Postharvest Biology and Technology of Apricot

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Introduction

Apricot (*Prunus armeniaca* L.) belongs to the family Rosaceae; subfamily Prunoideae and genus *Prunus*. Rosaceae is one of the largest families in angiosperms, having about 3400 species, including peaches, almonds, apples, plums, cherries, etc. They are mostly distributed throughout the northern temperate regions of the globe. Apricots thrive best in regions with cold winters and moderately high temperatures in the spring and early summer (Guclu et al. 2006; Ahmadi et al. 2008). Apricot is a drupe fruit in which a hard stone (endocarp) having a kernel/seed inside is surrounded by an outer fleshy part (exocarp and mesocarp). Its cultivation dates back to 2000 BC and China is considered to be the center of its origin (Crisosto et al. 1999). However, apricot gradually passed through the Persian Empire into the Mediterranean and was best adapted, whereas Romans were believed to have introduced apricots to Europe (Crouzet et al. 1990). Apricots are grown worldwide, with an annual global production of 3,881,204 tons in 2016. Armenia, Afghanistan, Iran, Italy, and Turkey are the largest producers of both fresh and dried apricots (FAOSTAT 2014). The color of apricots varies from orange to orange red, while some cultivars are creamy white to greenish white (Ruiz et al. 2005; Riu-Aumatell et al. 2005).

Apricot fruits are mostly destined for fresh consumption because of their short shelf life. Further, rapid softening and susceptibility to physical damage and diseases creates hurdles in their distribution. Apricots are usually harvested at the preclimacteric stage without attainment of proper flavor and taste. The stage of development at the time of harvest and changes which occur during the postharvest

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period determine the optimum fruit quality. Postharvest technology of apricots should aim at the reduction of fruit losses as well as optimization of quality throughout the postharvest chain. With advances in logistics and packaging technology, the consumption of fruits has become possible, even in distant markets.

Nutritional Value

Apricots are generally considered to be a rich source of carotenoids, ascorbic acid, polyphenols, iron, potassium, polysaccharides, fiber, and minerals (Jiménez et al. 2008; Ali et al. 2011; Hussain et al. 2011). Apricot fruits are not only important from the nutritional point of view, but they also play a very important role in maintaining optimum health. Malic acid, citric acid, and succinic acid are the major organic acids present in apricots (Bartolozzi et al. 1997). These organic acids not only contribute organoleptic properties of fruits, but they also have some other benefits. Succinic acid helps in treating diabetes, malic acid possesses some bactericidal properties, oxalic acid is used for curing wounds and ulcers, while citric acid functions as a crystal thickener in bones (Carocho et al. 2013).

Phenolic compounds and carotenoids are of immense importance due to their antioxidant potential and role in preventing many diseases. In apricots, the total phenolic composition ranges from 50 to 563 mg GAE/100 g on a fresh weight basis (Sartaj et al. 2013). Chlorogenic acid, neochlorogenic acid, (+)catechin, (−)epicatechin, and rutin are the main phenolics present in apricots (Erdogan-Orhan and Kartal 2011). About 250 g of fresh apricots or 30 g of dried apricots can meet the daily body requirements of provitamin A (Sartaj et al. 2013). Carotenoids prevent oxidative damage through scavenging the reactive oxygen species. The intake of carotenoids can decrease the risk of certain diseases like lung and prostate cancers, cardiovascular diseases, and eye problems (Johnson 2002).

Maturity Indices

The harvest date is usually determined by a change in skin color from green to yellow and also depends on the varietal character of the fruit. However, the soluble solids content (SSC) and flesh firmness are also considered as important maturity indices (Feng et al. 2013). Apricots are harvested at the preclimacteric stage and quickly marketed, as mature fruits can experience reduced shelf life and become susceptible to mechanical damage (Aubert and Chanforan 2007). Thus, apricots are picked before reaching the highest organoleptic qualities. This may lead to low rates of consumption among consumers, mainly due to the lack of flavor and internal breakdown problems (Bruhn et al. 1991). Thus, the harvesting of fruits should be planned in a manner so as to provide a balance between optimum storage potential and eating quality.

Quality Indices

Apricot fruit quality is defined by physical, biochemical, sensory, mechanical, and functional properties. Carlos and Kader (1999) provided a number of quality indices for apricots, which include fruit size, shape, and absence of defects and damage. The quality components, viz., color, SSC, and firmness of fruits, are important to the growers as well as the processors, as they affect the product appearance and consumer acceptance (Gomez et al. 2005; Luchsinger and Walsh 1998). Apricots are especially characterized for their aroma, in addition to their color, sweetness, and texture of the fruit. Practically, apricot fruit must be sweet in taste with good flavor and optimum firmness to avoid any physical damage prior to its consumption. Fruits with total soluble solids (TSS) greater than 10°Brix and acidity of about 0.7–1.0% are widely accepted among consumers. Apricots with flesh firmness of 2–3 pounds are considered ready to eat.

