecting composition of sweet cherries which are categorised as climate or soil factors (Longstroth and Perry, 1996). Pre-harvest factors and temperature, light intensity, fruit crops maturity may affect the content and stability of phytochemicals and the nutritional value in sweet cherries (Ferretti, 2010). Light intensity increases levels of ascorbic acid and different growing temperatures also affect total phenolic content of sweet cherries. High temperature growing conditions (25-30°C) significantly enhance anthocyanin and total phenolic content (Karlidag, 2009). The soil types, decayed

organic matter, mulching and fertilization also influence the water and nutrient supply to the plant and affect the nutritional composition of the fruit (Ferretti, 2010). The two key physiological factors related to composition of cherries are maturation and ripening. The enzymes responsible for textural changes during ripening and maturation are pectin methyl-esterase (PME), polygalacturonase (PG) and β-galactosidase (β-Gal) (Remen et al., 2003). Reports have shown that PME and PG work together in softening by increasing solubilisation of the cell walls. The ripening of sweet cherries and their rapid increase in size and weight occurs simultaneously during the last few weeks prior to harvest (Revell, 2008). Anthocyanins and hydroxycinnamic esters are the major polyphenol groups in cherries (Chaovanalikit and Wrolstad, 2004; Goncalves et al.,2004; Mozetic et al., 2002), which contribute to total antioxidant activity (Khanizadehet al., 2007; Vangdal et al., 2007; Vursavus et al., 2006; Serranoet al., 2005; Goncalves et al., 2004b). The main characteristic aspect of the maturation of cherry fruits is the change of the initial green colour to red, violet or blackish colour which is caused by accumulation of anthocyanins and by chlorophyll degradation. This accumulated anthocyanin content is the most important indicator of quality and maturity of fresh cherry (Esti et al., 2002). The total anthocyanins are higher in ripe cherries than in partially ripe ones (Goncalves et al., 2004). The content of cyanidin-3-rutinoside and cyanidin-3-glucoside in cherries decreases several fold during cold storage for 15 days at 1°C (Esti et al., 2002). However, the occurrence and relative amounts of the major anthocyanins cyanidin-3-rutinoside and cyanidin-3-glucoside do not change by the stage of ripeness. In addition, the hydroxycinnamic acid profile and the ratio between the two major hydroxycinnamic acid, neochlorogenic acid and 30-p-coumarylquinnic acid, are not maturation dependent, except in the

very early stages of the fruit. Minor anthocyanins, which together represent on average 2% of total anthocyanins, stabilize their relative amounts in the final phases of maturity (last 2 days). The dry matter content and total soluble solids content (^{o}Brix) increase during development (Kovács et al., 2009). The concentration of fructose and glucose, the main sugars found in sweet cherries (Serrano et al., 2005), increase during ripening. However, the concentration of glucose increases more than that of sucrose as found in almost 13 varieties of cherries (Usenik et al., 2008). Fruits become much sweeter during ripening as sugar concentrations increase while acids, predominantly malic acid, remain relatively constant. The major serious limitations for profitable sweet cherry production is the fungal diseases which kill the flowers and shoots, or rot the fruits, caused by rainfall and high humidity during the growing season, particularly at blooming or harvesting time (Simon, 2006).

4.2 Compositional changes during post harvest

Sweet cherries are extremely difficult fruit to handle after harvest because they deteriorate rapidly after harvest mainly due to bruising of the skin, softening, changes in the sugar-acid balance, desiccation and browning of the stem, surface pitting and decay (Alique et al., 2005; Bernalte et al., 2003; Petracek et al., 2002; Dugan and Roberts, 1997) and are very susceptible to bruising (pitting) (Kupferman and Sanderson, 2001). During the ripening of sweet cherries, there occurs an increase in fruit weight, soluble solids content, fructose, malic acid and total antioxidant activity, as well as in bioactive compounds and decrease in firmness and glucose level. The most rapid fruit size increase occurs in the first week of ripening of sweet cherries (Blazkova et al., 2002).Water is lost rapidly from both the fruit as well as from the stem which in turn is responsible for the subsequent loss of sugar in the cells, softening of the fruit,

and darkening of the stem (Yaman et al., 2001). During storage the fruit metabolism continues inducing changes in the phenolic and other antioxidant content (Amarowicz et al., 2008). In sweet cherries, storage is found to have variable effects on the total phenolic and anthocyanin contents which are depended on the cultivar and the storage conditions (Mozetic et al., 2006; Goncalves et al., 2004a,b). An increase in phenolic content has been observed in the days following fruit harvest and is generally stable during storage (Kevers et al., 2007). During cold storage and subsequent shelf-life, a general increase (over 40–60% on average) in phenolic compound is observed (Serrano et al., 2009 and Gonçalves et al., 2004). Cherries loose their shiny red colour after their harvest (Bernalte et al., 2003; Esti et al., 2001) which was mainly thought to be caused by total and individual anthocyanin decrease (Mazza and Miniatti, 1993). However, some new data clearly described non-correlation between anthocyanin change and colour loss of cherries. Other physiological and biochemical processes in the fruit, like loss of cell compartment and acid degradation are more crucial compared to anthocyanins in colour changes of cherries (Bernalte et al., 2003; Esti et al., 2001; Zhang et al., 2000). In addition, an accumulation of anthocyanins and especially of cyanidin-3-O-rutinoside takes place and produces the red-purple colour typical of the fruit. As cherry skin colour changes from full light red to full dark, fruit weight, soluble solids content, TSS/TA ratio increases (Romono et al., 2006), firmness changes with the changes in skin colour (Mitcham ,1998) and an accumulation of total phenolic compounds takes place(Serradilla et al., 2010). Sweet cherries soften and darken, and changes occur in the sugar-acid balance during storage which affects flavour. The softening and changes in texture of cherries during storage (Vidrih et al., 1998) influence the organoleptic qualities of fruit and often dictate shelf life (Batisse et al., 1996). The total amount

of oxidation enzymes like peroxidase (POX) and polyphenoloxidase (PPO) increase significantly during storage and the activity of pectinmethylesterase (PME) and polygalacturonase (PG) present in sweet cherries increase approximately 2-2.5 fold during the storage period of 5 days (Remen et al., 2003).

