Chapter 15.1

Stone fruits: Peaches, nectarines, plums, apricots

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Quality characteristics

Controlled and Modified Atmospheres for Fresh and Fresh-Cut Produce
https://doi.org/10.1016/B978-0-12-804599-2.00017-X

Peach, nectarine, plum, and apricot have great economic impact worldwide, but are characterized by high perishability and short market life. Such commodities display a climacteric increase in ethylene production and an equally rapid rate of ripening. Interestingly, differences in the pattern of softening rate and ethylene production may exist within cultivars of the same species, i.e., stony-hard peach fruit (Begheldo et al., 2008) or plum fruit with a suppressed climacteric pattern (El-Sharkawy et al., 2007; Minas et al., 2015). Breeding programs have released a significant number of new cultivars with appreciably better appearance (i.e., lack of corky spot in peaches) and high soluble solids content. Postharvest losses are mainly due to decay and the incidence of chilling-related disorders, such as internal breakdown (IB), woolliness (mealiness), and translucency (Lurie and Crisosto, 2005; Manganaris et al., 2008a).

Main causes of quality loss

Peach and nectarine are highly susceptible to chilling injury (CI) symptoms, evident as dry fruit with a mealy or woolly texture (mealiness or woolliness), hard-textured fruit with no juice (leatheriness), fruit with flesh or pit cavity browning (internal browning), or flesh bleeding (internal reddening) and development of "off flavor," usually well before visual symptoms are evident (Crisosto and Labavitch, 2002; Lurie and Crisosto, 2005) (Fig. 1). Such disorders are genetically influenced and triggered by a combination of storage temperature and duration. Fruit size, storage atmosphere, and temperature have

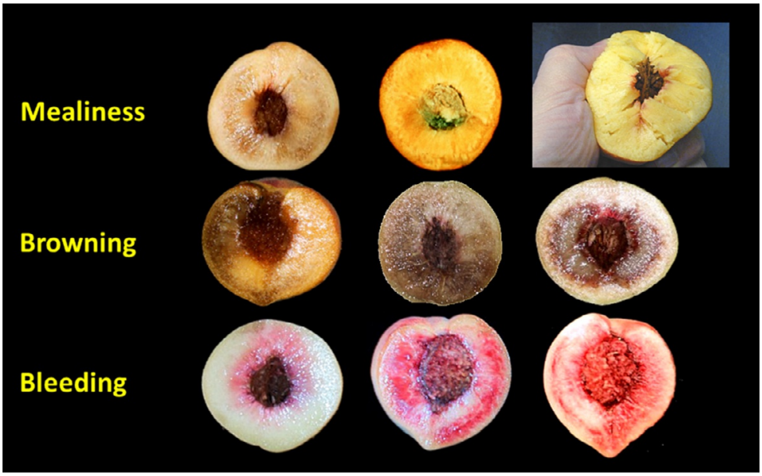

FIG. 1 Chilling-related disorders in peaches, evident as mealiness (woolliness), flesh browning (internal breakdown), and flesh reddening (bleeding). *(Source: Crisosto and Peace)*

significant effects on development of CI symptoms in peach and nectarine (reviewed in Crisosto et al., 2009). Overall, physiological disorders due to extended cold storage are key issues that limit the storage potential of peach fruit to a few weeks. In all susceptible cultivars, flavor is lost before visual CI symptoms are evident.

Plums include the European species (*Prunus domestica* L.), which is consumed fresh or dried, and the Japanese species (*Prunus salicina* Lindell), which is mainly consumed fresh. Plums are climacteric fruits that undergo rapid deterioration after ripening, including softening, dehydration, and decay. Commercial storage conditions (0–5°C and 80%–95% RH) can delay softening, but may also promote development of storage disorders, manifested as translucency, bleeding, flesh browning, and/or failure to ripen (reviewed in Manganaris et al., 2008b) (Fig. 2). Unlike to peach and nectarine, plums respond to exogenous ethylene, a key ripening regulator, and treatments with 1-MCP, an ethylene action inhibitor, delay fruit ripening (Manganaris et al., 2007, 2008a). Besides fast ripening, postharvest diseases are a main concern throughout the supply chain. Postharvest life varies among cultivars and is strongly affected by temperature.