Apricots are traditionally harvested and graded on the basis of visual color. This may only be an approximation of fruit maturity, as other significant factors, like firmness, TSS, etc., are not taken into account. Further, this visual determination of color is subjective and likely to be influenced by environmental conditions.

New and rapid analytical methods for assessing fruit quality attributes has increased during the last decade (Chen and Sun 1991). Near-infrared spectroscopy is probably the most studied and accomplished non-destructive method applied to agricultural products. Camps and Christen (2009) reported that near-infrared spectroscopy technology could be applicable to apricot quality also and that such portable devices can help to classify fruits as per the given variability and could assist in complete follow-up of the fruits in orchards and during postharvest. Petrisor et al. (2010) confirmed the use of the acoustic impulse response technique for the determination of texture as a non-destructive measuring tool for distinguishing different stages of ripeness in apricots. Further, online packing house, screening of color, firmness, and SSC are done by using non-destructive technologies, which can aid in measuring maturity indices for fruit quality at harvest as well as after storage (Feng et al. 2013).

The electronic tongue system, which is based on potentiometric or voltammetric chemical sensors (showing sensitivity to various substances), has recently proved to be a promising tool for monitoring the effects of postharvest techniques on the apricot ripening process. The use of such type of sensors is mostly done for measuring organoleptic properties. In apricots, it was used to detect considerable differences among controlled atmosphere and 1-methylcyclopropene (1-MCP)-treated fruits (Kantor et al. 2008).

Ripening

Ripening constitutes the period from the last stages of growth to the earliest stages of senescence, making a fruit more attractive and appealing for consumption (Tucker and Grierson 1987). It comprises several changes, which are genetically well

programmed to give attractiveness and palatability to the fruit (Lelievre et al. 1997; Giovannoni 2001). This developmental stage may lead to some prominent effects, like increase in size, sugars, change in color, soft texture, development of aromatic volatiles, synthesis and degradation of pigments, and reduction in acidity of the fruit. As the ripening stage advances, the susceptibility to pathogen infection increases (Adams-Phillips et al. 2004; Giovannoni 2004).

For determining the taste of ripe fruits, the level of sugars and acids are important and the TSS/acidity ratio is used as an index of consumer acceptance. During growth and ripening stages, sugar accumulates due to carbon import from photosynthetic leaves in the form of sucrose and sorbitol in the Rosaceae family, which leads to an increase in TSS (Rhodes 1980). Moreover, apricots have sucrose as the predominant sugar, which is usually accumulated at the S_3 stage due to an increase in sucrose synthase (Morandi et al. 2008). Malic acid (the predominant acid in apricots) accumulates during the first rapid growth phase and diminishes during the maturation and ripening stages (Serrano et al. 2005). Ayour et al. (2016) reported that acidity decreases from semi-ripe, commercially ripe, and tree ripe stages, while pH, ripening index, and TSS increase. This change may be due to gluconeogenesis, which leads to the metabolic conversion of acids into sugars. Thus, ripening induces an increase in the TSS and a decrease in titratable acid content, creating the situation for the characteristic apricot fruit taste.

The composition, structure, and morphology of the fruit cell wall influence texture. Ripening leads to softening, solubilization, and depolymerization of cell wall polysaccharide and loss of sugars. These changes are mostly due to the presence and action of cell wall degrading enzymes (Brummell 2006; Goulao and Oliveira 2008). However, besides respiratory peak exhibition, ripening also involves ethylene production. The softening of apricot fruits has been reported to start even when ethylene was undetected, which shows its sensitivity to ethylene (Mencarelli et al. 2001). Cardarelli et al. (2002) reported that exogenous treatment with propylene stimulated ethylene production and also resulted in fruit softening. This confirms the role of pectin methyl esterase and glycosidases in the softening of apricot via ethylene tissue sensitivity. Electron microscopy has revealed that ripening induces changes in texture involved in the dissolution of middle lamella, which follows distortion of the primary cell wall structure, thus making the cell wall thinner.

During ripening, carotenogenesis takes place parallel to the loss of chlorophyll, in which chloroplasts are converted into chromoplasts by the degradation of chlorophyll and synthesis of carotenoids (Hortensteiner 2006). This leads to the development of yellow and orange colors. Maturity has an important effect on the evolution of pigment content. While the surface color of fruit is initially green, it starts to turn yellow with ripening due to the degradation of chlorophyll. The carotenoid content of apricots varies from 0.1 to 4 mg/100 g (Kurz et al. 2008). From the nutritional point of view also, carotenoids are a widespread group of pigments due to their provitamin A activity (Schieber and Carle 2005). β-Carotene is reported to be the main pigment in apricot clones (Ayour et al. 2016). Furthermore, good correlation between carotenoid content and color of skin and flesh was reported by Ruiz et al. (2005)

in apricot fruits. Fruits having orange flesh exhibit more carotenoid content than lighter colored fruits.

The concentration of phenolic constituents increases with the maturity of fruit and, at the fully ripened stage, it attains a maximum; however, some phenolic constituents may also decrease with the stage of maturity (Dragovic-Uzelac et al. 2007). Some studies have also shown high concentrations of phenolic compounds in unripe apricot fruits (Kalyoncu et al. 2009).