In cherries, impact damage increases as fruit temperature decreases and this can result in pitting damage. Delay in storage and conditioning or heat treatments (at moderate or high levels) before cold storage, can alleviate low temperature damage, enhance resistance to pathogen infection, inactivate pathogens, and reversibly inhibit fruit ripening or largely delay senescence. Parameters such as climatic, agronomic (crop load, culture in greenhouses or fields, biological culture, etc.) and degree of ripening may also influence the phenolic content of fruit tissues (Drogoudi et al., 2009; McGhie et al., 2005; Serrano et al., 2005; Goncalves et al., 2004a,b). Influences of storage conditions on firmness have been measured and it has been found that while changing from initial green to over-ripe stage, a typical firmness increase is observed in the initial development period of the fruit, followed by a decrease in firmness until a practically constant minimum value is reached (Mafraa et al., 2001; Demir and Kalyoncu, 2003). The time to reach the maximum firmness and the rate of softening are the characteristic for the cultivar (Muskovics et al., 2005). The rate of decrease of firmness after the peak value is different in different cultivars and the decrease in firmness simply reflects cell enlargement during fruit growth. Changes in firmness correlate with changes in skin colour (Bernalte et al., 1999; Mitcham et al., 1998), and firmness and surface pitting are also found to be connected features (Toivonen et al., 2004). Burlat cherries are very sensitive to cracking and their postharvest shelf-life extension is very complicated, and need to be harvested at optimum ripeness degree to improve postharvest

quality (Remen et al., 2003).TSS content in sweet Burlat cherries increases from initial 15.5°Brix to approximately 18.0°Brix as a result of the water loss (approx. 9%) during 5 days storage and the TA shows a slight decrease (Remen et al., 2003). During storage, the fruit metabolism continues inducing changes in the phenolic and other antioxidant content (Amarowicz et al., 2008). In sweet cherries, storage was found to have variable effects on the total phenolic and anthocyanin contents which were depended on the cultivar and the storage conditions (Mozetic et al., 2006; Goncalves et al., 2004a,b; Esti et al., 2002). The total phenolic content increases during storage as has been observed in cultivars like Van and Tragana in most location sites, while storage shows no effect in phenolic content of Burlat cherries (Goncalves et al., 2004a; Esti et al., 2002).

5. Modified Atmosphere Packaging (MAP) for Fresh Cherries

MAP came into existence in 1927 for shelf-life extension of apples by storing them in atmospheres with reduced O_2 and increased CO_2 concentrations. MAP is defined as a technique of sealing actively respiring produce (fruits and vegetables) in polymeric film packages to modify the O_2 and CO_2 levels within the package atmosphere (Mattheis et al., 2000). It is often desirable to generate an atmosphere low in O_2 and/or high in CO_2 to influence the metabolism of the product being packaged, or the activity of decay-causing organisms to increase storability and shelf life (Zagory et al., 1988). For some products, modifying both O_2 and CO_2 may be desirable, and indeed, altering the O_2 level automatically alters CO_2 level (Beaudry, 1999). In recent years, MAP has become more prevalent to extend the shelf life of fresh cherries (Shelton, 1994). MAP designed specifically for sweet cherries has gained acceptance in many of the larger sweet cherry production areas in the world, such as in the Pacific Northwest of the USA (Padilla-

Zakour et al., 2007), Canada, Europe, and Australia (Rai et al., 2002). In these regions, MAP of sweet cherries has been used to reduce the transportation cost (using ships instead of air freight, for example) to overseas markets. Efficiently designed MA packages have been shown to reduce respiration rates and ripening of fruits and thus improve moisture retention (Mitcham et al., 2002; Aharoni et al., 2007). One of the most important attributes of MAP is that it can preserve green stem colour and fruit firmness, both critical attributes for marketing cherries in retail stores (Padilla-Zakour et al., 2004; Kappel et al., 2002; Remon et al., 2000). Furthermore, packaging isolates the product from the external environment (Mattheis et al., 2000). The primary limitation of MAP application in the early studies was the lack of control of O_2 levels in the package (Beaudry, 2000; Beaudry, 1999).

The use of MAP has been reported to be effective in delaying the physico-chemical changes related to quality loss of sweet cherries (Tian et al., 2004; Petracek et al., 2002; Spotts et al., 2002; Remon et al., 2000). It effectively retards the deterioration of certain cherry quality parameters (Artes et al., 2001) and decay caused by fungal growth (Tian et al., 2001). MAP involves changing the levels of gases in the package to slow down natural spoilage processes including reduction in respiration rates, reducing oxidation and preventing bacterial and fungal growth. MAP is most effective when used with refrigeration, as lower temperatures help slow spoilage (Mullan et al., 2002). In MAP of cherries, the respiration rate and the rate of all metabolic processes are decreased by reducing the amount of available O_2 to the produce resulting in delayed ripening and senescence, which may be seen as chlorophyll retention, delayed softening and the prevention of discoloration. MAP also reduces the quantity of water vapour lost from the produce. MAP uses the gases produced and consumed during the respiration

of fresh produce, that is CO_2 and O_2 respectively, to produce a favourable atmosphere in a specially designed polymeric film package and it is this atmosphere which slows the metabolic activity of the produce to a very low level, and thus enables the storage of highly perishable produce for prolonged periods. Different gases adjusted in MAP include O_2, CO_2 and N_2 (Coles et al., 2003).

Carbon dioxide discourages the growth of aerobic bacteria and fungi at low temperatures. CO_2 levels in MAP of sweet cherries do not appear to influence the rate of respiration or the production of ethanol or acetaldehyde (Petracek et al., 2002; Jaime et al., 2001). However, CO_2 concentrations greater than 30% have been associated with brown skin discoloration and off-flavour. The solubility of CO_2 decreases dramatically with increasing temperature and hence, the storage temperature of MAP product should be kept as low as possible. Oxygen is required by many bacteria and fungi that commonly cause food spoilage and favours several food spoilage reactions, including fat oxidation (rancidity), browning reactions and colour changes. To prevent these reactions, the concentration of O_2 in a package can be reduced to a minimum. However, total exclusion of O_2 favours the growth of specific anaerobic like *Clostridium botulinum*. Concentrations of $O_2 \leq 1\%$ have been reported as crucial for the onset of pitting and off-flavours in some sweet cherry cultivars. Nitrogen is a non-reactive gas that has no smell or taste and is used as a filler gas to replace O_2 and thus prevent spoilage or to replace CO_2 and prevent package collapse. MAP with CO_2 / O_2 concentrations of 8% / 5% and 10% / 5% effectively reduced rotting, browning of peduncles, darkening of fruit colour and loss of firmness and acidity as compared to fruit packed in macro-perforated box liners in sweet cherries (Crisosto et al., 2002) O_2 MAP with 9-12% CO_2 and 1-3% O_2 effectively prolong shelf

life, especially for fruit harvested at the red colour (Remon et al., 2000). MAP is used either actively or passively.

