Postharvest Biology and Technology of Peach

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Introduction

Peach (*Prunus persica* (L.) Batsch) belongs to the family Rosaceae and is native to China (Lurie and Crisosto 2005). The Chinese literature dates its cultivation in China to 1000 BC (Crisosto and Valero 2008). Once, peach was called Persian apple and it was probably carried from China to Persia (Iran) and, thus, peach quickly spread from there to Europe (Lurie and Crisosto 2005). Currently, the world production of peaches stands at 21.2 million tons and the largest producer of peach fruit is China, followed by the United States, Italy, Turkey, Chile, Japan, Australia, and Russia (USDA 2017). Peach is the third most important deciduous fruit crop in the world (Llácer et al. 2009) and the second most important in the European Union, after apple. Spain is the second largest producer in the European Union, after Italy, with 29% of the total production (Europêch 2011).

Peaches are characteristically soft-fleshed and highly perishable fruit, having limited market life. A peach fruit contains approximately 87% water with 43 kcal of energy per 100 g of fruit. It contains carbohydrates, organic acids, pigments, vitamins, volatiles, antioxidants, and trace amounts of proteins and lipids, which make it very attractive to consumers (Crisosto and Valero 2008). It is rich in ascorbic acid (vitamin C), carotenoids (provitamin A), and phenolic compounds that act as

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natural antioxidants (Tomás-Barberán et al. 2001; Byrne 2002). They are highly perishable climacteric fruit and would suffer rapid ripening and deterioration after postharvest, and, thus, have a limited postharvest life at room temperature. During storage time, peach fruit may undergo softening and rotting, which largely cause loss of quality (Razavi and Hajilou 2016). According to Crisosto et al. (2008), peaches with flesh firmness between 9 and 13 Newtons are considered as being at the 'ready-to-eat' stage. Below these values, the fruit could be considered as being in the overripe stage, hence commercially unmarketable.

To improve the storage life and postharvest nutritional quality, and retard metabolic changes which deteriorate peach fruits quickly at ambient temperature after harvest, cold storage is widely used (Girardi et al. 2005). However, peach fruit succumbs to chilling injury within 1–2 weeks when stored at 2–5 °C (Lurie and Crisosto 2005). Chilling injury is characterized by internal browning, mealiness, juicelessness, failure to ripen normally, leatheriness, and other imperfections which are related to cell wall integrity and pectin metabolism (Lurie and Crisosto 2005). Several other techniques used to improve the shelf life of peach are controlled atmosphere storage, modified atmosphere packaging, heat treatment, intermittent warming, chemical treatments, irradiation, and use of nanocomposite packaging material and edible coatings.

Peach fruits are susceptible to attack of phytopathogenic fungi such as *Monilinia laxa*, *Monilinia fructicola* (responsible for brown rot) (Mari et al. 2008), and *Rhizopus stolonifer* (responsible for *Rhizopus* rot) (Salem et al. 2016). These molds are the leading causes of postharvest decay in fully mature and ripe peaches. Thus, control of mold disease is especially important during storage because it develops at both low as well as high temperatures (1–2 °C for gray mold; above 15 °C for black mold) and spreads quickly among fruits (Karabulut et al. 2004). The losses due to fungal decay can be reduced by using synthetic fungicides which can ensure product protection. But the negative impact of these synthetic fungicide residues on human health and the environment has promoted deregulation and restricted use of key chemical fungicides throughout the world (Cetinkaya et al. 2006). Apart from this, the use of gamma irradiation (Kim et al. 2010) and heat treatment (Spadoni et al. 2014) were effective methods to inactivate fungal rots in peaches.

Nutritional Composition

Peach is a good source of ascorbic acid (vitamin C), carotenoids, and phenolic compounds that act as natural antioxidants (Tomás-Barberán et al. 2001; Byrne 2002). The ascorbic acid content of various cultivars of California peach ranged from 6 to 9 mg/100 g in white flesh and from 4 to 13 mg/100 g in yellow flesh (Gil et al. 2002). In another study, the ascorbic acid content of 5–6 mg/100 g in European peach cultivars was observed (Carbonaro et al. 2002).Gil et al. (2002) reported that the total carotenoids concentration was in the range of 71–210 mg/100 g fresh weight for yellow-fleshed and 7–20 mg/100 g for white-fleshed peach cultivars. The main carotenoid detected was β-carotene (provitamin A), but small quantities of α-carotene and β-cryptoxanthin are also present in some peach cultivars.

Fruit phenolics have a role in fruit color, taste, and health beneficial property (Tomás-Barberán et al. 2001). The total phenolics concentration expressed as mg/100 g fresh weight varied from 28 to 111 for white-fleshed and from 21 to 61 mg/100 g of fresh fruit for yellow-fleshed California cultivars (Gil et al. 2002). Other European cultivars had values of 38 mg/100 g (Proteggente et al. 2002), while the Spanish cultivar 'Caterina' showed values of 240 and 470 mg/100 g for pulp and peel, respectively (Goristein et al. 2002). Belhadj et al. (2016) reported that the Chatos variety of peach showed the highest content in the first stage of maturation (around 36.4 mg GAE/g FW) compared with the Elegant Lady variety of peach, which presented 18.37 mg GAE/g FW. It was further reported that the Chatos variety of peach showed the highest content of flavonoids during the first stage of maturation (around 1.22 mg RE/g FW) in comparison with the Gladys variety at the same stage, which was 0.51 mg RE/g FW. The higher concentrations of flavonoid compounds in the first stage of maturation as compared to stages 2 and 3 could be explained by the condensation of different phenolic acids during later stages of maturation, then forming complex phenolic compounds such as tannins and lignin (Ahmed et al. 2009).

Peach fruit accumulates different types of soluble sugars and sugar alcohols, mainly sucrose, glucose, fructose, and sorbitol. Sucrose is the predominant sugar in the peach mesocarp at maturity, accounting for approximately 40–85% of the total sugar content, followed by glucose and fructose, together representing approximately 10–25%, and sorbitol accounting for less than 10%. Sucrose, glucose, and fructose represent about 75% of peach fruit soluble sugars (Crisosto and Valero 2008; Cirilli et al. 2016). The total sugar content increases continuously during peach development up to full maturity, remaining constant or slightly decreasing during postharvest storage (Borsani et al. 2009). Hexoses are the most abundant sugars in immature peach fruit until the beginning of rapid growth by cell elongation, when sucrose becomes the predominant type (Vizzotto et al. 1996; Zanon et al. 2015).

Minerals in peach fruits include macroelements (K, Mg, and Ca) and microelements (Mn, Fe, Cu, and Zn). Iordănescu et al. (2015) while studying the minerals in peach cultivars belonging to the world germplasm collection in the conditions of west Romania, reported that the K content varies between 97.0 mg/100 g FW in the Giala di Roma cultivar and 106.0 mg/100 g FW found in Springold cultivar. In terms of microelement content, iron represents the principal element in the analyzed samples. The Fe content varies between 0.250 mg/100 g FW in the Poli and 0.480 mg/100 g FW in the July Elberta cultivars. The highest Zn content was recorded in the Piros Magdalena and Eureka cultivars (1.84 and 1.80 mg/100 g FW, respectively). Cu and Mn were detected in lower quantities in peach cultivars and hybrids.

Maturity

Maturity is the starting point of postharvest quality management. Therefore, it must be ensured that properly matured fruits should be harvested (Ahmad and Siddiqui 2015). At which stage of maturity a fruit should be harvested is crucial to its subsequent storage, marketable life, and quality. Maturity always has a considerable

influence on the quality of fresh produce as well as the storage potential and occurrence of many storage disorders (Siddiqui and Dhua 2010).