One of the important changes associated with fruit ripening is the development of flavors, which is one of the important parameters in the assessment of fruit quality. A significant number of volatile compounds is released by fruits and they vary in quantity as well as quality. The first significant study on apricot flavors was conducted by Tang and Jennings (1967, 1968), who identified nine major aromatic components. So far, more than 200 compounds have been identified in apricot, which can contribute to the aroma of fruits (Nijssen et al. 2007). Compounds like hexyl and butyl acetate are described as the main contributors, while ethyl acetate, linalool, γ-hexalactone, α-terpineol, and γ- and δ-decalactone are considered subsidiary compounds associated with apricot aroma (Aubert and Chanforan 2007; Defilippi et al. 2009). Variability in aromatic compounds depends mostly on cultivar, maturity, storage, and processing conditions. Aubert et al. (2010) reported a significant increase of lactones, esters, and terpenic compounds during the postharvest maturation stage.

Harvesting

The harvesting method adopted is crucial for determining the postharvest life, as mature fruits are more susceptible to injuries incurred during the harvesting process. As most of the postharvest pathogens are weak, they need entry points to invade fruits. Thus, mechanical injury caused during harvesting can predispose soft fruits like apricot to postharvest pathogens. Therefore, hand/manual harvesting is generally a preferred way of harvesting apricots destined for the fresh market, so as to minimize the occurrence of damage. However, it involves more time and cost. Mechanical harvesting can be used to harvest large acreages of apricot fruits rapidly but it increases the possibility of exposing fruit tissue to injuries.

Fast ripening and susceptibility to mechanical damage are two important obstacles in apricot handling and distribution. Thus, for improving the fruit quality and time of its distribution, utmost care should be taken during fruit picking and unloading in the packing line, decreasing transfers from one container to another, and the use of a suitable packing line should be encouraged (Miller 1992). Impact injury in apricot causes cellular damage, which is internal and cannot be visible until fruits are ripe. However, in some cases when impact injury is high and severe, damage can occur on peels also (De Martino et al. 2002).

Effect of Ethylene

Apricot is a climacteric fruit exhibiting a peak in ethylene production near ripening. According to the production of ethylene, apricots can be divided into three groups, i.e., low, medium, and high (Manolopoulou and Mallidis 1999). In apricots, the emission of ethylene starts relatively early before other ripeness characters are well advanced and can influence both fruit development and ripening. It can be produced from the amino acid methionine by the conversion to *S*-adenosyl-L-methionine. *S*-Adenosyl-L-methionine is transformed by the action of enzyme 1-aminocyclopropane-1-carboxylic-acid synthase to 1-aminocyclopropane-1-carboxylic-acid and then 1-aminocyclopropane-1-carboxylic-acid is oxidized to ethylene by the action of the enzyme 1-aminocyclopropane-1-carboxylic-acid oxidase (Lin et al. 2009). Although the role of ethylene as a modulator of gene expression is well documented in other species, the mechanism remains to be elucidated in apricot. Usually in climacteric fruits during ripening, a small amount of ethylene is needed to stimulate its own production for inducing autocatalysis (Lelievre et al. 1997).

The use of different ethylene scrubbers for removing ethylene from storage rooms is in commercial use, especially when ventilation cannot be used. For extending the postharvest life, delay in ripening is expected, which can be achieved by inhibiting ethylene biosynthesis or action. Various ethylene inhibitors can be used, such as aminoethoxyvinylglycine and 1-methylcyclopropene (1-MCP), which have a greater effect on the ripening of medium and high ethylene producers, rather than on low and suppressed climacteric cultivars (Defilippi et al. 2005; El-Sharkawyet al. 2008). However, reduction in the preharvest fruit drop and the rate of development of maturity attributes in several fruits including apricot have been the main focus of the use of aminoethoxyvinylglycine (Palou and Crisosto 2003; Valdéset al. 2009). 1-MCP helps in blocking ethylene receptors for extended periods of time and, hence, hinders the expression of physiological effects induced by ethylene (Watkins 2006; Valdéset al. 2009). This chemical has been reported to delay the ripening of apricots provided its time of application, cultivar, and maturity of fruit are taken into consideration (Li Dong et al. 2002). Exogenous applications of ethylene as well as propylene hasten fruit softening. In impact bruising, an increase in ethylene production takes place in tissues away from the injured site of apricot fruits (De Martino et al. 2002).

In fruits like apple, plum, and banana, the production of volatile compounds and ethylene action remains closely correlated. However, it is unclear whether the production of esters is regulated by ethylene during apricot ripening (Abdi et al. 1998). Biotechnological approaches such as using sense/antisense technology for studying the effect of ethylene on fruit development and ripening have also been used (Ayubet al. 1996; Dandekaret al. 2004). Munoz-Robredo et al. (2012) reported that ethylene, especially at the ready-to-eat phase, influences apricot fruit ripening.