Passive MA involves the creation of a high-CO_2, low-O_2 atmosphere by the food product itself due to respiration. The food (usually a fruit or vegetable) is placed in a sealed package as a consequence of a commodity's respiration, i.e. O_2 consumption and CO_2 evolution. If a commodity's respiration characteristics are properly matched to film permeability values, then a beneficial modified atmosphere can be passively created within a package. If a film of correct intermediary permeability is chosen, then a desirable equilibrium modified atmosphere is established when the rates of O_2 and CO_2 transmission through the package equal a product's respiration rate. The combination of passive MAP with several essential oils has been also shown to improve the beneficial effects of the headspace gas composition on the quality of cherries (Serrano et al., 2005). In active packaging, a beneficial equilibrium atmosphere may be established by pulling a slight vacuum and replacing the package atmosphere with a desired mixture of CO_2, O_2 and N_2, more quickly than a passively generated equilibrium atmosphere. Another active packaging technique is the use of O_2, CO_2 or ethylene scavengers/emitters. Such scavengers/emitters are capable of establishing a rapid equilibrium atmosphere within hermetically sealed produce packages. Active MA may be achieved either through gas flushing or compensated vacuum.

Gas flushing involves running the mixture of gases through a package and then sealing it resulting in some O_2 left in the package. The gas flush technique is normally accomplished on a form fill-seal machine. The replacement of air inside a package is performed by a continuous gas stream. The great advantage of the gas flush technique is the speed of machine as the action

is continuous and hence, the product rate is also very high. Compensated vacuum involves two steps: creating a vacuum in the package, and then filling it with the gas mixture resulting in little to no O_2 left in the package. Since the replacement of air is accomplished in a two-step process, the speed of operation of the equipment is slower than the gas flush technique. Different O_2 and CO_2 concentrations and mixtures of gases are being used for different cherry cultivars.

Different packaging materials are used while packaging foods by MAP. The levels of O_2 and CO_2 within a package depend on the interaction between commodity respiration and the permeability properties of the packaging film and/or microperforations (Kader et al., 1997). Although an increasing choice of packaging materials is available to the MAP industry, most packs are still constructed from four basic polymers: polyvinyl chloride (PVC), polyethylene terephthalate (PET), polyproylene (PP) and polyethylene (PE) (Kader, 2002). The two ways for creating film barriers that control movement of O_2 and CO_2 into or out of the package are continuous films and perforated films with small holes or microperforations. The relative permeability to O_2 and CO_2 differ substantially between continuous and perforated films and results in considerable differences in gas exchange behaviour (Mattheis and Fellman, 2000). In packages with continuous films, the permeability of the package to CO_2 is usually 2 to 8 times that of O_2 permeability and it is only 0.77 times in case of perforated films. The O_2 and CO_2 permeability of continuous films increases with temperature while the diffusion of gases through perforations is extremely insensitive to temperature changes.

6.0 Effect of MAP on physiochemical quality and stability

Modified atmosphere packaging appears to offer cherry growers a tool for maintaining quality during storage and marketing. MAP treatments maintain fruit colour and intensity,

preserve green stem colour, maintain fruit firmness, prevent water loss and shrivelling, and keep cherries in excellent condition (Wargo et al., 2003). MAP helps to maintain the colour of sweet cherries (Kahlke et al., 2009). The total anthocyanin content of sweet cherry increases slightly with MAP storage (Conte et al., 2009; Padilla-Zakour et al., 2007; Remón et al., 2000). This increase in anthocyanin content in sweet cherries is most probably counterbalanced by CO_2 concentrations in the headspace that inhibits enzyme activity favouring stability of colour (Remón et al., 2004; Rocha and Morais, 2001). The firmness of sweet cherries stored in MAP slightly decrease with storage time. However, sweet cherry firmness increases when stored in controlled atmosphere packaging (Tian et al., 2004). Most of the sweet cherry cultivar acidity is lost with MAP. It shows a slight increase after 5 days storage period followed by a gradual decrease so that the final values are approximately 10-15% lower than the initial ones (Remon et al., 2003). The pH and TSS remain relatively stable with modified atmosphere packaging. However, there is a slight increase in the pH values of sweet cherries, most probably due to the decrease in acidity (Serrano et al., 2005; Remón et al., 2003). Soluble solids content of sweet cherries is found to remain almost constant during MAP Storage (Remon et al., 2003). Weight loss in cherries is higher than in other commodities not only due to their low skin diffusion resistance (Serrano et al., 2005), but also to a higher surface/volume ratio. Concerning the effects of the modified atmosphere on weight loss kinetic, it is seen that cherries stored under MAP have a higher percentage weight loss, compared to sample packaged under ordinary conditions (Conte et al., 2009)

7.0 Properties of sweet cherries at different storages

Sweet cherries (*Prunus avium* L.) are one of the most popular temperate fruit and the main characteristics often used for cherry quality assessment are colour, sweetness, sourness and firmness (Esti et al, 2002). Kupferman and Sanderson (2001) studied the use of MAP liners at different temperatures and demonstrated that fruit deterioration was slowed significantly at lower temperature as compared to fruit held at higher temperatures. The range of total soluble solids (TSS) accounts for 11-20 °Brix and it remains almost in the same range in refrigerated as well as MAP storage for several weeks (Meheriuk et al., 1995; Crisosto et al., 2003; Alique et al., 2003; Remon et al., 2003; Wargo et al., 2003; Tian et al., 2004; Serrano et al., 2005). During cold storage TSS decreases or remains constant while TA decrease, resulting in an increase in TSS/TA ratio, regardless of packaging conditions used (Conte et al., 2009). The acidity of Sweet cherries range from 0.4–1.5% in normal storage and behaves differently in different storages. Titratable acidity of sweet cherries decline steadily over the storage period and by week 10 achieves about 50% of its value (Meheriuk et al., 1995). Titrable acidity decrease in normal, refrigerated as well as in MAP storage at different temperatures and ranges from 0.97-0.44 (Crisosto et al., 2001; Kupferman and Sanderson, 2001; Alique et al., 2003; Remon et al., 2003; Wargo et al., 2003; Tian et al., 2004; Serrano et al., 2005). TA decreased from 0.97% at harvest to 0.67% in cherries packed in the perforated box liner. Cherries packed in the solid box liner had 0.63% while cherries packed in any of the MAP box liners ended with 0.70% after 45 days cold storage (Crisosto et al., 2003). Titratable acidity shows a slight increase after 5 days in MAP storage and then a gradual decrease in the last time points so that the final values are approximately 10–15% lower than the initial ones (Remon et al., 2003). The fruits stored in 5% O_2 plus 10% CO_2 had a higher titratable acidity contents than those in MAP and CA with high