Maturity stage at harvest has been described as a key factor affecting fruit quality (Infante et al. 2012), but this is difficult to determine since flesh firmness (Remorini et al. 2008) and ground skin color, among other parameters described to determine fruit ripeness, do not evolve coordinately during stone fruit maturation (Infante et al. 2008). Many studies have investigated the peach maturity level using destructive or non-destructive methods (Herrero-Langreo et al. 2012; Zhang et al. 2017). Among these non-destructive approaches, visible/near-infrared spectroscopy seems particularly promising, since it provides fast and reliable information on the internal characteristics of many fruit species (Farneti et al. 2015). Nascimento et al. (2016) used near-infrared spectroscopy to investigate peach maturity predictions by the partial least squares model of the soluble solids content and fruit firmness in low chilling peach. They created prediction models for soluble solids content and fruit firmness, and established the optimization potential of the model. Matteoli et al. (2015) proposed a spectral-based non-destructive method for the classification of peach maturity levels that estimates the firmness of the flesh to classify the maturity level by the reflectance spectra. They used multiple retrieval techniques and the fuzzy classification system, and this method lays the foundation for the automatic classification of peach fruit maturity.

The index of absorbance difference (I_{AD}) is an indicator that is based on the close relationship between the degradation of chlorophyll and the maturity of the fruit, which is determined by the difference between the absorption using near-infrared spectroscopy. It directly reflects the actual content of chlorophyll a (Ziosi et al. 2008). The non-destructive measurement of I_{AD} is not harmful to fruit, the reading is fast, convenient, and it is more desired than the destructive assays, such as firmness and soluble solids content. Therefore, it is highly suitable for fruit quality estimation at the end of the supply chain. Currently, I_{AD} predication is carried out mostly on stone fruit trees, such as peach (Shinya et al. 2013) and plum (Infante et al. 2011). Lurie et al. (2013) collected the I_{AD} at harvest of both early- and late-maturity peach varieties, carried out a non-linear regression analysis of the change in firmness during shelf time, and established the logistic model of firmness change. They used time resolution reflectance spectroscopy to evaluate the degree of maturity and believed that the measurement of I_{AD} at harvest might classify the fruits into various categories based their potential shelf time, which may ensure better fruit quality.

During the maturation of peach fruit, the internal soluble solids content rises, firmness declines (Dabbou et al. 2016; Spadoni et al. 2016), red color appearance increases, and the green color in the pericarp fades (Zhang et al. 2015). Zhang et al. (2017) reported that peach (Xiahui 8 variety) had relatively high soluble solids content, a^* and a^*/b^* values, and a low fruit firmness at maturity degree II, which indicated that the I_{AD} for degree II fruit was lower than that for degree I fruit. The a^*/b^* value can reflect the true color of the fruit (Rodrigo and Zacarias 2007) and was higher in the degree II fruit than in degree I peach of variety Xiahui 8 (Zhang et al. 2017). This is consistent with the opposite change in I_{AD}, which indicated that the pericarp I_{AD} value is closely related to the color of the pericarp. A significant differ-

ence in pericarp color, I_{AD} value, and most quality indicators was seen in the fruits at the different maturity degree points. This suggested that light absorption and scattering are the main impacting factors on I_{AD}, which will further affect the pericarp pigment and the change in fruit texture (Zerbini et al. 2006; Muhua et al. 2007; Ziosi et al. 2008).

Fruit Ripening

The postharvest lifetime of fruits can vary from days to several months, and is dependent on a multiplicity of internal and external factors (Tian et al. 2013). The ripening of peach fruit involves many biochemical and physiological processes, such as the degradation of chlorophyll and starch, the biosynthesis of pigments and volatile compounds, the accumulation of sugars and organic acids, as well as the modifications of the structure and composition of cell wall polysaccharides (Giovannoni 2001;Goulao and Olivera 2008). Once ripeness has been reached, the texture of the mesocarp continues to change and soften and, thus, the firmness of the fruit is rapidly lost (Brummell 2006).

The ripening process and fruit genotype are considered as fundamental factors that affect the biosynthesis of phytochemicals. The ripening and respiratory climacteric response are closely associated and are characterized by a burst of respiration that follows a response to ethylene production (Dangl et al. 2000). Peaches can be classified as climacteric fruit according to the patterns of respiration and ethylene evolution, which is a consequence of a dramatic increase in the levels of 1-aminocy clopropane-1-carboxylic acid synthase and1-aminocyclopropane-1-carboxylic acid oxidase, the two enzymes of the biosynthetic pathway (Ruperti et al. 1998, 2001; Giovannoni 2001; Prasanna et al. 2007). This ethylene production plays a key role in peach fruit ripening by coordinating the expression of ripening-related genes responsible for flesh softening, color development, and sugar accumulation, as well as other processes, such as abscission (Ruperti et al. 2002;Trainotti et al. 2006).

The ethylene produced in the early stage of peach fruit ripening indicated it to be a predictor of fruit ripening (Tonutti et al. 1997). However, in some late-maturing cultivars, the time point of respiration peak coincides with that of the peak of ethylene production (Ferrer et al. 2005). In some other cultivars, the peak of ethylene production occurs after the peak of respiration. These differences might be due to the different physiological processes in different fruit cultivars (Huan et al. 2016).

The development and ripening of climacteric fruits are oxidative processes, producing reactive oxygen species (ROS), such as superoxide radical (O_2^-) and hydrogen peroxide (H_2O_2) (Pandey et al. 2013). Huan et al. (2016) reported the roles of ROS as both toxic byproducts and as signaling molecules in fruit development and ripening. Superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPX) play important roles in balancing the induction and removal of ROS in plants, and are respectively encoded by families of closely homologous genes. The experimental results indicated that O_2^- and H_2O_2 acted as potential signaling mole-

cules in the middle stage of fruit development, and only H_2O_2 might function as a main toxic molecule to stimulate lipid peroxidation and oxidative stress in the late stage of fruit ripening. *PpaCu/Zn-SODs* were the most abundant members in the *PpaSOD* gene family and they expressed steadily in peach fruit development and ripening. Low temperature (4 °C) postponed and suppressed the climacteric peaks of respiration and ethylene, significantly enhanced the activities of CAT and GPX, and upregulated the expression of *PpaCAT1* and *PpaGPX6* in the late stage of fruit ripening. *PpaCAT1* and *PpaGPX6* were two key genes in alleviating oxidative stress in the late stage of fruit ripening.

The softening and textural changes that occur during fruit ripening are characteristic of particular species, and are due to differences in cell wall thickness and composition, cell size, shape, packing, contents, and turgor (Harker et al. 1997). Modification of the cell wall is believed to underlie changes in firmness and texture, but the type and magnitude of the alterations carried out during ripening vary considerably (Brummell et al. 2004). According to their texture at full ripening, two groups for the classification of peach fruit are melting flesh and non-melting flesh. When fully ripe, the flesh of melting flesh fruit is soft, juicy, and, therefore, extremely susceptible to handling and physical injuries, whilst non-melting flesh fruit remain firm even when fully ripe and soften slowly when overripe but never melt (Bassi and Monet 2008). Polygalacturonase is one of the pectin-degrading enzymes and plays a central role in the ripening process (Wakabayashi 2000). Ripening-related *exo*-polygalacturonase activity is found in both melting and non-melting peach, but *endo*-polygalacturonase activity accumulates only in ripening melting varieties, coincident with the melting phase (Orr and Brady 1993). The lack of a melting phase in non-melting peach varieties appears to be either due to a deletion of *endo*-polygalacturonase genes or to a truncation of their mRNAs, which causes an absence of immunodetectable *endo*-polygalacturonase protein (Callahan et al. 2004). Thus, *endo*-polygalacturonase-mediated pectin modification may play an important role in the later stages of softening and textural changes in melting flesh peach (Brummell et al. 2004).

Cold Storage

Peaches are highly perishable climacteric fruit and would suffer rapid ripening and deterioration after postharvest, and, thus, have a limited postharvest life at room temperature. Every year, harvesting season falls during a fixed period for 2–3 months (Ahmad and Siddiqui 2015). An increase in the shelf life of peach fruits would help the growers to supply their produce according to the market demand and fetch them better prices, and also make the fruits available to the consumers over an extended period of time (Pongener et al. 2011). Nowadays, low temperature is the most commonly applied method to extend postharvest life and maintain the quality of peach fruits (Razavi and Hajilou 2016).