Preharvest Factors Influencing Fruit Quality

Postharvest quality depends greatly upon the preharvest factors, as not much can be done to improve the fruit quality after harvest. Apricot quality is quite variable and factors like variety, geographical origin, fruit location on the tree, irrigation frequency, use of fertilizers, pest control, growth regulators, climatic conditions like temperature, hail, high wind velocity, heavy rainfall, etc. influence the overall fruit quality. Additionally, plant age, pruning, and light penetration also contribute to fruit quality and suitability, as these factors can modify the physiology, chemical composition, and morphology of fruits. Other preharvest factors that affect apricot fruit quality are crop loads, e.g., a lower crop load may result in fruits with high fresh weight, SSC, and less postharvest mealiness development. The position of fruits also influences fruit quality; for example, fruits produced in upper canopy locations are generally large in size with higher SSC than fruits in the lower canopy. Fruits from older wood age classes result in lower incidence of postharvest mealiness (Stanley et al. 2014). Consequently, the impact of these multidimensional factors results in significant fruit variability at the time of harvest, making the segregation of fruits in homogeneous batches very difficult (Grotte et al. 2006).

Tzoutzoukou and Bouranis (2008) reported that preharvest Ca foliar treatments given to apricots result in the increase in firmness and Ca content of fruit, while lowering C_2H_4 production, respiratory rates, and soluble polyuronide content. These are considered as positive changes which favor the postharvest life and marketability of apricot fruits. Preharvest Ca treatment may also influence fruit ripening and its biochemical composition (Sartaj et al. 2013).

Regulated deficit irrigation during less sensitive, non-critical phenological stages of apricot trees resulted in the saving of water resources, as well as a slight increase in TSS and firmness of fruits at the time of harvest and during its cold storage. This demonstrates it to be a viable approach for safeguarding fruit quality as well as preserving natural resources (Perez-Pastor et al. 2007).

Postharvest Handling

Apricots have a limited postharvest life at ambient temperature, as they experience rapid ripening and deterioration after harvest. The rate of deterioration is affected by intrinsic factors, as well as storage factors like temperature, relative humidity, and gaseous composition.

Precooling is a critical step in the food chain for the removal of field heat prior to transportation or storage. It helps to reduce the respiration rate of fruits, process of senescence, inhibits pathogen development, and fruit decay (Yan et al. 2017). Thus, in climacteric fruits, postharvest changes are delayed by immediate precooling and low-temperature storage. Agar et al. (2006) found that extension in the shelf life of apricots and improvement in appearance were observed when fruits were subjected

to forced-air precooling at 0 °C. Tonini and Caccioni (1991) observed that precooling using air causes early fruit flesh softening and hydrocooling may accentuate rotting in apricot fruits. However, they concluded that forced-air cooling is the most effective method of apricot precooling.

The application of low temperature is the most reliable means used for not only extending the postharvest life but also for maintaining the quality. However, it may not be enough to preserve the quality of apricots during storage and marketing (Pretel et al. 2000). Thus, complementary techniques like modified atmosphere packaging (MAP), controlled atmosphere (CA) storage, irradiation, application of edible coatings, and use of some chemical compounds are of the main interest. One of the ways for controlling bruise injury in fruits is likely to be achieved by lowering the temperature, which has an impact on cellular turgor. However, when low temperature was used on the early-harvested apricot fruits, it hindered proper aroma development (Botondi et al. 2003). Low temperature has also been shown to inhibit ethylene production as well as the appearance of bruise symptoms (De Martino et al. 2002).

Packaging

Apricots are usually picked into picking bags or plastic totes (Carlos and Kader 1999). Fruits are prepared for the market either in the field or at the packing house and involves cleaning, sorting (according to size and quality), waxing, and postharvest chemical dipping prior to packing into containers. Corrugated fiberboard and reusable plastic containers are used for packaging. Apricot fruits are packed in a tray in either single or two layers or filled by volume (about 10 kg in a box). While packing, uniformity in size should be maintained and not more than 5% count of the apricots in each container may vary by more than 6 mm when measured through the widest portion of the cross-section. They can also be arranged in polystyrene trays with plastic film, which makes it more attractive to consumers. Lately, apricots have been sold in a flow pack, which is a transparent plastic polyvinyl chloride basket wrapped in a transparent plastic having small holes for gaseous exchange. Harvested apricot fruits, when packed with low-density polyethylene ethylene and polyvinyl chloride and stored for 30 days at 0 °C and 95% RH, showed better preservation of fruit quality attributes as compared to control fruits (Kuzucu and Önder 2010).

Modified Atmosphere Packaging

Modified atmosphere technology in conjunction with low temperature can be used as a way of maintaining commercial quality of fruits like apricot. Permeability of the film to the gas, the rate of respiration of the fruits, and temperature are the main

factors which affect extension of shelf life (Beaudry 1999; Cameron et al. 1994). The atmosphere surrounding apricots can be maintained either passively or actively (Pretel et al. 2000).