Apricots are highly susceptible to fruit disorders, evident as gel breakdown (translucent, gelatinous mass) or internal breakdown (flesh browning). In addition, apricots are susceptible to decay by several fungal species, including *Monilinia fructicola*, *Botrytis cinerea*, *Penicillium expansum*, and *Rhizopus stolonifer*.

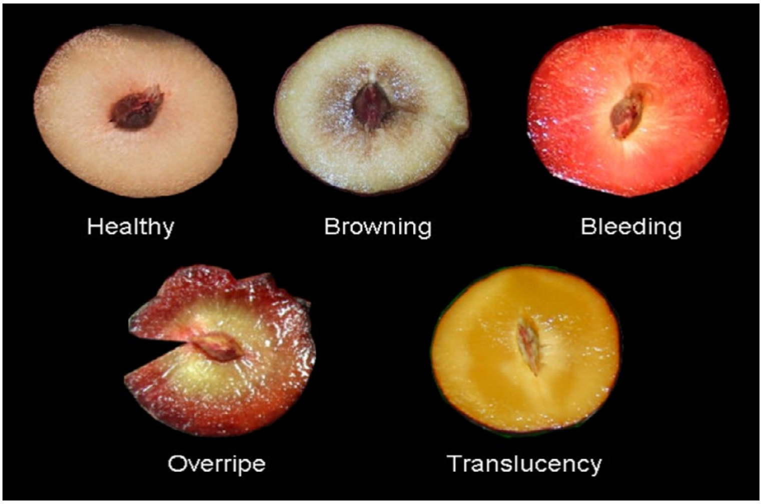

FIG. 2 Chilling-related disorders in plums, evident as flesh browning (internal breakdown), flesh reddening (bleeding), and translucency. Healthy and overripe fruit are also depicted. *(Source: Crisosto)*

Optimum storage conditions

Temperature

Prompt cooling and low-temperature storage (0°C) at high relative humidity are recommended to delay ripening and maintain fruit quality, while all stone fruits are susceptible to cold storage disorders when stored at 5°C. Rapid cooling to target temperature is essential to minimize quality loss. The suppression of ethylene synthesis using postharvest applications of 1-metylcyclopropene (1-MCP), an ethylene inhibitor, to plums will suppress ethylene production and delay ripening without affecting normal ripening at a later time (Manganaris et al., 2007, 2008c). 1-MCP has not been proven beneficial for extending the market life of peaches and nectarines (Dal Cin et al., 2006), making it important to dissect potential benefits of CA/MAP technologies.

CA/MAP considerations for peach

CA as a supplement to managing temperature and relative humidity is used widely as a postharvest technology to extend the postharvest life of horticultural products. There have been significant advances for some fleshy fruit commodities with the development of new, interactive Dynamic Controlled Atmosphere (DCA) storage systems (Zanella et al., 2008; Prange et al., 2013; Bessemans et al., 2016). However, application of CA/MAP technologies to peach and nectarine has not been proven beneficial and the limited number of studies performed does not reflect the economic importance of these commodities. Furthermore, after prolonged storage under CA regimes, fruit may have an acceptable appearance, but being inferior in sensory characteristics such as aroma and taste.

CA is particularly critical to extend the shelf life of stone fruits destined for a distant market. South Africa and Chile are important suppliers of stone fruit to the northern hemisphere from November to March. Such long-distance shipping requires maintaining fruit quality during sea freight for at least four weeks after harvest (Maré et al., 2005). Furthermore, premium quality fruit sent to distant and premium markets, such as from California to Australia, will gain appreciably higher prices that justify special treatment. Despite commercial use of CA conditions in peach, there is inconsistency in the potential benefits of reducing CI symptoms. In addition, there is great variability in the gas concentrations applied to peach and nectarine fruits and contradictory results have been reported about the optimal gas concentration (Fig. 3).