Cold storage is among the methods used to extend the postharvest life of peach fruits (Lurie and Crisosto 2005). The peach fruits have a shelf life of 2–3 days under ambient conditions and about 2 weeks under cold storage conditions (Kader 2001). According to de Souza et al. (2009), refrigerated storage slows the plant metabolism by decreasing the respiratory rate and enzymatic activity. Cold storage at 4 °C induced greater ethylene production and 1-aminocyclopropane-1-carboxylic acid oxidase activity, accompanied by greater firmness loss in all peach cultivars except for the stony-hard phenotype cultivars (Giné-Bordonaba et al. 2016). Peaches are sensitive to low temperature, which can cause physiological disorders of fruit flesh, usually called chill damage or chilling injury, during cold storage (Jin et al. 2009a). Chilling injury develops more rapidly and severely when fruits are stored at temperatures between 2.2 and 7.6 °C than those stored at 0 °C (Crisosto et al. 1999). Therefore, the maximum storage life of peach fruit can be achieved near or below 0 °C (Lurie and Crisosto 2005).

Controlled Atmosphere Storage

Controlled atmosphere (CA) storage is a system of the storage of fresh produce in an atmosphere that differs from normal atmosphere in respect to CO_2 and O_2 levels. CA storage of peaches with elevated CO_2 and reduced O_2 concentrations delayed or prevented the appearance of mealiness, internal reddening, and flesh browning (Lurie and Crisosto 2005), and maintained the high quality of produce, including firmness (Fernández-Trujillo et al. 2000). In a study carried out by Yang et al. (2006), the investigators reported that yellow peaches were stored under controlled atmospheres of 2% O_2 + 5% CO_2, 5% O_2 + 10% CO_2, 2% O_2 + 10% CO_2, and 5% O_2 + 5% CO_2, with normal atmosphere at 2 °C, to investigate the effect of different concentrations of O_2 and CO_2 on the structure of a single sodium carbonate soluble pectin molecule. The microstructure changes, including aggregates and branches, were studied by atomic force microscopy on, initially, the 15th and 45th days. The microstructure of sodium carbonate soluble pectin molecules and polymers showed that aggregates separated gradually with the storage time. The degradation took place in the linear backbone as well as in side chains. The degradation of sodium carbonate soluble pectin molecules was inhibited by lower O_2 and higher CO_2 concentrations.

de Santana et al. (2011a) reported that the use of controlled atmosphere with elevated CO_2 and reduced O_2 concentrations prevented the onset of the chilling symptoms. Thus, the effects of three different conditions of controlled atmosphere (CA1, CA2, CA3, and control) were evaluated in order to extend the storage life of 'Douradão' peaches. After 14, 21, and 28 days, samples were withdrawn from CA and kept in fresh air at 25 ± 1 °C and 90 ± 5% RH to complete ripening. On the day of removal and after 4 days, the peaches quality characteristics were evaluated. The results showed that the use of CA during cold storage reduced weight loss and prevented postharvest decay. CA2 (5.0 kPa CO_2 and 1.5 kPa O_2) and CA3 (10.0 kPa

CO_2 and 1.5 kPa O_2) treatments were effective in keeping the good quality of 'Douradão' peaches during 28 days of cold storage; the ripe fruits showed reduced incidence of woolliness, and adequate juiciness and flesh firmness. CA1 (3.0 kPa CO_2 and 1.5 kPa O_2) and control treatments (fresh air: 0.03 kPa CO_2 and 20.9 kPa O_2) did not present marketable conditions after 14 days of cold storage.

Modified Atmosphere Packaging

Modified atmosphere packaging (MAP) techniques have been applied to extend the shelf life of peaches because of the resulting reduction in injuries caused by low temperatures (Crisosto and Valero 2008). MAP of peaches slowed down the respiration rate and retarded the decrease in titratable acidity values, maintained the fruit sugar, flesh firmness, total soluble solids, vitamin C, and fruit juice contents, and slowed deterioration through decreasing fruit injury and browning rates (Oliveira et al. 2015).

Fernández-Trujillo et al. (1998) reported that firm-breaker and firm-mature flat peaches were stored in air for 10 days at 20 °C, or precooled and sealed in either one of two unperforated or one macroperforated polypropylene film for 14 or 21 days at 2 °C. The atmosphere inside the macroperforated film bags remained close to the composition of air during storage. In unperforated bags, steady-state atmospheres were reached within 6 and 9 days: firm-breaker fruit (12% CO_2 and 4% O_2 in standard type polypropylene, 23% CO_2 and 2% O_2 in oriented type polypropylene); firm-mature fruit (22% CO_2 and 3% O_2 in standard polypropylene and 21% CO_2 and 2% O_2 in oriented polypropylene). After 14 days storage plus a 3-day shelf life test, woolliness and slight internal browning developed in fruit stored in macroperforated polypropylene. Ethanol and acetaldehyde accumulated to higher levels in oriented polypropylene bags for both firm-breaker and firm-mature fruit. Modified atmospheres in both unperforated bags were associated with lower weight loss, less senescence and chilling injury, absence of decay, and delayed ripening changes of the fruit after a shelf life period.

de Santana et al. (2011b) reported on peaches cv. Douradão packed in polypropylene trays and placed in low-density polyethylene (LDPE) bags (30, 50, 60, and 75 μm thickness) with active modified atmosphere (10 kPa CO_2 + 1.5 kPa O_2, balance N_2). Fruits were kept at 1 ± 1 °C and 90 ± 5% RH for 28 days. After 14, 21, and 28 days, samples were withdrawn from the modified atmosphere and kept in air at 25 ± 1 °C and 90 ± 5% RH for ripening. On the day of removal and after 4 days, peaches were evaluated for woolliness incidence and pectolytic enzymes activities. The respiratory rate and ethylene synthesis were monitored during 6 days of ripening. The results showed that LDPE film 50 μm and LDPE film 60 μm treatments had a positive effect on the inhibition of the development of woolly texture and reduced pectin methylesterase activity on the ripe fruits, keeping the good quality of the

'Douradão' peach variety during 28 days of cold storage. The treatments control, LDPE film 30 μm, and LDPE film 75 μm showed higher woolliness incidence and did not present marketable conditions after 14 days of cold storage.

In another study, Malakou and Nanos (2005) reported on peaches (cv. Royal Glory) treated in 46 °C hot water containing 200 mM NaCl for 25 min, sealed in low-thickness polyethylene bags, and stored at 0 °C for 1 and 2 weeks. Quality was evaluated initially and after each storage period plus 1 day of shelf life. Hot water treatment did not cause any fruit damage based on external observations, specific conductivity, and total phenol content evaluations, but reduced firmness loss, possibly in combination with MAP and kept the cellular membranes functioning better. Polyethylene bags were of low thickness and modified atmosphere conditions inside the bags were found to be inadequate (O_2 levels >15%, CO_2 levels <5%) to significantly affect the ripening process during cold storage, but could be harmful after 10 h at room temperature (O_2 levels <3%, CO_2 levels >13%). Mass losses were kept low in polyethylene bags. Juice soluble solids concentration, pH, and acidity were not affected by the hot water treatment before and after cold storage. Hot water combined with MAP during storage resulted in good quality fruit after 1 week duration for postharvest handling.

Heat Treatment

Peach fruit was subjected to hot water and moist hot air treatment at varying temperatures. The activities of polyphenol oxidase and polygalacturonase were monitored during storage for 0, 3, and 6 days. Polyphenol oxidase activity decreased in all treatments during storage. This decrease was greater in hot water-treated fruits than in fruits treated by hot air. Polyphenol oxidase activity decreased with the increase in treatment duration. However, the polygalacturonase activity increased in heat-treated fruits as well as controls. This increase was more in mild heat treatments as compared to severe heat. Polyphenol and pectin contents decreased during storage in both heat treatments (Bakshi and Masoodi 2010).