O_2 level during all the storage periods. The microperforated films preserve fruit acidity and firmness than macroperforated films while slowing down the darkening of colour, loss of quality and decay (Alique et al., 2003). Remen et al. (2003) reported that modified atmosphere packaging using polypropylene films extend the shelf life of cherry after harvest up to 15-20 days at 5°C and caused a slight increase in acidity after 5 days followed by a gradual decrease in the last time points so that the final values are approximately 10-15% lower than the initial ones. The relationship between TSS, acidity and visual appearance plays an important role in determining consumer acceptance of this fruit (Crisosto et al., 2003). MAP prevents decay of stem colour and maintains its greenness for several months as compared to refrigerated storage in which the greenish colour is maintained for less time. Stems of sweet cherries remain green during the l0-week storage period (Meheriuk et al., 1995). MAP treatments maintained fruit color and intensity, preserved green stem colour, and kept cherries in excellent condition during four weeks of storage (Wargo et al., 2003). Stem remained green in cherries with antifungal treatment (eugenol, thymol or menthol) while they became brown in cherries without treatment (Serrano et al., 2005). However, cherries packaged with eucalyptol behaved even worse than control cherries, with generation of off-flavours, loss of quality and stem browning. Sweet cherries are known for the shiny red colour, an important quality attribute for the consumer, through which high quantities of polyphenols (anthocyanin) content is expressed. Anthocyanin content of cherries stored at refrigerated temperature decreased during storage, probably due to the high oxidative activity of polyphenyloxidase and increasing pH (Conte et al., 2009) and the same results were obtained by Esti et al. (2002). Remen et al. (2003) reported that anthocyanin content increased after harvest under MAP conditions but more so in cherries without MAP

conditions. The total anthocyanins in Lambert sweet cherries after 12 days storage in the refrigerator showed no change and an average 9% decrease from 576 to 525 mg was found in cherries treated with 1-methylcyclopropene (Mozetic et al. 2006). Cherry firmness decreased from 238 g to approximately 193 g by 45 days of cold storage (Crisosto et al., 2003) and from 240-205 g in MAP storage. Alique et al. (2003) and Serrano et al. (2005) also reported firmness decrease in sweet cherries with storage time. Firmness of sweet cherries decreases more in normal storage than under MAP conditions. However, Kupferman and Sanderson (2001) reported firmness increase in case of sweet cherries when stored in MAP-(Lifespan liners) at 34°F and Wargo et al. (2003) reported the same results when cherries were stored in LDPE bags at 38°F for 28 days under normal conditions. The fruits stored in 5% O_2 plus 10% CO_2 had a higher degree of firmness (Tian et al., 2004). Higher values of firmness are obtained when sweet cherries are treated with gibberlic acid during their storage (Usenik et al., 2005). Packing in MAP at 0°C did not alter the subsequent respiratory intensity of the fruits at 20°C; however, the respiratory intensity at 20°C did increase when the storage temperature was raised to 4°C (Alique et al., 2003). At low temperatures, the respiration rate of the fruit is lower and therefore less O_2 is used. At warmer temperature, respiration rate of sweet cherries increase and the O_2 in the bag can be depleted leading to fruit injury (Wargo et al., 2003). The results indicated that MAP storage with 5% O_2 plus 10% CO_2 more significantly inhibited the enzymatic activities of polyphenol oxidase (PPO) and peroxidase (POD), reduced malondialdehyde (MDA) content, effectively prevented flesh browning, decreased fruit decay and extended storage life of sweet cherry fruit than did other treatments (Tian et al., 2004). PME activity increase approximately 2-2.5 fold during the storage period of 10 days (Remen et al., 2003). Vitamin C contents decrease

rapidly with storage time. Sweet cherries stored in 5% O_2 +10% CO_2 had a relatively higher vitamin C content than that in other treatments (Tian et al., 2004).

8.0 Future Research

This article reviews the factors responsible for the shelf life of sweet cherries and the importance of modified atmosphere packaging technique in preserving their quality. Certainly, it is important to harvest cherries before they are too mature since the best quality of cherries is obtained when harvested in the early to mid maturity stage. Precooling (preferably hydro-cooling) is essential for the removal of field heat or the reduction in temperature of the cherries as soon as possible after harvest. Efficiently designed grading and packaging machines (during classification and grading) can effectively reduce quality deterioration of cherries. Research on fresh cherries still needs to be done to obtain microbiologically safe products, keep its nutritional value and sensory quality. The shelf life has to be enhanced to allow distribution and marketing. More investigation about the processes that rule the physiology and, therefore, limit the shelf life of fresh produce should be undertaken. Storage and distribution systems need to control temperature and RH, and gas packaging serves as important supplement. In designing CA, MA or MAP systems, it would be prudent to realistically evaluate the time and temperature conditions that the product will likely encounter throughout the postharvest chain, as well as the likelihood of mixed load conditions. It then will become possible to design systems such as a combination CA/MAP and other available techniques that can maintain optimum atmospheres and product quality throughout the postharvest handling chain. In addition, modelling of the package atmosphere composition, respiration rate and internal atmospheres in the fruit tissue throughout storage are of capital importance to design appropriate packages. Along with

physico-chemical analysis, consumer panels and their preferences at different markets should be monitored. Furthermore research on quality of cherries should also take into consideration the prevention of nutritional losses as influenced by processing and storage conditions. Besides these parameters, a strong direction and approach is required for processing and distribution of fresh sweet cherries thereby developing some technology which will solve some of the hindrances that the cherries producers and processors are facing to get stable quality throughout the storage. Critical evaluation at every step along with selecting premium product quality should be the key element of the cherry processing and packaging.

References

Aharoni, N., Rodov, V., Fallik, E., Afek, U., Chalupowicz, D., Aharon, Z., Maurer, D. and Orenstein, J. (2007). Modified atmosphere packaging for vegetable crops using high water-vapour-permeable films. p.73-112. In: *C. Wilson (ed.), Intelligent and active packaging for fruits and vegetables.* CRC Press, FL. USA.

Alique R., Martinez, M.A., Alonso, J. (2003). Influence of the modified atmosphere packaging on shelf life and quality of Navalinda sweet cherry. *European Food Res Technol.* 217, 5, 416-420.

Alique, R., Zamorano, J. P., Martínez, M. A., & Alonso, J. (2005). Effect of heat and cold treatments on respiratory metabolism and shelf-life of sweet cherry, type picota cv"Ambrunés". *Postharvest Biology and Technology*, 35, 153–165.