An early study documented that the combination of 1–2 kPa O_2 and 3–5 kPa CO_2 delays ripening without a pronounced effect on alleviating chilling disorders, while O_2 concentrations below 1 kPa and CO_2 above 10 kPa may induce failure to ripen, skin and flesh browning, and “off flavors” (Kader and Mitchell, 1989). Elevated concentrations of CO_2 (higher than 10 kPa) suppress fungal growth, mainly *B. cinerea* and *M. fructicola*, while short-term exposure

FIG. 3 Postharvest performance of 'July Red' peaches after cold storage under different controlled atmosphere regimes. *Upper panels:* Luft Ko (*left*) and 10% CO_2, 8% O_2 (*right*). *Lower panels:* 0% CO_2, 8% O_2 (*left*) and 20% CO_2, 8% O_2 (*right*). *(Source: Crisosto)*

to 15 kPa CO_2 was beneficial to midseason 'Summer Red' nectarine inoculated with brown rot (Ahmadi et al., 1999). However, when high CO_2 concentrations (10 kPa CO_2 + 10 kPa O_2) were applied for 6 weeks to three nectarine cultivars, this strategy prevented CI disorders (internal breakdown and reddening) but failed to develop increased extractable juice, rendering the fruit of unacceptable quality (Lurie, 1992).

CA technology has been used jointly with other protocols, giving promising results for extended cold storage of peach fruit. In particular, delayed storage (48 h at 20°C) of 'Flavortop' nectarines followed by CA storage (10 kPa CO_2, 3 kPa O_2) alleviated or prevented woolliness symptoms during six weeks cold storage (Zhou et al., 2000). The beneficial effect of this combined strategy was attributed to distinct mechanisms: delayed storage initiated ripening so that, after removal from storage, polygalacturonase (PG) activity was higher and pectin esterase (PE) activity was lower than in control fruits, leading to normal softening. Therefore CA storage suppressed PG activity during storage, but allowed its recovery after removal from cold storage and maintenance at room temperature.

CA storage at 5 kPa O_2 + 5 kPa CO_2 reduced CI in 'Okubao' peach fruits and delayed the reduction in key antioxidant enzymes like peroxidase (POD), superoxide dismutase (SOD), and catalase (CAT) found in the control. Such results suggest that potentially, the decreased activity of these enzymes may contribute to CI development in peach fruits (Wang et al., 2005). CA better maintained quality of 'Chiripá' peaches than air storage, through preservation of tissue integrity and decreased incidence of woolliness and decay due to pathogens (Girardi et al., 2005). CA storage was better than conventional cold storage in maintaining aroma and flavor quality of 'Rich Lady' peach fruit (Ortiz et al., 2009). In contrast, there were no significant differences in flesh firmness between air- and CA-stored (3 kPa O_2, 10 kPa CO_2) 'Rich Lady' peaches (Ortiz et al., 2012).

Peach fruit grown under deficit irrigation had better postharvest performance after two weeks storage in CA (3-4 kPa O_2 and 12–14 kPa CO_2) and additional ripening for four days at 15°C than conventionally irrigated controls; this preharvest/postharvest combination is particularly beneficial for water savings and quality maintenance (Falagán et al., 2015). Controlled Atmosphere storage (5 kPa CO_2 and 10 kPa O_2) allowed up to 45 days storage of late-season, non-melting 'Jesca' and 'Evaisa' peach fruits, but when CA storage was combined with intermittent conditioning (24 h at 20°C every six days), detrimental effects occurred (Ferrer-Mairal et al., 2012).