Spadoni et al. (2014), while investigating the influence of hot water treatment on brown rot of peach and rapid fruit response to heat stress, reported on peach fruits that were wounded, inoculated with conidia of *Monilinia laxa* and, 15 min, 3, 6, 12, 24, and 48 h after inoculation, treated by dipping in hot water at 60 °C for 20 s. It was observed that brown rot was inhibited by 85.7% when peach fruits were heat-treated 48 h after inoculation. The expression levels of cell wall genes (β-galactosidase, pectin lyase, polygalacturonase, and pectin methyl esterase) showed a general decrease in hot water-treated fruit as compared to the control, whereas phenylalanine ammonia lyase, chitinase, heat stress-related genes, and ROS scavenging genes increased their expression level in hot water-treated samples with respect to the untreated ones.

Intermittent Warming

Intermittent warming (IW) represents an effective and environmentally friendly approach to relieve chilling injury in fruit, and this process is being applied to enhance the quality and shelf life of many fruits and vegetables (Biswas et al. 2012; Liu et al. 2015; Zhou et al. 2015). This method has been shown to be effective in delaying or preventing chilling injury in peach cultivars (Zhu et al. 2010). IW involves exposing fruit to one or more periods of warm temperature during low-temperature storage. Xi et al. (2012) studied the effect of IW on yellow-fleshed peach fruit (melting type) stored at 5 °C or exposed to 20 °C for 1 day every week during storage, and reported that flesh browning was observed on the third day of shelf life at 20 °C after 21 days of storage at 5 °C, while no flesh browning was found in IW-treated fruit for up to 28 days. Significantly lower ester contents were found in peach fruit with flesh browning. The expression profiles of *PpAAT1* were similar to alcohol acyltransferase activity profiles, both of which increased during shelf life of fruit treated with IW. As precursors of esters, the levels of linoleic and linolenic acids were high in IW-treated peach fruit. Treatment with IW effectively alleviated the loss of aroma-related esters associated with flesh browning, and high levels of alcohol acyltransferase activity and *PpAAT1* expression in IW treated peach fruit contributed to the formation of the esters.

Fernández-Trujillo and Artés (1998) reported that firm-breaker and firm-mature peaches were conventionally stored for 4 weeks at 2 °C and 90–95% relative humidity or subjected to IW cycles of 1 day at 20 °C every 6 days of storage at 2 °C. Warming periods induced ripening (reduced flesh firmness, extractable juice, and titratable acidity), while during continuous storage, abnormal values of these parameters were found. After 2 weeks at 2 °C and particularly after the subsequent 3 days at 20 °C, woolliness and, to a lesser extent, vitrescence and dryness of the cortical tissue were detected. Severe levels of these disorders were found more frequently in firm-breaker than in firm-mature fruits, which mainly developed vitrescence. Three cycles of IW prevented chilling injuries but increased weight loss and senescence symptoms. Compared with conventional storage, IW increased the shelf life of firm-mature and firm-breaker peaches by 1 and 2 weeks, respectively.

In another study, Fernández-Trujillo and Artés (1997) reported that peaches were stored at the firm-breaker stage of maturity for 3 weeks at 0.5 °C. A factorial design, involving three cycles of IW for 1 day to 20 °C every 6 days of storage at 0.5 °C, and MAP were applied. During storage, respiratory activity, ethylene emission, flesh firmness, titratable acidity, total soluble solids content, and pH were monitored. The factorial design made it possible to evaluate the effects of interactions between these factors on fruit behavior. The different behaviors induced by IW and MAP account for the different patterns of ethylene emission, flesh firmness, total soluble solids, and total soluble solids/titratable acidity ratio. IW had a prolonged effect on ethylene emission, which continued to be stimulated after the first and second warmings. Intermittently warmed fruits also had the best quality attributes at the end of storage. However, IW did not improve ripening sufficiently when applied

in combination with MAP. Both IW and MAP prolonged shelf life by about 1 week which is more than the improvement by conventional cold storage.

Chemical Treatments

Chemical treatments of peach fruit, such as pretreatment with 1-methylcyclopropene, methyl jasmonate, salicylic acid, calcium chloride, oxalic acid, melatonin, and nitric oxide, are efficient in preserving quality and enhancing the shelf life.

1-Methylcyclopropene

1-Methylcyclopropene (1-MCP), an ethylene action inhibitor, prevents the ripening effects of ethylene in many climacteric fruits (Blankenship and Dole 2003). 1-MCP has been identified to bind irreversibly to ethylene receptors and prevent ethylene-dependent responses. The use of 1-MCP in postharvest science is providing both the potential to maintain fruit quality after harvest and a powerful tool to gain insight into the fundamental processes that are involved in ripening and senescence (Watkins 2006). The effect of 1-MCP on the biochemical and physiological metabolisms of peach fruit has been extensively investigated. 1-MCP can dramatically delay ripening (Hayama et al. 2008), lower ethylene production and respiratory rates (Blankenship and Dole 2003), and maintain good quality of peach fruit (Liu et al. 2005).

1-MCP was applied to early season, melting flesh peach fruit to try to extend their shelf life. 'Almog' and 'Oded', two white-fleshed peaches, were tested. The application of 1-MCP was at both 20 and 0 °C for 5, 10, and 20 h and at concentrations ranging from 0.5 to 20 μL L^{-1}. When treated at 0 °C, the fruits were stored for 5 days before removal to 20 °C for ripening. 1-MCP slowed fruit softening in a concentration- and time-dependent manner, extending the period before the fruits became oversoft. The inhibition of softening was greater when fruits were treated and held at 20 °C than if they were treated at 0 °C and held for 5 days at 0 °C before ripening at 20 °C. Five μL L^{-1} of 1-MCP for 20 h was the optimum concentration and duration of treatment for inhibition of softening. Ethylene production in peaches was not inhibited by 1-MCP at 20 °C but was inhibited after application at 0 °C. Respiration and soluble solids content were not affected by 1-MCP treatment. Titratable acidity loss was inhibited by 1-MCP in 'Almog', but the low-acid cultivar 'Oded' was not affected. When fruit from two harvests, early and late, were examined for their response to 1-MCP, softening was slower in fruit from both harvests. It appears that 1-MCP at high concentrations can extend the shelf life of rapidly softening, perishable fruits, such as early season, melting flesh peach fruit (Liguori et al. 2004).

Jin et al. (2011) investigated the effects of different concentrations (0, 0.1, 0.5, 1, and 5 μL L^{-1}) of 1-MCP on chilling injury, fruit quality, and antioxidant enzyme activities in cold-stored peach fruit and found that the treatment with 0.5 μL L^{-1} 1-MCP significantly alleviated chilling injury symptoms, including internal browning, flesh mealiness, and maintained higher fruit quality. In addition, 1-MCP inhibited the activities of polyphenol oxidase, peroxidase, maintained higher activities of antioxidant enzymes, and kept the balance of the polygalacturonase/pectin methylesterase ratio. The treatment of 1-MCP markedly inhibited the increase of electrolyte leakage and the accumulation of malondialdehyde and hydrogen peroxide. Thus, 1-MCP (0.5 μL L^{-1}) treatment is effective in preventing chilling injury and maintaining overall quality in peach fruit. The effect of 1-MCP on alleviating chilling injury may be due to its capability to enhance antioxidant enzyme activities and to reduce oxidative damage.

Liu et al. (2015) investigated the postharvest characters, phenolic compounds, and total antioxidant activities in response to 1-MCP during the ripening process of peach fruit. Peaches were treated with air (control) or 5 μL L^{-1} of 1-MCP for 24 h, followed by storage for up to 10 days at 20 °C. 1-MCP treatment best retained firmness, soluble solids, titratable acidity, and ascorbic acid. Additionally, ethylene production and respiration rate were delayed. Moreover, treatment with 1-MCP effectively postponed the onset of peak values of phenolic compounds positively identified in the peach fruit. Total antioxidant activities are an important nutritional attribute in the human diet. Our study showed that 1-MCP delayed the increase of antioxidant activity and suppressed antioxidant activities during the prolonged ripening period. These results demonstrated that 1-MCP treatment is a good practice for maintaining fruit quality, but may have complex effects on phenolic metabolism and antioxidant activity.