Amarowicz, R., Carle, R., Dongowski, G., Durazzo, A., Galensa, R., Kammerer, D., Maiani, G., Piskula, M.K. (2008). Influence of postharvest processing and storage on the content of phenolic acids and flavonoids in foods: *review. Mol. Nutr. Food Res.* 53, 151–183.

Anonymous (2013). Available from http://www.uga.edu/fruit/cherry.html

Artes F., Tudela J.A., Artes-Hldez F. (2001). *Acta Hort (ISHS),* 553:663–664.

Batisse, C., Buret, M., Coulomb, P.J. (1996). Biochemical differences in cell wall of cherry fruit between soft and crisp fruit. *J. Agric. Food Chem*. 44, 453-457.

Beaudry, R.M. (1999). Effect of O_2 and CO_2 partial pressure on selected phenomena affecting fruit and vegetable quality. *Postharvest Biol. Technol*. 15:293-303.

Beaudry, R.M. (2000). Responses of horticultural commodities to low oxygen: limits to the expanded use of modified atmosphere packaging. *Hort Technology*, 10:491-500.

Bernalte, M. J., Sabio, E., Hernandez, M. T., & Gervasini, C. (2003). Influence of storage delay of Van sweet cherry. *Postharvest Biology and Technology*, 28(3), 303–312.

Blazkova, J., Hlusickova, I., Blazek, J. (2002). Fruit weight, firmness and soluble solids content during ripening of Karesova cv. sweet cherry. *HORT. SCI.* 29, (3): 92–98.

Bright, J. & Marte, S. (2004). 'Cherry Growing in NSW'. *In:* Agriulture, N. (ed.) *Agfacts.*

Burkhardt, S., Tan, D.X., Manchester, L.C., Hardeland, R., Reiter, R.J., (2001). Detection and quantification of the antioxidant melatonin in Montmorency and Balaton tart cherries (Prunus cerasus). *J. Agric. Food Chem*. 49, 4898–4902.

Chadha. K.I., (2006). Cherry, *Handbook of Horticulture*, p: 161-165.

Chaovanalikit A., Wrolstad R. E. (2004). Total anthocyanins and total phenols of fresh and processed cherries and their antioxidant properties. *J Food Science* 69(1):FCT76-FCT72.

Connolly, D.A.J., McHugh, M.P., Padilla-Zakour, O.I. (2006). Efficacy of a tart cherry juice blend in preventing the symptoms of muscle damage. *Br. J. Sports Med*. 40, 679–683.

Conte, A., Scrocco, C., Brescia, I., Del Nobile, M. A. (2009). Packaging strategies to prolong the shelf life of minimally processed lampascioni (Muscari comosum). *Journal of Food Engineering*, 90, 199–206.

Crisosto, C. H., Crisosto, G. M., & Metheney, P. (2003). Consumer acceptance of "Brooks"and "Bing" cherries is mainly dependent on fruit SSC and visual skin colour. *Postharvest Biology and Technology*, 28, 159–167.

Crisosto, C. H., Crisosto, G. M., & Ritenour, M. A. (2002). Testing the reliability of skin colour as an indicator of quality for early season "Brooks" (Prunus avium L.) cherry. *Postharvest Biology and Technology*, 24, 147–154.

Demir, F., Kalyoncu, I.H. (2003). Some nutritional, pomological and physical properties of cornelian cherry (*Cornus mas* L.). *J. Food Eng*. 60, 335–341.

Drake, S.R., Elfving, D.C. (2002). Indicators of maturity and storage quality of 'Lapins' sweet cherry. *HortTechnology* 12, 687–690.

Drogoudi, P.D., Tsipouridis, C.G., Pantelidis, G. (2009). Effects of crop load and time of thinning application on split pits, yield, fruit quality and leaf mineral content in 'Andross' peach. *J. Hortic. Sci. Biot.* 84, 505–509.

Esti, M., Cinquanta, L., Sinesio, F., Moneta, E., & Mateo, M. D. (2002). Physicochemical and sensory fruit characteristics of two sweet cherry cultivars after cool storage. *Food Chemistry*, 76(4), 399–405.

Ferretti G., Bacchetti T., Belleggia A and Neri D. (2010). Cherry Antioxidants: From Farm to Table. *Molecules*, 15, 6993-7005.

Garcia-Closas, R., Gonzalez, C.A., Agudo, A., Riboli, E., (1999). Intake of specific carotenoids and flavonoids and the risk of gastric cancer in Spain. *Cancer Causes Control* 10, 71–75.

Girard, B and Kopp, T.G. (1998). Physicochemical characteristics of selected sweet cherry cultivars. *J. Agric. Food Chem.*, 46, 471-476.

Goncalves B., Landbo, K.K., Let, M., Silva, A.P., Rosa, E., Meyer, A.S. (2004b). Storage affects the phenolic profiles and antioxidant activities of cherries (*Prunus avium* L) on human low-density lipoproteins. *J Sci Food Agric* 84: 1013-1020.

Goncalves, B., Landbo, A., Knudsen, D., Silva, A.P., Moutinho-Pereira, J., Rosa, E., Meyer, A. (2004a). Effect of ripeness and postharvest storage on the phenolic profiles of cherries (Prunus avium L.*). J. Agric. Food Chem*. 52, 523–530.

Goncalves, B., Silva, A.P., Moutinho-Pereira, J., Bacelar, E., Rosa, E., Meyer, A.S. (2007). Effect of ripeness and postharvest storage on the evolution of colour and anthocyanins in cherries (Prunus avium L.). *Food Chem*. 103, 976–984.

Harman, S.M. (2009). Tart cherry juice decreases oxidative stress in healthy older men and women. *J. Nutr*. 139, 1896–1900.

Jacob, R.A., Spinozzi, G.M., Simon, V.A., Kelley, D.S., Prior, R.L., Hess-Pierce, B., Kader, A.A. (2003). Consumption of cherries lowers plasma urate in healthy women. *J. Nutr*. 133, 1826–1829.

Jaime, M. P., Oria, R., & Salvador, M. L. (2001). Respiration rate of sweet cherries: Burlat, Sunbursty Sweetheart cultivars. *Journal of Food Science, 66,* 43 –47.

Jakobek, L., Seruga, M., Medvidovic-Kosanovic , M., Novak, I. (2007a). Anthocyanin content and antioxidant activity of various red fruit juices. *Dtsch. Lebensm.-Rundsch*. 103, 59–64.

Kahlke C.J., Padilla-Zakour O.I., Cooley H.J., and Robinson R.L. (2009). Shelf-life and marketing window extension in sweet cherries by the use of modified atmosphere packaging. *New York fruit quarterly*. Volume 17; P 21-24.