A comprehensive study on the effect of three CA storage regimes (2 kPa O_2/5 kPa CO_2, 3 kPa O_2/10 kPa CO_2, and 6 kPa O_2/17 kPa CO_2) on four commercially important peach and nectarine cultivars ('Big Top', 'Venus,' 'Early Rich,' and 'Sweet Dream') highlighted the significance of gas composition on flavor perception: fruit placed in 2/5 O_2/CO_2 were less flavorful than those at 3/10 or 6/17. These results can be qualitatively extended to juiciness and sweetness, since these sensory properties are strongly correlated (Cano-Salazar et al., 2013). Extended cold storage (34 days) of 'Miraflores' peaches at two different regimes (2°C and 2 kPa O_2 + 15 kPa CO_2 or 2 kPa O_2 + 10 kPa CO_2) reduced disease incidence and intensity and maintained better sensory properties when CO_2 did not exceed 10 kPa (Truque et al., 2012). However, excessive concentrations of CO_2 (17 kPa) combined with 6 kPa O_2 proved beneficial for some fresh peaches and nectarines shipped from Chile (Retamales et al., 1992).

Another tool to reduce CI in peach is modified atmosphere packaging (MAP). Promising effects of MAP on cold storage potential of 'Chaoyang' honey peach were observed, using three different thicknesses (15, 25, and 40 μm) of low-density polyethylene (LDPE) films (An et al., 2007). MAP inhibited the climacteric peak, reducing color change and softening. The LDPE25 bags had a steady-state atmosphere of 4 kPa O_2 + 5 kPa CO_2 and provided the best quality after 20 days cold storage at 2°C. MAP technology has been tested intensively on several California-bred yellow flesh peach cultivars grown in Chile, without consistent success (Zoffoli et al., 2002). Despite high CO_2 concentrations reached during simulated shipping, flesh mealiness and flesh browning development limited the potential benefits of this technology. In some commercial situations, box MAP increased the decay incidence due to lack of proper cooling and condensation during transportation. Fruit damage was also observed when MAP-packed fruit (O_2 < 3 kPa and CO_2 > 13 kPa) were exposed to warm temperatures during postharvest distribution (Malakou and Nanos, 2005).

CA/MAP considerations for plum

Although softening can be delayed by CA and modified atmospheres, this technology is not widely used commercially, since the benefits are not as pronounced as in other fruit species and contradictory results exist about the cost/benefit of CA storage in plums. For some cultivars, O_2 concentrations of 1–2 kPa delay ripening and CO_2 concentrations of 0–5 kPa suppress fruit softening. Oxygen concentrations under 1 kPa may induce failure to ripen and off flavors, while CO_2 >15 kPa is associated with flesh browning (Kader, 1997). Another early study found plums amenable to CA/MAP and the storage time of Japanese plums, particularly late-season cultivars, could be increased two to three months beyond the normal storage time of four to six weeks (Lurie et al., 1999). More recent studies found that 'President' and 'Valjevka' (*P. domestica* L.) fruits benefited from ULO storage (0.9 kPa O_2, 1.0 kPa CO_2) after 30 days at 3.0–3.3°C (Goliáš, 2007), while optimum CA conditions delayed fruit ripening and CI through augmentation of antioxidant metabolism and suppression of oxidative processes (Singh and Singh, 2013).

When 1-MCP treatment was followed by CA (1.8 kPa O_2+2.5 kPa CO_2), storage potential of 'Angeleno' plum was extended from 40–60 days to 80 days (Menniti et al., 2006). The effects of CA (1 kPa O_2 + 3 kPa CO_2 or 2.5 kPa O_2 + 3 kPa CO_2) on 1-MCP-treated 'Blackamber' plums were beneficial in delaying fruit ripening, retarding lipid peroxidation, and reducing the incidence and severity of CI during 5 or 8 weeks of storage compared to normal air and MAP (~10 kPa O_2 and 3.8 kPa CO_2) (Singh and Singh, 2012). This study concluded that the development of CI symptoms in plums, a manifestation of oxidative damage to the fruit tissue, was significantly reduced after 1-MCP treatment followed by CA storage. However, 1-MCP-treated 'Laetitia' plums developed physiological disorders, evident as flesh browning after 60 days CA storage (1 kPa O_2 + 3 kPa CO_2) (de Alves et al., 2009).