In another study, Liu et al. (2018) reported that peach fruit were picked at their physiologically mature stage and treated with 5 μL L^{-1} 1-MCP, IW, and a combination of 1-MCP and IW. The severity of chilling injury (CI), quality characters, and phenolic composition, as well as antioxidant properties, were measured during refrigerated storage at 2 °C plus 3 days of shelf life at 20 °C. The results showed that all applied treatments dramatically prevented the degree of flesh browning for 'Yuhualu' peach fruit. Furthermore, 1-MCP treatment was able to alleviate the negative impact of IW, and the combination of 1-MCP and IW possessed the lowest CI index and the highest fruit qualities. Additionally, treatment with 1-MCP alone or combined with IW effectively delayed and elevated the accumulation of phenolics and antioxidant capacities for peach fruit during the entire cold storage and subsequent shelf life period. The application of 1-MCP plus IW could be a favorable practice for preventing chilling injury and maintaining fruit quality for peach fruit during refrigerated storage.

Methyl Jasmonate

Jasmonates are ubiquitous non-classic plant hormones involved in plant responses to various biotic and abiotic stresses (Wasternack 2007), and also respond to fruit growth and ripening (Ziosi et al. 2008). Methyl jasmonate application inhibited or enhanced fruit ethylene production in peaches, apples, and pears at the fruit ripening stage (Fan et al. 1997; Kondo et al. 2007). Methyl jasmonate application resulted in downregulation of the ethylene biosynthetic and softening-associated genes expression during the early and late fruit development stages (Ziosi et al. 2008; Ruiz et al. 2010). Therefore, jasmonates and ethylene may affect the peach fruit ripening process. Meng et al. (2009) investigated changes in the physiology and quality of peach fruits treated by methyl jasmonate under low temperature. The results showed that the treatment of peach fruits with methyl jasmonate decreased the chilling injury index, which was possibly attributed to the higher activity of peroxidase and lower content of phenolic compounds than that without methyl jasmonate treatment. Moreover, treatments with methyl jasmonate not only enhanced the rate of soluble solids content/titratable acidity in peach fruit, but also affected the degradation of cell wall, perhaps by the regulation of cell wall-modifying enzymes and the calcium content in the cell wall of flesh.

Jin et al. (2009b) reported that peaches were harvested at the firm-mature stage and treated with various combinations of methyl jasmonate (MJ) and hot air (HA). The results showed that fruit treated with 1 μmol L^{-1} MJ vapor at 38 °C for 12 h (HMJ) and heat treatment at 38 °C for 12 h, and then treated with 1 μmol L^{-1} MJ vapor at 20 °C for 24 h (HA + MJ) had the highest quality and lowest percentage of chilling injury symptoms. HA treatment alone significantly inhibited internal browning but caused more severe flesh mealiness than other treatments. This side effect was counteracted by MJ. The percentage of extractable juice in combined treatments was higher than that in the control; however, no significant effect was found on firmness. The combined treatments resulted in higher activities of phenylalanine ammonia-lyase, superoxide dismutase, and polygalacturonase, and lower activities of polyphenol oxidase and peroxidase than the control. The combination of HA and MJ vapor treatment might be a useful technique to alleviate chilling injury and maintain peach fruit quality during cold storage. In another study, Yu et al. (2016) reported that the pretreatment of peach fruits with methyl jasmonate in combination with hot air is often effective in reducing chilling injury during cold storage. Peach fruit was treated with hot air at 37 °C for 3 days or methyl jasmonate vapor at 10 μmol L^{-1} for 24 h before storage at 5 °C. Both treatments resulted in an initial increase and then a decrease in sucrose content over the course of storage time. Soluble sugar metabolism affects the quality and chilling resistance of postharvest peach fruit. The results showed that the increase in sucrose observed during cold storage, associated with higher sucrose phosphate synthase and lower acid invertase levels, enhances the chilling tolerance observed in HA and MJ treated fruit.

Salicylic Acid

Salicylic acid (SA), a phenolic compound which is found in a wide range of plant species, has been reported to play a vital role in regulating plant growth and development (Wang et al. 2006). SA induces H_2O_2 accumulation at high temperatures while reducing H_2O_2 at lower temperatures. SA is involved in chilling tolerance through H_2O_2 metabolism mediation (Kang et al. 2003; Wang et al. 2006). SA has also been reported to reduce spoilage in peach fruit by controlling cell membrane electrolyte leakage, decreasing respiration and ethylene production, maintaining flesh firmness, and increasing antioxidant enzymes activities (Han et al. 2003). SA has been reported to regulate antioxidants and maintain dietary value during storage (Hussain et al. 2008).

Tareen et al. (2012) studied the effectiveness of SA at different concentrations (0, 0.5, 1.0, 1.5, or 2.0 mmol L^{-1}) on the postharvest life of peach fruit (cv. 'Flordaking') and reported that fruits were treated with SA immediately after harvest and stored at 0 °C for 5 weeks. Generally, all of the SA concentrations gave a higher activity of superoxide dismutase, catalase, and peroxidase during 5 weeks of storage. The 2.0 mmol SA concentrations showed the highest activity for enzymatic antioxidants. The fruit-browning enzyme polyphenol oxidase activity decreased in SA-treated fruits. SA-treated fruits exhibited higher radical scavenging activity than control fruits. The SA 2.0 mmol concentration resulted in increased fruit weight, firmness, and decreased juice pH. The higher concentration of SA (2.0 mmol) proved to be the most effective in keeping peach fruit quality intact, along with maintaining skin color and delaying fruit surface decay during storage. Conclusively, amongst all treatments, the SA 2.0 mmol application exhibited maximum antioxidants enzymatic activities, minimum weight loss, stored firmness, and decreased pH during the storage period.

In another study, Wang et al. (2006) reported on the peach fruit at commercial maturity immersed in 0, 0.35, 0.7, and 1 mM SA solution for 5 min, stored at 0 °C for 28 days, then moved to 20 °C for 3 days to simulate shelf life. The results showed that only 1 mM SA significantly maintained higher firmness and lower chilling injury, decay index, and thiobarbituric acid-reactive substance of fruit compared with the control. Studies were then conducted to determine if 1 mM SA alleviated chilling injury by influencing antioxidant systems and/or heat shock proteins of the peach fruit. The reduced-to-oxidized ascorbate ratio in 1 mM SA-treated fruit was 39, 61, and 55% higher than that in controls at the midpoint of storage, the end of storage, and after 3 days of shelf life, respectively. The reduced-to-oxidized glutathione ratio in SA-treated fruit was 68% higher than that in controls at the midpoint of storage. Ascorbate peroxidase and glutathione reductase activities in SA-treated fruit were significantly greater than those in controls during cold storage.

Calcium Chloride

Calcium is a major element of fruit, and also functions as an intracellular signal transduction molecule in many physiological processes. Calcium has an important influence on fruit quality and storability, and is used to maintain the quality of fruit during postharvest, reduce decay, and extend shelf life. Rahman et al. (2016) investigated the impact of calcium chloride ($CaCl_2$) concentrations and storage duration on the quality attributes of peach. The peach fruit were dipped in 0, 2, and 4% $CaCl_2$ solution for 10 min and transferred to cold storage at temperature 8–10 °C with a relative humidity of 80–85%. The application of $CaCl_2$ solution and storage duration significantly influenced the fruit quality of peach fruit. However, the application of $CaCl_2$ solution significantly reduced weight loss (4.98%), disease incidence (2.08%), total sugars (5.31%), TSS/acid ratio (16.27), TSS (7.38°Brix), and increased the fruit firmness (2.21 kg cm^{-2}), titratable acidity (0.47%), and ascorbic acid (5.35 mg/100 g) of peach fruits. The storage duration of peach fruit also significantly affected the fruit quality attributes during storage. The peach fruit stored for 30 days showed less fruit firmness (0.74 kg cm^{-2}) and titratable acidity (0.31%), ascorbic acid (4.45 mg/100 g), and increased weight loss (19.74%), disease incidence (16.11%), total sugars (6.07%), TSS/acid ratio (27.62), and TSS (8.54°Brix) of peach fruit. It was concluded that the peach fruit should be treated with 4% $CaCl_2$ solution to retain the quality attributes for 30 days storage.