Kalyoncu I. H., Ersoy N. and Yılmaz M. (2009). Some physico-chemical properties and mineral contents of sweet cherry (*Prunus avium* L.) type grown in Konya. *African Journal of Biotechnology* .Vol. 8 (12), pp. 2744-2749.

Kang, S.-Y., Seeram, N.P., Bourquin, L.D., Nair, M.G. (2003). Tart cherry anthocyanins inhibit tumor development in ApcMin mice and reduce proliferation of human colon cancer cells. *Cancer Lett*. 194, 13–19.

Kappel F., Fischer-Fleming B., Hogue E. (1996). Fruit characteristics and sensory attributes of an ideal sweet cherry. *Hort. Sci*., 31: 443–446.

Kappel, F., Toivonen, P., McKenzie, D.L. and Stan, S. (2002). Storage characteristics of new sweet cherry cultivars. *HortScience* 37(1):139-143.

Khanizadeh, S., Tsao, R., Rekika, D., Yang, R., & DeEll, J. (2007). Phenolic composition and antioxidant activity of selected apple genotypes. *Journal of Food, Agriculture & Environment,* 5(1), 61–66.

Kim, D.O., Heo, H.J., Kim, Y.J., Yang, H.S., Lee, C.Y. (2005). Sweet and sour cherry phenolics and their protective effects on neuronal cells. *J. Agric. Food Chem*. 53, 9921–9927.

Kris-Etherton, P.M., Hecker, K.D., Bonanome, A., Coval, S.M., Binkoski, A.E., Hilpert, K.F., Griel, A.E., Etherton, T.D. Bioactive compounds in foods: their role in the prevention of cardiovascular disease and cancer. *The American Journal of Medicine.* 113 , 71–88.

Kroon, P.A., Williamson, G., (1999). Hydroxycinnamates in plants and food: current and future perspective. *J. Sci. Food Agric*. 79, 355–361.

Kupferman, E and Sanderson, P. (2001). Temperature management and modified atmosphere packing to preserve sweet cherry quality. *Postharvest information network*.p:1-9.

Long. L.E., M. Whiting M. and Nuñez-Elisea R. (2007). Sweet Cherry Cultivars for the Fresh Market. *PNW* 604, 1-10.

Looney N.E., Webster A.D., Kupperman E.M. (1996). Harvest and Handling Sweet Cherries for the Fresh Market. *Cherries, Crop Physiology, Production and Uses*.: 411–441.

Mamani-Matsuda, M., Kauss, T., AL-Kharrat, A., Rambert, J., Fawaz, F., Thiolat, D., Moynet, D., Caves, S., Malvy, D., Mossalayi, M.D. (2006). Therapeutic and preventive properties of quercetin in experimental arthritis correlate with decrease macrophage inflammatory mediators. *Biochem. Pharmacol*. 72, 1304–1310.

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

Mattheis, J.P. and J.P. Fellman. (2000). Impact of modified atmosphere packaging and controlled atmosphere on aroma, flavor and quality of horticultural produce. *HortTechnology* 10:507-510.

Mazza, G., & Miniatti, E. (1993). Anthocyanins in fruits, vegetables, and grains (pp. 57–60).

McGhie, T., Hunt, M., Barnett, L.E. (2005). Cultivar and growing region determine the antioxidant polyphenolic concentration and composition of apples grown in New Zealand. *J. Agric. Food Chem*. 53, 3065–3070.

Meheriuk, M., Girard, B., L., Moyls, Beveridge, H.J.T., D.L. McKenzie, D.L., J. Harrison, J., Weintraub, S., & Hocking ,R. (1995). *Food Research International*, Vol. 28, No. 3, pp. 239-244.

Mitcham, E.J., Clayton, M and Biasi, W.V. (1998). Comparison of devices for measuring cherry fruit firmness. *HortScience*: 33(4):723–727.

Mitcham, E.J., Crisosto, C.H. and Kader, A.A. (2002). Sweet cherry recommendations for maintaining postharvest quality. *Postharvest Technology Research and Information Center*. 29 May, 2003.

Mozetic, B., Simcic, M., Trebse, P. (2006). Anthocyanins and hydroxycinnamic acids of Lambert Compact cherries (Prunus avium L.) after cold storage and 1-methylcyclopropene treatment. *Food Chem*. 97, 302–309.

Mozetic, B., Trebse, P., & Hribar, J. (2002). Determination and quantitation of anthocyanins and hyxdroxycinnamic acids in different cultivars of sweet cherries (Prunus avium L.) from Nova Gorica region (Slovenia). *Food Technology and Biotechnology*, 40(3), 207–212.

Mozetic, B., Trebse, P., Simcic, M., & Hribar, J. (2004). Changes of anthocyanins and hydroxycinnamic acids affecting the skin colour during maturation of sweet cherries (Prunus avium L.). *Lebensmittel Wissenschaft und Technologie*, 37(1), 123-128.

Muskovics, G, Felfoldi, J., Kovacs, E., Perlaki, R., Kallay, T. (2006). Changes in physical properties during fruit ripening of Hungarian sweet cherry (*Prunus avium* L.) cultivars. *Postharvest Biology and Technology*. 40, 56–63.

Padilla-Zakour, O.I., Ryona I., Cooley H.J., Robinson T.L., Osborne, J. and Freer J. (2007). Shelf-life extension of sweet cherries by field management, post-harvest treatments, and modified atmosphere packaging. *New York Fruit Quarterly* 15(2):3-6.

Padilla-Zakour, O.I., Tandon, K.S and Wargo, J.M. (2004). Quality of modified atmosphere packaged 'Hedelfingen' and 'Lapins' sweet cherries (*Prunus avium L.*). *HortTechnology*. July-September 14(3): 331-337.

Petracek, P. D., Joles, D. W., Shirazi, A., & Cameron, A. C. (2002). Modified atmosphere packaging of sweet cherry (Prunus avium L., cv. "Sams") fruit: metabolic responses to oxygen, carbon dioxide, and temperature. *Postharvest Biol Technol.* 24, 259-270.

Powrie, W.D. & Skura, B.J. (1991). Modified atmosphere packaging of fruits and vegetables. In: *Modified Atmosphere Packaging of Food* (edited by B. Ooraikul & M.E. Stiles). Pp. 169-242. Chichester: Ellis Horwood Ltd.

Rai, D.R., Oberoi, H.S. and Baboo, B. (2002). Modified atmosphere packaging and its effect on quality and shelf life of fruits and vegetables- an overview. *J Food Sci. Technol.* 39, 199-207.

Remón, S., Ferrer, A., Lopez-Buesa, P., Oria, R. (2004). Atmosphere composition effects on Burlat cherry colour during cold storage. *Journal Science Food Agricultural*, 84, 140–146.