Decrease in the decay development and gel breakdown was observed in apricots stored at concentrations between 10 and 15 kPa of CO_2. Two modified atmosphere packaging (MAP) treatments which produced 13–15 kPa CO_2 and either 3 or 10 kPa O_2 prevented decay development in Canino apricots for 35 days of storage and 4 days at 20.8 °C, whereas control fruits exhibited 30% decay (Kosto et al. 2002). In the same study, Canino apricots exhibited no internal browning after 2 days, while the control fruits showed internal browning up to 40%.

Polyvinyl chloride, polyethylene terephthalate, polypropylene, and polyethylene are the typical polymers used to store fruits for MAP (Mangaraj et al. 2009) and, preferably, the film must be thick (15–100 μm) for commercial and mechanical reasons (Varoquaux et al. 2002). Pretel et al. (2000) reported that the MAP approach is effective in maintaining apricot fruit quality during cold storage, while Pala et al. (1994) observed that the shelf life of fruits stored at 0 °C and packed using 50-μm low-density polyethylene film increased from 4 to 6 weeks of storage.

Innovative biodegradable packaging materials used as an alternative to regular plastic films in MAP showed that apricot fruits can be stored at 1 ± 0.5 °C and 90–95% RH for 21 days. Biodegradable packaging was the only one wherein gases were found to be stabilized and maintained until the end of storage, i.e., gases exchanged at the same rate from fruit skin as they diffused from biodegradable package and, thus, maintaining the equilibrium. However, considering other quality parameters like loss in fruit weight, fruit firmness, etc., multilayer packaging materials were considered the best for apricot fruits (Peano et al. 2014).

Controlled Atmosphere (CA) Storage

Generally, an atmosphere with 2–3% O_2 and 2–3% CO_2 is considered optimum for storing apricots. However, the exact gas composition may vary with the variety. Retention of fruit color, firmness, and extension in storage life are the major benefits of CA storage. Flesh browning and loss of flavor is also observed in fruits stored at high CO_2 concentrations (>5%) for more than 2 weeks. For most of the apricot cultivars, extension of shelf life is expected at a CO_2 level of 10–15 kPa and an O_2 level of 2–5 kPa. If apricot fruits are given prestorage treatment with 20% CO_2 for 2 days, reduction in the incidence of decay is observed during transport, as well as subsequent storage (Carlos and Kader 1999). The effect of modified atmosphere and controlled atmosphere conditions on the fruit quality of ‘Aprikoz’ apricots was compared and it was observed that fruits stored at CA were better in terms of external appearance and taste (Koyuncu et al. 2010). Furthermore, controlled atmosphere can be used as an effective method wherein ethylene production can be reduced (Gorny and Kader 1997) and can also lead to improvement in the postharvest storage quality of fruits (Guelfat-Reich and Ben-Arie 1967; Wankier et al. 1970; Claypool and Pangborn 1972).

Chemical Treatments

1-Methylcyclopropene

Apricots, when exposed to postharvest treatments of 1-methylcyclopropene (1-MCP), chlorine dioxide, calcium, and heat in sealed containers and then stored at 20 °C for 10 days, resulted in reduced respiration and malondialdehyde (MDA) content, delay in softening and postharvest decay, while increasing antioxidant capacity. 1-MCP treatment of apricots helped in the maintenance of membrane integrity, alleviation of lipid peroxidation, and enhancement of antioxidant ability. Thus, the use of 1-MCP as well as chlorine dioxide treatment helped in maintaining the quality of fruits and extending the shelf life at room temperature (Wu et al. 2015). 1-MCP was able to alleviate flesh browning in apricots even at low concentration. Canino apricots were treated with 1-MCP prior to storage and did not respond favorably, but when 1-MCP was applied as a poststorage treatment, it delayed ripening and improved fruit quality. Therefore, for successful 1-MCP application, proper selection of maturity or physiological stage is important (Dong et al. 2002).

The treatment of apricot fruits with 1 μL L^{-1} 1-MCP for 4 h at 20 °C and later storage at 0 or 20 °C was able to delay ethylene production and reduce the respiration rate. At both storage temperatures, fruits were able to maintain firmness and titratable acidity. 1-MCP-treated fruits exhibited less color changes, as well as delayed volatile production. Thus, by applying 1-MCP, inhibition of fruit ripening and improvement of poststorage quality of climacteric fruits like apricot is expected (Fan et al. 2000). Bruising of apricot fruits accelerated ripening as well as loss of firmness; however, the treatment of apricot fruits with 1-MCP helps in preventing the loss of tissue integrity and decreases in ethylene and CO_2 production, regardless of the time of application (De Martino et al. 2006). The application of 1-MCP has been shown to delay fruit softening, which is closely related to ethylene inhibition. Apricots treated with 0.75 μL L^{-1} of 1-MCP showed higher fruit firmness than fruits treated with 0.25–0.5 μL L^{-1}, confirming the reduction of softening to be dose-dependent. When apricots are harvested at S_1 and S_2 ripening stages and treated with 1-MCP, they exhibited less color changes than controls, confirming that 1-MCP retards the evolution of color in apricots. Control fruits exhibited change in color from yellow to dark orange. This effect was observed to be dose–dependent, as fruits treated with 0.5 μL L^{-1} remained more yellow than those treated with 0.3 μL L^{-1} after 21 days of cold storage (Valero and Serrano 2010).