In another study, Gupta et al. (2011) reported on peach fruits of cv. 'Earli Grande' treated with $CaCl_2$ (4 and 6%) and stored at 0–2 °C and 85–90% RH for 21 days, followed by storage at ambient conditions (28–30 °C, 65–70% RH) for 72 h. $CaCl_2$ at 6% effectively reduced spoilage, physiological loss in weight, and maintained fruit firmness, palatability rating, acidity, vitamin A content, and pectin methyl esterase activity during storage. The results revealed that peach fruits harvested at the optimum stage followed by postharvest dip in 6% $CaCl_2$ solution for 10 min can be stored for 3 weeks in cold storage (0–2 °C, 85–90% RH), with a poststorage shelf life of 3 days at ambient conditions (28–30 °C, 65–70% RH), with acceptable edible quality of fruits.

Gang et al. (2014) investigated the effects of $CaCl_2$ and salicylic acid either alone or in various combinations on the fruit quality and chilling injury of honey peaches during 20 days of cold storage and, subsequently, 3 days of ambient temperature storage. The results showed that combined treatments were better than those of each individual treatment. The combination of $CaCl_2$ and salicylic acid was the most effective treatment in alleviating chilling injury by controlling membrane permeability, inhibiting the respiration rate, and delaying polyphenol oxidase activity. The single $CaCl_2$ application was the most viable in maintaining fruit quality by keeping firmness and retarding weight loss rate during cold and subsequent ambient temperature storage. Therefore, the combined treatment of $CaCl_2$ and salicylic acid was the most effective in peach preservation, and the single $CaCl_2$ treatment can also be promoted.

Oxalic Acid

Oxalic acid (OA) is a natural organic acid present in plants. It has been reported that OA may play a role in response to environmental stress, systemic resistance, and programmed cell death in plants (Liang et al. 2009). In recent years, the treatment of OA in postharvest fruits has received much attention. It has been noted that OA increases resistance to chilling injury and maintains the postharvest quality of peach and plum fruit (Sayyari et al. 2010; Wu et al. 2011).

Razavi and Hajilou (2016) investigated the enhancement of postharvest nutritional quality and antioxidant capacity of peach fruits by preharvest oxalic acid treatment. Their results showed that the application of OA significantly enhanced antioxidant enzymes catalase, peroxidase, and superoxide dismutase activities in peach fruits during cold storage. In addition, the increases in total flavonoids, phenolics, and antioxidant activity were higher in treated than in control fruits, leading to fruit with high bioactive compounds and antioxidant potential assayed by 1,1-diphenyl-2-picrylhydrazyl and ferric-reducing antioxidant power methods. During storage, the softening rate was higher in non-treated fruit. Thus, preharvest treatments with OA could be a promising strategy to maintain fruit quality and antioxidant capacity, as well as maintain a high flesh firmness following postharvest storage and export.

In another study, Jin et al. (2014) investigated the effects of postharvest OA treatment on 'Baifeng' peach fruit stored at 0 °C and reported that the internal browning was significantly reduced by OA treatment in peaches. OA treatment markedly inhibited the increase of ion leakage and the accumulation of malondialdehyde. Meanwhile, OA significantly increased the contents of adenosine triphosphate and energy charge in peach fruit. The enzyme activities of energy metabolism, including H^+-adenosine triphosphatase, Ca^{2+}-adenosine triphosphatase, succinic dehydrogenase, and cytochrome C oxidase, were markedly enhanced by OA treatment. The ratio of unsaturated/saturated fatty acid in OA-treated fruit was significantly higher than that in control fruit. The alleviation in chilling injury by OA may be due to enhanced enzyme activities related to energy metabolism and higher levels of energy status and unsaturated/saturated fatty acid ratio.

Melatonin

Melatonin (MT) performs diverse physiological functions in plants. In addition to serving as darkness signaling and plant growth-promoting regulators, another noticeable role is its antioxidant activity associated with the protection of plants against internal and environmental oxidative stresses (Reiter et al. 2015; Tan 2015; Zhang et al. 2015). Cao et al. (2016) proved that MT ensures better prevention of chilling injury in peach fruit during low-temperature storage, and such an effect has

been attributed, in part, to MT-induced promotion of polyamine, γ-aminobutyric acid, and proline.

Gao et al. (2018) studied the effects of 0.1 mM MT on peach fruit during storage at 1 °C for 28 days and reported that MT treatment delayed the development of chilling injury (CI) in peach fruit, as illustrated by MT-treated fruit showing lower CI incidence, CI index, and firmness loss than the control fruit. MT application prevented membrane lipid peroxidation and contributed to maintaining a higher ratio of unsaturated to saturated fatty acids in peach fruit. MT treatment also stimulated the activities of glucose-6-phosphate dehydrogenase, shikimate dehydrogenase, and phenylalanine ammonia lyase, but inhibited the activities of polyphenol oxidase and peroxidase. This would help in activating the accumulation of total phenolic and endogenous salicylic acid that might have a direct function in the alleviation of CI. In another study, Gao et al. (2016) reported on two cultivars of peach fruit, 'Shahong' and 'Qinmi', that were treated with MT at 0.1 mmol L^{-1} and then stored at ambient temperature (25–28 °C) for 7 days. The results showed that MT treatment effectively slowed the process of senescence in both peach cultivars, as indicated by reduced weight loss, decay incidence, and respiration rate, as well as maintained firmness, total soluble solids, and ascorbic acid contents. MT treatment significantly enhanced the activities of superoxide dismutase, catalase, peroxidase, and ascorbate peroxidase in both cultivars, but decreased the activity of lipoxygenase, levels of superoxide anion and hydrogen peroxide, and malondialdehyde content. These results indicate that the activation of antioxidant enzymes to scavenge superoxide anion and hydrogen peroxide by MT treatment was associated with the maintenance of membrane integrity, which might be a part of the mechanism implicated in the delay of senescence in peach fruit.

Nitric Oxide

Nitric oxide (NO) is an important bioactive signaling molecule with diverse physiological functions in phylogenetically distant species (Perazzolli et al. 2006). The use of NO on postharvest fruit ripening has become a focus for many researchers because of the potential of NO to maintain fruit quality after harvest and to be a powerful tool for gaining insight on ripening processes (Manjunatha et al. 2010). An increasing number of studies indicate that the NO signal influencing fruit ripening is complicated. NO appears to play significant roles in the transit and storage of fruit commodities, and the effects of NO were linked to the inhibition of pectin depolymerization (Zhang et al. 2011), reduction of chilling injury (Singh et al. 2009), decrease in ethylene production (Zhu et al. 2006), and inhibition of phenolic metabolism (Zhu et al. 2009).

The effects of NO on ethylene biosynthesis and lipoxygenase activity in peach fruit were studied by Zhu et al. (2006). It was observed that, in peaches treated with 5 and 10 μL L^{-1} NO, 1-aminocyclopropane-1-carboxylicacid (ACC) oxidase activ-

ity, ethylene production, and lipoxygenase activity were reduced. This led to the accumulation of ACC and 1-malonylaminocyclopropane-1-carboxylic acid during storage. There was no evidence that ACC synthase activity was affected significantly by any concentration of NO. A plausible mechanism is proposed that NO is bound to ACC oxidase to form an ACC oxidase–NO complex, which is chelated by ACC to produce an ACC–ACC oxidase–NO complex, leading to a decrease in ethylene production. The increase in concentration of ACC in NO-treated peaches may result in the redirection of ethylene to 1-malonylaminocyclopropane-1-carboxylic acid production. This is a secondary effect of NO. In another study, Flores et al. (2008) reported on peaches of cv. 'Rojo del Rito' treated with 5 μL L^{-1} of NO for 4 h, at 20 °C, and then stored at the same temperature for 14 days. The ethylene production and respiratory rate of fruits treated with NO were lower than those of control fruits. Treated fruits underwent a lesser loss of firmness during storage. The degree of disintegration of cell membranes, assessed as the percentage of electrolyte leakage, was also lower in fruits treated with NO.