Remón, S., Ferrer, A., Marquina, P., Burgos, J. and Oria, R. (2000). Use of modified atmospheres to prolong the postharvest life of Burlat cherries at two different degrees of ripeness. *J Sci. Food Agric*. 80:1545-1552.

Remón, S., Venturini, M. E., Lopez-Buesa, P., & Oria, R. (2003). Burlat cherry quality after long range transport: optimisation of packaging conditions. *Innovative Food Sci. Emerging Technol*. 4, 425-434.

Rocha, A. M. C. N., & Morais, A. M. M. B. (2001). Influence of controlled atmosphere storage on polyphenoloxidase activity in relation to colour changes of minimally processed Jonagored apple. *International Journal of Food Science and Technology*, 36, 425-432.

Romanazzi, G., Nigro, F., & Ippolito, A. (2003). Short hypobaric treatments potentiate the effect of chitosan in reducing storage decay of sweet cherries. *Postharvest Biology and Technology,* 29, 73–80.

Romanazzi, G., Nigro, F., & Ippolito, A. (2009). Effectiveness of a short hyperbaric treatment to control postharvest decay of sweet cherries and table grapes. *Postharvest Biology and Technology*, 49, 440–442.

Romanazzi, G., Nigro, F., Ippolito, A., & Salerno, M. (2001). Effect of short hypobaric treatments on postharvest rots of sweet cherries, strawberries and table grapes. *Postharvest Biology and Technology*, 22, 1–6.

Romano, G.S., Cittadini, E.D., Pugh, B. and Schouten, R. (2006). Sweet cherry quality in the horticultural production chain. *Stewart Postharvest Review*, 6:2, 1-9.

Salvador, M., Jaime, P. and Oria, R. (2002), Modeling of O_2 and CO_2 exchange dynamics in Modified atmosphere packaging of Burlat Cherries. *Journal of Food Science*, 67: 231–235.

Schick, J.L, Toivonen, P.M.A. (2002). Reflective tarps at harvest reduce stem browning and improve fruit quality of cherries during subsequent storage. *Postharvest Biology and Technology*. 25, 117-121.

Seeram, N.P., Momin, R.A., Nair, M.G., Bourquin, L.D. (2002). Cyclooxygenase inhibitory and antioxidant cyanidin glycosides in cherries and berries. *Phytomedicine* 8, 362–369.

Serra A.T., Seabra I.J., Braga M.E.M., Bronze M.R., de Sousa H.C. and Duarte C.M.M. (2010). Processing cherries (Prunus avium) using supercritical fluid technology.Part1: Recovery of extract fractions rich in bioactive compounds. *J. of Supercritical Fluids* xxx. xxx–xxx.

Serradilla M.J., Lozano M., Bernalte M.J., Ayuso M.C., Margarita López-Corrales M.L., González-Gómez D. (2010). Physicochemical and bioactive properties evolution during ripening of 'Ambrunés' sweet cherry cultivar. *LWT - Food Science and Technology*. xxx , 1-7.

Serrano, M., Díaz-Mula, H. M., Zapata, P. J., Castillo, S., Guillén, F., Martínez-Romero, D. (2009). Maturity stage at harvest determines the fruit quality and antioxidant potential after storage of sweet cherry cultivars. *Journal Agricultural and Food Chemistry*, 57(8), 3240-3246.

Serrano, M., Guillen, F., Martinez-Romero,D., Castillo, S., Valero, D.(2005a). Chemical constituents and antioxidant activity of sweet cherry at different ripening stages, *Journal of Agricultural and Food Chemistry* 53 , 2741-2745.

Serrano, M., Martínez-Romero, D., Castillo, S., Guillén, F., & Valero, D. (2005b). The use of antifungal compounds improves the beneficial effect of MAP in sweet cherry storage. Innovative. *Food Science and Emerging Technologies*, 6, 115–123.

Seske, L. (1996). Respiration and storage potential in Norwegian grown sweet cherries. Acta Horticulturae, 410, 357-362.

Shelton, P. (1994). Cherry industry looks to modified atmosphere pack. *Good Fruit Grower* 5(5):34.

Simon, G. (2006). Review on rain induced fruit cracking of sweet cherries (*Prunus avium* L.), its causes and the possibilities of prevention. *International Journal of Horticultural Science*, 12 (3): 27–35.

Spotts, R. A., Cervantes, L. A., & Facteau, T. J. (2002). Integrated control of brown rot of sweet cherry fruit with a pre-harvest fungicide, a postharvest yeast, modified atmosphere packaging, and cold storage temperature. *Postharvest Biology and Technology*, 24, 251–257.

The Indian Express. Himachal predicts all-time high cherry production. Express News Service : Shimla, Mon Apr 26 2010, .http://www.indianexpress.com/news/himachal-predicts-alltime-high-cherry-production/611163/

Tian, S. P., Jiang, A. L., Xu, Y., Wang, Y. S. (2004). Responses of physiology and quality of sweet cherry fruit to different atmosphere in storage. *Food Chemistry*, 87, 43–49.

Tian, S.P., Fan, Q., Xu, Y., Wang, Y.S., Jiang, A. (2001). Evaluation of the use of high CO_2 concentrations and cold storage to control *Monilinia fructicola* on sweet cherries. *Postharvest Biology and Technology*, *22*: 53–60.

Toivonen, P.M.A. (2002). Reflective tarps at harvest reduce stem browning and improve fruit quality of cherries during subsequent storage. *Postharvest Biology and Technology* 25, 117-121.

Traustadtir, T., Davies, S.S., StoTian, S. P., Jiang, A. L., Xu, Y., &Wang, Y. S. (2004). Responses of physiology and quality of sweet cherry fruit to different atmosphere in storage. *Food Chemistry*, 87, 43–49.

Usenik, V., Fabcic, J., Stampar, F. (2008). Sugars, organic acids, phenolic composition and antioxidant activity of sweet cherry (Prunus avium L.*). Food Chem*. 107, 185–192.

Valentina, U., Jemeja, F. and Franci, S. *Food Chem*. 107, 1, 185-192.

Venturini, M. E., Oria, R., & Blanco, D. (2002). Microflora of two varieties of sweetcherries: Burlat and Sweetheart. *Food Microbiology*, 19, 15–21.

Vursavus, K., Kelebek, H., & Selli, S. (2006). A study on some chemical and physicomechanic properties of three sweet cherry varieties (Prunus avium L.) in Turkey. *Journal of Food Engineering*, 74, 568–575.