Calcium

Calcium, a divalent cation (Ca^{2+}), has a structural function in the membranes and cell walls of fruits. It helps in maintaining membrane integrity, cell turgor, and retarding membrane catabolism. Thus, its application either preharvest or

postharvest helps in maintaining the overall fruit quality. The application of calcium mostly as calcium chloride to apricot fruits can be used for maintaining firmness, usually due to the lessening of solubilization of pectic substances (Ishaq et al. 2009).

The effect of preharvest calcium foliar application on ethylene production, respiratory rate, soluble polyuronides, and fruit firmness of 'Bebekou' apricot fruits was determined by Tzoutzoukou and Bouranis (1997). Treated fruits had significantly lower ethylene production rates than controls. After harvest, calcium-treated fruits displayed a 1-day delay in reaching the peak rate of ethylene production. The respiratory rate was significantly suppressed over a 5-day period at 21 °C out of the 7-day period examined immediately after harvesting. However, after 4 weeks of storage at 0 °C, there was no significant effect of calcium on the respiratory rate. The respiratory peak rate occurred earlier in the control fruits compared to that of the calcium-treated fruits at harvest time. Calcium-treated fruits were about 70% firmer than the untreated ones at harvest time. Fruit firmness was positively correlated to the calcium content of fruits, while the soluble polyuronide content of the fruit was negatively correlated to fruit calcium.

Pre- and postharvest applications of calcium salts on fruits have been successfully used to reduce loss of firmness and to slow down the ripening process. Antunes et al. (2003) studied the effect of postharvest calcium chloride application on the quality preservation of apricot cv. 'Beliana' and cv. 'Lindo' during storage. After harvest, apricots were dipped in 0, 1, 3, or 5% chloride solutions. Fruits treated with 3 and 5% chloride lost more weight than the other treatments in both cultivars. The cultivar 'Lindo' lost generally more weight than 'Beliana'. Firmness decreased through storage without differences between treatments in 'Beliana', but 'Lindo' fruits treated with 3 and 5% chloride lost less firmness than the other treatments. Fruits of cultivar 'Beliana' did not show differences in SSC among treatments. However, 'Lindo' fruits had lower SSC when treated with 1% chloride. Dipping apricot fruits in concentrations up to 1% $CaCl_2$ can improve storage ability.

Salicylic Acid

Salicylic acid, as a natural phenolic acid, has also shown promising effects on the inhibition of ethylene production, reducing respiration, and delaying senescence in apricot fruits (Chan et al. 2007), and, thus, enhancing the fruit quality (Tareen et al. 2012). Salicylic acid treatment retarded the ripening progress and quality loss. Its application enhanced the activity of phenylalanine ammonia-lyase (PAL), hydrophilic total antioxidant activity (H-TAA), and content of phenolics in fruit via regulating the metabolism of H_2O_2 during postharvest storage (Wang et al. 2015).

Putrescine

Polyamines are well known to improve the storability of many horticultural crops. The effect of exogenously applied putrescine on the postharvest storage life of apricot 'Tokhm-sefid' fruit at 2 °C was investigated by Zokaee Khosroshahi & Esna-Ashari (2007). The application of putrescine caused a reduction in ethylene production, as well as an increase in fruit flesh firmness. Soluble solids content and pH were reduced, and titratable acidity was increased in putrescine-treated fruits. The loss of fruit fresh weight was affected by putrescine in a concentration-dependent manner. Thus, fruit treated with higher concentrations of putrescine showed lower fresh weight loss.

During the handling and packaging of apricot fruits, several changes, such as increase in fruit firmness, delay in color changes, inhibition of ethylene production, and reduced mechanical damage, were observed after treatment with putrescine (Martínez-Romero et al. 2002).

Edible Coatings

The effectiveness of chitosan coating treatment to control weight loss and maintaining fruit quality of apricot was investigated by Ghasemnezhad et al. (2010). Fruits were coated with 0.25%, 0.5%, and 0.75% chitosan, as well as distilled water (control), and stored at 0 °C and 80 ± 2% relative humidity for 25 days. Weight loss from all treated and untreated fruits increased over storage time. The weight loss of chitosan-coated fruits was increased in comparison to untreated samples. Chitosan coatings significantly increased the content of total phenolics and antioxidant activity.

Mature apricots were coated with different concentrations of sucrose polyesters by Şümnü and Baymdirh (1995). The respiration rates, weight loss, color change, soluble solids, ascorbic acid content, titratable acidity, and pH of apricots were effectively reduced by both the 10- and 15-g L^{-1} concentrations during ambient storage. After 10 days of cold storage, both concentrations caused firmer fruit, higher pH, titratable acidity, soluble solids, and ascorbic acid.