The effect of NO solution on pathogen infection and defense response of peach fruit against brown rot disease caused by *Monilinia fructicola* was investigated by Gu et al. (2014). The results showed that 15 μmol L^{-1} NO solution did not significantly inhibit spore germination, germ tube length, or pathogenicity of *M. fructicola*, but significantly reduced disease incidence and lesion areas in the fruit. Although 100 μmol L^{-1} NO solution effectively inhibited the spore germination, germ tube elongation, and pathogenicity of *M. fructicola*, the high concentration of NO solution caused damage to the fruit. Moreover, 15 μmol L^{-1} NO enhanced the activities of chitinase and β-1, 3-glucanase in the fruit.

Irradiation

Irradiation treatment of peach fruits after harvest have evoked much interest for the control of microbial pathogens, mold growth, and delay of ripening, thus increasing the shelf life of fruits (Kim et al. 2010). Hussain et al. (2008) investigated the effect of gamma irradiation on retaining the quality of peach fruit. The peach fruit, after harvesting at the proper maturity stage, was irradiated in the dose range of 1.0–2.0 kGy, stored under ambient (25 °C, RH 70%) and refrigerated (3 °C, RH 80%) conditions, and evaluated for different quality parameters. The anthocyanin evaluation of the fruits revealed that irradiation enhanced the color development under both storage conditions. The gamma irradiation dose of 1.2–1.4 kGy proved to be effective in maintaining higher TSS concentration, reducing weight loss, and significantly delaying the decaying of the fruit by 6 days under ambient conditions and by 20 days under refrigerated conditions.

Kim et al. (2010) investigated the effect of gamma irradiation (0.5–2 kGy) on the physicochemical properties of peaches during 6 days of storage at 20 °C and found that the gamma irradiation was able to inactivate the four pathogens *Botrytis cinerea*, *Penicillium expansum*, *Rhizopus stolonifer*, and *Monilinia fructicola*. Hardness

significantly decreased with increment of the irradiation dose level, whereas soluble solid and total polyphenol contents increased with increment of the irradiation dose. The radical scavenging activity of the irradiated peach was higher than that of the control, and its activity increased with increment of the irradiation dose level. These results suggest that gamma irradiation of peaches improved antioxidant activity but dramatically affected the hardness throughout the entire storage time.

Six varieties of peaches were irradiated in small batches at 0.29, 0.49, 0.69, and 0.90 kGy to observe the sensitivity of peaches at different dose levels. There was no dose effect on titratable acidity, Brix, and weight loss due to irradiation. Peaches irradiated at 0.69 and 0.90 kGy were darker in flesh color, more juicy, and less firm. Commercial-scale irradiation did not adversely affect shelf life but was seen to enhance ripening. Overall, consumers rated the acceptability of irradiated peaches higher than untreated peaches (McDonald et al. 2012).

Edible Coatings

Edible coatings are applied on fruits to minimize the release of respiration gases during storage, thus increasing the storage life of fruits (Ruoyi et al. 2005). Edible coating materials such as polysaccharides, proteins, and essential oils may serve as edible coatings for extending the shelf life of fruits (Rojas-Graü et al. 2008; Bosquez-Molina et al. 2010). Extending the shelf life of fresh peach using edible coatings is beneficial to preserve and maintain freshness due to its short postharvest life at room temperature and high susceptibility to pathogens causing brown rot, which is a major disease of peach fruit (Zhou et al. 2008; Sasaki et al. 2010).

Asghar et al. 2014 investigated the effects of edible gum, glycerin, and calcium lactate treatment on the postharvest quality of peach fruits stored for 32 days at 10 °C. Different concentrations of additives were prepared, e.g., peaches in treatments AS_1 and AS_2 were dipped in 1% and 2% calcium lactate solution, respectively, for 20 min and coated with xanthan gum (1%) + glycerin (2.5%), whereas peaches with treatment of AS_3 and AS_4 were dipped in 1% and 2% calcium lactate solution, respectively, for 20 min and coated with gum arabic (1%) + glycerin (2.5%), respectively. The fruits were packed in corrugated soft board cartons and stored for 1 month at ambient temperature and analyzed for various physicochemical and sensory attributes every4 days of storage. The results indicated that storage intervals and treatments had significant effects on the quality characteristics of the whole peach fruits throughout storage. Physicochemical analysis of peach fruits revealed that fruits treated with 1% and 2% calcium lactate solution and edible coating of xanthan gum (1%) + glycerin (2.5%) had little improvement on shelf life extension, while fruits treated with 1% and 2% calcium lactate solution and edible coating of gum arabic (1%) + glycerin (2.5%) maintained maximum firmness, total soluble solids, ascorbic acid content, overall acceptability, increased sugar/acid ratio, and reduced decay index and weight loss during storage.

Guillén et al. (2013) reported on harvested peaches that were coated with either *Aloe vera* and *Aloe arborescens* gels and allowed to ripen at 20 °C for 6 days. Both coatings significantly delayed ethylene production. Changes in quality parameters related to peach postharvest ripening, such as color changes, reduction of acidity, and increase in the ripening index (total soluble solids/total acidity ratio) were significantly delayed in coated fruit. In addition, both coatings significantly reduced weight loss, especially the *A. arborescens* gel. Thus, *A. arborescens* gel could be even more effective than *A. vera* gel for use as an edible coating for preserving the quality of peach fruit.

Hazrati et al. (2017) studied the effect of A*loe vera* gel coating on peach fruits during the cold storage period and reported that *Aloe vera* gel coating had significant positive effects on weight loss, color change, and sensory evaluation. The amount of weight loss, color change, total soluble solids, and titratable acidity in fruits with coating was lower than in control fruit. Also, the results showed that *A. vera* gel coating can enhance visual properties and could also lead to more favorable taste and texture.

Hussain et al. (2016) reported on carboxymethyl cellulose (CMC) coatings alone and in combination with gamma irradiation tested for maintaining the storage quality and control of postharvest gray and black mold disease of peaches. Matured green peaches were coated with CMC at a 0.5–1.0% (w/v) level and gamma irradiated at 1.2 kGy. The treated fruit including control was stored under ambient (temperature 25 °C, RH 70%) and refrigerated (temperature 3 °C, RH 80%) conditions. In fruits treated with individual treatments of 1.0% (w/v) CMC, 1.2 kGy irradiation, and combination of 1.0% (w/v) CMC and 1.2 kGy irradiation, no decay was recorded up to 6, 8, and 14 days of ambient storage. Irradiation alone at 1.2 kGy prevented the onset of disease incidence up to 4 days compared to 2 days by 1.0% (w/v) CMC coating following 30 days of refrigeration. A combination of CMC at 1.0% (w/v) and 1.2 kGy irradiation prevented disease incidence of peach up to 7 days during postrefrigerated storage at 25 °C, RH 70% following 30 days of refrigeration.

Gad et al. (2016), while investigating the development of nano-chitosan edible coating for peach fruits cv. 'Desert Red', reported on fully mature peach fruits harvested and then coated with one of the following nano-chitosan concentrations: 0.2, 0.4, and 0.8%. The fruits were stored at 0 °C and 90–95% relative humidity for 28 days and quality parameters were analyzed in weekly intervals after 7, 14, 21, and 28 days. The results of the two successive seasons 2015/16 indicated that the nano-chitosan 0.4% treatment gave the lowest fruit decay percentage and TSS/acid ratio compared with other treatments in both seasons. The highest concentration of nano-chitosan reduced fruit weight losses and maintained fruit pulp firmness. With the advancing of the cold storage period, fruit weight losses, fruit decay percentage, and TSS/acid ratio were gradually increased, while fruit pulp firmness, total soluble solids, and acidity were decreased. The best qualities of peach fruits were obtained from the 0.4% nano-chitosan treatment after 28 days of cold storage, while 0.8% nano-chitosan treatment increased the fruit decay percentage.