Wang, H., Cao, G., Prior, R.L. (1997). Oxygen radical absorbing capacity of anthocyanins. *J. Agric. Food Chem*. 45, 304-309.

Wang, L. and Vestrheim, S. (2002). Controlled Atmosphere Storage of Sweet Cherries (*Prunus avium* L.). *Acta Agriculturae Scandinavica, Section B - Plant Soil Science*, 52, 4, 136-142.

Wargo J.M., Padilla-Zakour O.I., Tandon K.S. (2003). Modified atmosphere packaging maintains sweet cherry quality after harvest. *New York Fruit Quarterly*, 11, 5-8.

Zagory, D. and Kader, A.A. (1988). Modified atmosphere packaging of fresh produce. *Food Tech*. 42:70-74, 76-77.

Zhang, D., Quantick, P. C., & Grigor, J. M. (2000). Changes in phenolic compounds in Litchi fruit during postharvest storage. *Postharvest Biology and Technology*, 19, 165–172.

Table 1. Impact of ambient, refrigerated and modified atmosphere packaging of sweet cherries.

Cultivar	Storage conditions	Storage time (days)	TSS	T.A.	°Brix/acidity	pH	Stem color (%green)	Anthocyanins (mg/g)	Firmness (0-100)$_a$	Color (hue°)	References
Lapins	MAP-(LDPE bags, 0°C)	0	17.52	0.721	24.30	_	100	_	77.20	31.60	Mehruik et al., 1995
		42	17.30	0.601	28.80	_	70	_	77.00	33.20	
		70	18.05	0.373	48.40	_	55	_	68.70	27.20	
Bing	Normal-(Solid box liners,34°F)	0	_	0.97	_	_	100	_	240	32.5	Crisosto et al., 2001
		30	_	0.75	_	_	60	_	210	37.0	
		45	_	0.65	_	_	35	_	195	50.0	
	MAP-(MAP box liners,34°F)	0	_	0.97	_	_	100	_	240	32.5	
		30	_	0.77	_	_	75	_	210	37.0	
		45	_	0.70	_	_	65	_	205	47.0	
Bing	MAP-(Lifespan liner, 34°F)	0	_	0.97	_	_	_	_	290	17.5	Kupferman and Sanderson, 2001
		19	_	0.71	_	_	_	_	300	19.4	
		34	_	0.60	_	_	_	_	317	19.5	
	MAP-(Liespan liner, 45°F)	0	_	0.97	_	_	_	_	290	17.5	
		19	_	0.58	_	_	_	_	295	17.6	
		34	_	0.61	_	_	_	_	255	18.3	
Bing	Ambient-(perforated boxes, 38° F)	0	15.80	0.97	_	_	100	_	240	32	Crisosto et al., 2003
		30	_	0.67	_	_	50	_	220	45	
		45	_	0.60	_	_	30	_	190	53	
	MAP-(MAP lifespan box liners, 38°F)	0	15.80	0.97	_	_	100	_	240	32	
		30	_	0.75	_	_	70	_	205	40	
		45	_	0.70	_	_	60	_	200	45	
Navalinda	Macroperforated (mp) film, 4°C and 20°C)	1	17.07	0.70	24.38	_	_	_	60	_	Alique, R. *et al.*, (2003)
		8	16.43	0.67	24.52	_	_	_	60	_	
		12	16.57	0.64	25.89	_	_	_	70	_	
	MAP-(microperforated PP films, , 4°C and 20°C)	1	18.06	0.70	25.80	_	_	_	65	_	
		8	17.41	0.70	24.87	_	_	_	55	_	
		12	16.31	0.69	23.63	_	_	_	55	_	
Burlat	Refrigerated-(unpackaged, 5°C)	0	15.80	0.65	24.30	_	_	0.30	_	_	Remon et al., 2003
		5	15.60	0.66	23.63	_	_	0.40	_	_	
		10	18.00	0.58	31.03	_	_	0.40	_	_	
	MAP-(PP bags with 676 ml m^{-2} h^{-1} atm^{-1} permeability for both O_2 and CO_2, °C)	0	15.80	0.65	24.30	_	_	0.30	_	_	
		5	15.00	0.67	23.28	_	_	0.37	_	_	
		10	16.00	0.62	25.80	_	_	0.35	_	_	
Lapins	Ambient-(LDPE, 38°F)	0	17.52	0.72	24.33	_	100	_	75.00	_	Wargo et al., 2003
		28	17.38	0.64	27.15	_	50	_	79.00	_	
	MAP-(LDPE, 38°F)	0	17.52	0.72	24.33	_	100	_	75.00	_	
		28	17.38	0.63	27.16	_	100	_	75.00	_	
Lapins	MAP-(PE bags with 5%O2 +10%CO2, 1 °C)	0	18.50	0.97	19.07	_	100	_	78.00	_	Tian et al., 2004
		20	18.50	0.80	23.12	_	100	_	80.00	_	
		40	18.00	0.75	24.00	_	95	_	80.00	_	
	MAP-(PE bags with 13–18%O2 + 2–4%CO2 , 1 °C)	0	18.50	0.97	19.07	_	100	_	78.00	_	
		20	18.50	0.70	26.42	_	100	_	78.00	_	
		40	18.00	0.65	27.69	_	90	_	77.50	_	
Starking	MAP-(PP Films without antifungal treatment,1°C)	0	16.57	0.91	18.20	3.70	100	_	1.48N	_	Serrano et al., 2005
		16	16.58	0.44	37.68	4.50	45	_	1.15N	_	
	MAP-(PP Films with antifungal treatment,1°C)	0	16.57	0.91	18.20	3.70	100	_	1.48N	_	
		16	16.58	0.60	27.63	4.20	80	_	1.10N	_	
Ferrovia	Refrigerated storage-(PP film, 0°C)	0	_	_	28.00	3.7	_	1.65	_	_	Conte et al., 2009
		14	_	_	28.50	3.8	_	1.29	_	_	
		20	_	_	33.00	3.8	_	0.95	_	_	
	MAP-(PP film, 0°C)	0	_	_	22.00	3.8	_	1.39	_	_	
		14	_	_	25.00	3.8	_	0.95	_	_	
		20	_	_	28.00	3.9	_	0.67	_	_	
	Refrigerated-(polyster film, 0°C)	0	_	_	28.00	3.7	_	1.65	_	_	
		14	_	_	27.50	3.8	_	1.29	_	_	
		20	_	_	31.00	3.8	_	1.09	_	_	
	MAP-(Polyester film, 0°C)	0	_	_	22.00	3.8	_	1.39	_	_	
		14	_	_	28.00	3.9	_	1.01	_	_	
		20	_	_	28.00	4.0	_	0.64	_	_	