Intermediate moisture apricots were coated with different formulations of natural corn protein 'zein' films by dipping treatment. Color change was reduced remarkably by the coating process. The control fruits presented higher values of a^*/b^* than the coated fruits. The total viable bacteria count of the control group was found to be significantly higher than the zein film-coated samples (Baysal et al. 2010).

Jiang et al. (2010) studied the effects of chitosan on the postharvest quality of apricot. The results show that, compared the control, 0.75 g L^{-1} chitosan treatment can reduce the rot ratio of fruit, alleviate fruit's ripening and softening significantly, and maintain higher total soluble solids content level. It can increase the activity of

peroxidase, superoxide dismutase, and catalase, but decrease the activity of polyphenol and the superoxide generation rate. It can also alleviate the degeneration of cell wall and chloroplast, and delay ripening and senescence in the storage of apricot fruits (Jiang et al. 2010).

Irradiation

Irradiation has become an effective means of processing and preserving food products. Irradiation has been recognized as an alternative to chemical treatments for treating agricultural products to overcome quarantine barriers in international trade. An irradiation dose of 0.3 kGy was well tolerated by apricots with less quality loss. However, with a higher irradiation dose of 0.6 kGy, loss of firmness, change in color, and accelerated internal breakdown were recorded (Arvanitoyannis 2010). Apricots, when irradiated (1 and 2 kGy), showed a significant reduction in the growth of aerobic bacteria, yeasts, and hardness during storage. However, pH, total sugars, vitamin C content, and overall acceptability of fruits was not affected (Jeong-Ok et al. 2008).

The ionization treatment significantly affected ethylene production in apricots and caused an earlier appearance of the climacteric peak and a decrease in the ethylene concentration at that peak. The texture of the apricot showed a slight tendency to softening when fruit were irradiated at 1 kGy. The other physicochemical and nutritional properties studied showed no significant changes when compared with non-irradiated fruit. Peroxidase activity, as part of the antioxidant defense system, showed a significant increase, this being greater with the higher radiation dose (Egea et al. 2004).

Sun-dried apricots were gamma irradiated in the dose range 1.0–3.0 kGy. The gamma-irradiated fruit, including control, was stored under ambient (15–25 °C, RH 70–80%) conditions. Radiation treatment at dose levels of 2.5 and 3.0 kGy proved to be significantly beneficial in the retention of higher levels of β-carotene, ascorbic acid, total sugars, and color values without impairing the taste as perceived by the sensory panel analysts. The above optimized doses, besides maintaining the higher overall acceptability of sun-dried apricots, resulted in 5 log reductions in microbial load just after irradiation and 1.0 and 1.3 log reductions in yeast and mold and bacterial count after 18 months of ambient storage (Hussain et al. 2011).

In another study, the effect of electron beam irradiation on sun-dried apricots was periodically evaluated for quality maintenance by Wei et al. (2014). The sun-dried apricots were treated with 1.0, 2.0, 3.0, 4.0, and 5.0 kGy of electron beam and subsequently stored at ambient temperature. Electron beam treatment at 1.0–3.0 kGy proved to be beneficial for retaining high levels of β-carotene, ascorbic acid, titratable acidity, total sugars, and color, without any significant effect on the sensory properties. After 10 months of storage, the maximum losses of ascorbic acid were 37.8% in control samples and 35.5% in 3.0 kGy-irradiated samples. Titratable acidity and total sugars were significantly enhanced immediately after 1.0–3.0 kGy irradiation

treatment, and both parameters showed no significant change after 10 months of storage. Samples subjected to electron beam treatment at 3.0 kGy maintained a high overall acceptability of sun-dried apricots. A decreased number of viable microorganisms to below detection limits was observed after 3.0 kGy irradiation, and, compared with the control, the logarithmic reductions after 10 months of storage were 0.98 for yeast and mold count, as well as 1.71 for bacterial count.

Postharvest Diseases

The presence of sugars, a wide range of organic acids, and high water content predisposes fruits to pathogenic infection. As fruits have low pH, they are more susceptible to fungal attacks than bacterial ones. Adopting good agricultural practices from flowering to harvest can reduce the incidence of diseases. Disease incidence also depends on the cultivar, as there are some varieties within the fruit which may be more susceptible to disease attack than others.

Brown Rot

Brown rot is caused by *Monilinia* spp. and is one of the devastating diseases of apricot (Fig. 1). Early infection may appear as blossom blight or shoot dieback, while later infections may result in fruit rot on the tree as well as during storage. The incidence of brown rot increases 2–3 weeks before harvest. Increased sugar content associated with ripening as well as decreased host defense system makes ripe fruits more susceptible to infection than immature fruits.