Hossein-Farahi et al. (2016) studied the influence of chitosan (CS) coating combined with calcium sulfate ($CaSO_4$) treatment on peach fruit and reported on fruits

coated with CS 2%, CS 3%, CS 2% + CaSO4 5%, and CS 3% + $CaSO_4$5%. Treated fruits were stored at 4 °C and 80% relative humidity for 60 days. The fruit weight loss percentage, fruit decay percentage, fruit firmness, and fruit shriveling percentage were monitored at an interval of 15 days up to 60 days. The weight loss of treated and untreated fruits increased during storage. At the end of 30 days storage, the weight loss of fruit coated with 3% chitosan was significantly reduced compared to other treatments. The highest and lowest fruit firmness was observed in peach coated with CS 3% + $CaSO_4$5% and uncoated fruits with values of 2.1 and 0.7 kg cm^{-2}, respectively. Until 45 days after harvest, peach coated with CS 3% showed the lowest fruit decay percentage and fruit shriveling percentage as compared to uncoated fruits. These results indicate that the application of CS edible coating treatment is an effective technique for keeping and maintaining organoleptic characteristics, as well as extending the postharvest life of peach fruits. The results recommend the application of 3% CS + 5% $CaSO_4$ to increase postharvest quality of peach cv. 'Alberta'.

Physiological and Microbiological Disorders

Peach fruits are susceptible to chilling injuries and attack of phytopathogenic fungi, such as *Monilinia laxa*, *Monilinia fructicola* (responsible for brown rot), and *Rhizopus stolonifer* (responsible for *Rhizopus* rot), which deteriorate fruit quality and consumer acceptance.

Physiological Disorders

Peaches perish quickly after harvest at ambient temperature due to their fast ripening and lack of anti-decomposition agents. Low-temperature storage is an effective method to slow these decay processes and maintain crop quality. However, peaches are sensitive to low temperature, which can cause physiological disorders of fruit flesh, usually called chilling injury or cold injury during cold storage, at market, or at home (Jin et al. 2009a). Chilling injury limits the storage period and shelf life of fruit, thus reducing consumer acceptance and economic value. Chilling injury develops more rapidly and severely when fruits are stored at temperatures between 2.2 and 7.6 °C than those stored at 0 °C (Crisosto et al. 1999). Chilling injury is genetically influenced and triggered by a combination of factors, such as storage temperature and storage period. It manifests itself as fruit that are dry and have a mealy or woolly texture (mealiness or woolliness), or hard-textured fruit with no juice (leatheriness), fruit with flesh or pit cavity browning (internal browning), or with flesh bleeding (internal reddening), and these symptoms are related to cell wall integrity and pectin metabolism (Lurie and Crisosto 2005). It was further investigated that peaches developing mealiness were found to be deficient in their ability

to produce ethylene, thus affecting their normal ripening process during storage (Zhou et al. 2001). The symptoms will develop and become evident immediately or over a period of several days once peaches are transferred to a warm environment (i.e., 20 °C or above) and the problem is commonly not noticed until the fruit reaches consumers (Lurie et al. 2011).

Fruk et al. (2014) reported that the metabolism of pectins participates in a number of physiological disorders during peach storage (e.g., mealiness, leatheriness, woolliness), and its biggest role is in the woolliness of these fruit, such that pectins in intercellular spaces bind the free juice into pectate gels. Disorders of pectin metabolism are caused by changes in the pectolytic enzyme activities (i.e., mainly *endo*-polygalacturonase and *exo*-polygalacturonase, pectin esterase, cellulose, lipoxygenase). Such disorders lead to an imbalance in the degradation of the pectins, which has the effect of binding the juice into pectate gels.

Several treatments to delay and limit the development of this disorder have been tested, such as controlled delayed cooling (Lurie and Crisosto 2005), modified atmosphere packaging (Steiner et al. 2006), IW (Fernández-Trujillo and Artés 1998), and pretreatment with 1-methylcyclopropene (Jin et al. 2011), melatonin (Gao et al. 2018), oxalic acid (Jin et al. 2014), and methyl jasmonate (Meng et al. 2009).

Microbiological Disorders

Brown Rot

Brown rot caused by *Monilinia laxa* Honey, *Monilinia fructicola* (winter) Honey, or *M. fructigena* (Aderhold & Ruhland) is a serious fungal disease of peaches (Mari et al. 2008). Postharvest losses due to brown rot are typically greater than preharvest losses, and routinely occur during handling, storage, and transport (Hong et al. 1997). Villarino et al. (2011) reported that the susceptibility of peaches to *M. laxa* infection was greatest when the pericarp was completely formed and the concentrations of chlorogenic and neochlorogenic acid in the pericarp are low. Melanin production by *M. laxa* is inhibited when the concentrations of chlorogenic and neochlorogenic acid in the pericarp are high and melanin is essential for penetration of the pericarp by *Monilinia* spp.

Rhizopus *Rot*

Rhizopus species are considered as among the most devastating fungi during the storage of various horticultural commodities (Salem et al. 2016). *Rhizopus* rot caused by *Rhizopus stolonifer* is one of the most common postharvest diseases of peach fruit (Northover and Zhou 2002). Among peach fruit, *Rhizopus* rot is second

only to brown rot by *Monilinia* spp. in causing serious economic losses (FAOSTAT 2015). The symptoms of *Rhizopus* rot rarely occur in orchards, as it is generally a problem of mature and fully ripe peach fruits and occurs mostly in storage. The pathogen enters the peach fruits only through injuries caused during harvesting (Parveen et al. 2016). *Rhizopus* rot appears particularly on mature fruit, when temperatures are higher than 5 °C (i.e., during processing at room temperature, shelf life, or at the consumer's home), and spreads quickly from infected to healthy fruit (Ogawa et al. 1995). The symptoms on these fruits appear as small water-soaked areas that become soft and rotten. The infected fruits are covered by white fluffy mycelium that later turn black due to sporulation. The infected tissue becomes a soft, watery rot (Parveen et al. 2016).

Control of mold disease is especially important during storage because it develops at both low as well as high temperatures (1–2 °C for gray mold; above 15 °C for black mold) and spreads quickly among fruits (Karabulut et al. 2004). The losses due to fungal decay can be ameliorated by using synthetic fungicides, which can ensure product protection. However, increased public awareness about the negative impact of these synthetic fungicide residues on human health and the environment has promoted the deregulation and restricted use of key chemical fungicides throughout the world (Cetinkaya et al. 2006). Microbial antagonists, natural compounds, or physicochemical treatments have been evaluated by different investigators (Droby et al. 2009; Nunes 2012). The use of gamma irradiation was an effective method to inactivate the four pathogens *Botrytis cinerea*, *Penicillium expansum*, *Rhizopus stolonifer* var. *stolonifer*, and *Monilinia fructicola* in peaches (Kim et al. 2010). Recent investigations reported a significant reduction of *M. laxa* incidence in fruit after water dipping at 48 °C for 12 min (Jemric et al. 2011); similarly, Spadoni et al. (2014) obtained an 85.7% reduction of brown rot in peach by dipping fruit in hot water at 60 °C for 20 s.

Conclusion

Peach is a popular summer fruit and there has been an increasing interest in their nutritional value due to their antioxidant potential. It is a highly perishable climacteric fruit and would suffer rapid ripening and deterioration after postharvest, and, thus, have a limited postharvest life at room temperature. To improve the storage life, postharvest nutritional quality, and retard metabolic changes which deteriorate peach fruits quickly at ambient temperature after harvest, low-temperature storage is widely used. However, peach fruit succumbs to chilling injury within 1–2 weeks when stored at 2–5 °C. Several treatments to delay and limit the development of these disorders have been tested, such as cold storage, controlled and modified atmosphere storage, modified atmosphere packaging, irradiation, IW, use of coatings, use of nanocomposite packaging material, use of fungicides, and different chemical treatments.

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