Disease incidence is increased due to warm, wet, or humid atmosphere, especially 2–3 weeks before harvest. These are conductive conditions for pathogen survival and infection, and can result in severe fruit loss. As most of the pathogens are weak, insect

Fig. 1 Brown rot of apricot

damage can further increase the chances of pathogen penetration by creating wounds as well as acting as vectors of fungal conidia. Initially, tan and circular brown spots appear on the fruits, which increase in size to engulf the whole fruit. Fruits eventually become shriveled black mummies, which may drop or remain attached to the tree. Disease can spread even after harvest and can result in serious postharvest losses.

Orchard sanitation is the removal of rotten/fallen fruit, and pruning will help in reducing the magnitude of infection. Harvesting should be done carefully so as to avoid the bruising of fruits. Precooling of the fruits and maintaining cool chain also helps in minimizing disease development and spread. Fruits with brown rot should be discarded and timely harvest of fruits should be encouraged. Treatments like the use of calcium chloride on fruits several weeks before harvest and surface coatings which provide physical barriers can also be used to minimize pathogen attack. Salicylic acid, as a natural phenolic acid, can be applied to enhance the local and systemic resistance in fruits against pathogens (Chan et al. 2007).

Physiological Disorders

Chilling Injury or Gel Breakdown

Fruits are usually stored at low temperatures for reducing the rate of physiological reactions, which may hasten senescence and subsequent loss of quality. Apricots and other stone fruits are, however, sensitive to low temperatures and may exhibit chilling injury after long cold storage periods. In earlier stages, it is mostly manifested as water-soaked areas, which may turn brown subsequently. Breakdown of tissue followed by sponginess and formation of a gel-like area near the stone affects consumer acceptance. This may occur due to imbalance in the activity of cell wall hydrolytic enzymes, leading to the accumulation of high molecular weight unmethylated pectins that can bind extracellular juice (Zhou et al. 2000). Apricots may appear normal even at advanced stages and it is observed that, if fruits are harvested at more advanced stages, increased chances of gel breakdown are observed. It is also found that the incidence of such disorders varies from year to year, even in the same orchard. In order to control chilling injury symptoms, intermittent warming heat shock is applied. Polyamines like putrescine, spermdine, and spermine can be used to reduce chilling injury and extend protection against lipid peroxidation by stabilizing membranes, thereby reducing changes in membrane permeability and fluid loss (Tassoni et al. 1989). When polyamines, viz., putrescine and spermdine, were used in apricot fruits, reduction in the severity of chilling injury was observed as compared to the control. Further, it was noticed that spermdine was more effective than putrescine (Saba et al. 2012). They can also help in maintaining firmness of fruits, inhibit ethylene production, and delay ripening.

Controlled or modified atmospheric storages have been seen to either increase or decrease its incidence, depending upon the concentration of gases used. Canino apricot, when held for 6 weeks in air at 5 kPa CO_2 and 3 kPa O_2, showed gel breakdown,

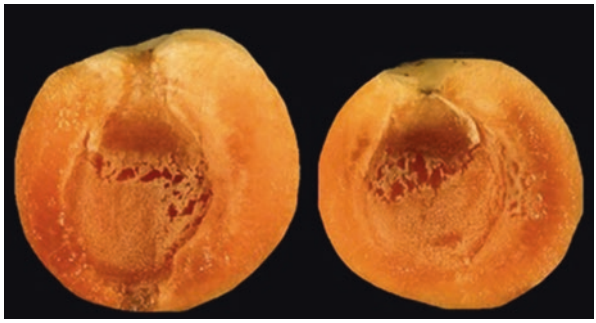

Fig. 2 Pit burn of apricot

but when CO_2 was increased to 10 or 15 kPa, it was prevented (Kosto et al. 2000). Furthermore, when apricot fruits were kept at 15 kPa CO_2, they exhibited only 7% internal browning, while at 9 kPa or less CO_2, up to 50% internal browning was exhibited. In many cultivars (Supergold, Imperial, and Peeka), gel breakdown was between 30 and 50% after storage in 15, 19, or 23 kPa CO_2 and 5 kPa O_2 (Truter and Combrink 1997).

Pit Burn

Pit burn occurs when apricot fruits are exposed to higher temperatures (>38 °C) before harvest and is manifested as flesh softening followed by browning, especially near the pit/stone area (Fig. 2). A higher nitrogen level aggravates the incidence of pit burn. However, the application of calcium can help to prevent it.

Conclusion

Apricots are an excellent source of carotenoids, ascorbic acid, polyphenols, minerals, sugars, and fiber. There is a great scope for combining pre- and postharvest strategies for the optimal quality shelf life of apricots. Preharvest conditions like cultivar, geography, irrigation, rainfall, wind velocity, fertilizers, and fruit location on the tree play a vital role in determining the overall quality of apricots. Ethylene is the prime internal factor, which causes an abrupt increase in respiration, leading to a short shelf life. Being a climacteric fruit, the harvesting of apricots is done prior to the attainment of complete maturity. The main disadvantage of this strategy is that the fruits are not of optimal quality in terms of color and flavor. Different strategies like precooling, low-temperature storage, modified atmospheric packing, controlled atmospheric packaging, chemicals, edible coatings, and irradiation have been employed for the retention of quality shelf life of apricots.

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