Maintaining plum fruit quality for 4 weeks or even longer is needed for orderly overseas marketing. New cultivars have extended the harvest season from late spring through the summer. The storage life of four Japanese plum cultivars was extended by 2–3 weeks during CA shipping compared to conventional refrigerated transportation (Maré et al., 2005). When 'Laetitia' plums were subjected to 60 days cold storage, although CA delayed fruit ripening, extended cold storage did not reduce the incidence of flesh browning (de Alves et al., 2010). In another study on the same cultivar, the recommended CA conditions were 2 kPa O_2 + 2 kPa CO_2 (Steffens et al., 2014).

The effects of different CA regimes have been proven beneficial for extended cold storage of the global cultivar 'Friar' (Crisosto and Garner, 2008) (Fig. 4). In addition, the efficacy of MAP (LifeSpan L316, FF-602, FF-504, 2.0 kPa vented area perforated, and Hefty liner) on quality and shelf life of the same cultivar stored at 0°C for 60 days was studied (Cantín et al., 2008). MAP box liners were recommended to improve market life of 'Friar' plums up to 45 days in cold storage. However, using box liners without CO_2 control may lead to cold storage disorders in fruit cold-stored for longer periods. After 60 days, fruit from the MAP box liners with higher CO_2 and lower O_2 concentrations had a greater incidence of cold storage symptoms, evident as flesh translucency, gel breakdown, and "off flavor," than

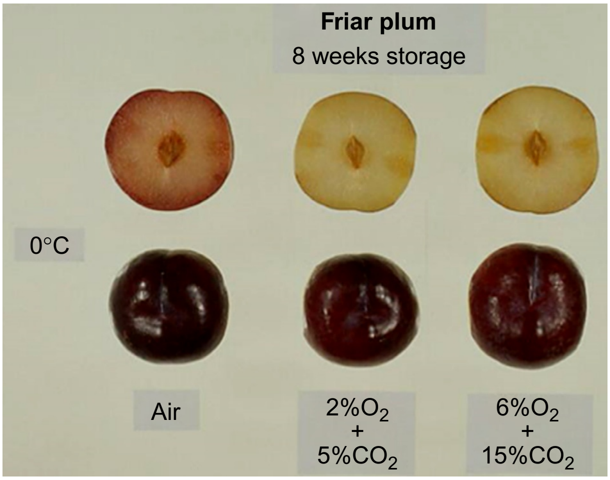

FIG. 4 The beneficial effect of controlled atmosphere in 'Friar' plums after extended cold storage. *(Source: Crisosto)*

fruit from other treatments. MAP such as Xtend and others must be hermetically sealed manually and its success depends on cultivar respiration rate, elapsed time during storage and transportation, and temperature management during transportation and retail handling.

Most studies indicated that when fruits were cold-stored at temperatures above 0°C, CA-treated fruit was firmer than air-stored fruit. However, evaluation of specific cultivars can determine the potential commercial benefits of CA at low cold temperatures, a demanding procedure due to the large number of commercial plums cultivars being distributed into the market. In addition, CA has a rather limited use for storage of plums for periods longer than 4 weeks.

CA/MAP considerations for apricot

CA and MA can delay onset of apricot flesh disorders, but have an accelerating effect if conditions are unfavorable. We have suggested that CA conditions (2-3 kPa O_2 + 2-3 kPa CO_2) can be employed, although these offer only moderate commercial benefits.

Early harvested apricot fruit did not benefit from low (1 or 2 kPa) oxygen because the fruit did not reach the optimal SSC, but in late-harvested fruits, 1 kPa O_2 at a higher temperature can be an alternative to low temperature for shipping or short-term storage (Botondi et al., 2000). 'Búlida' apricot fruits stored under three different CA regimes (20 kPa O_2 + 20 kPa CO_2, 1 kPa O_2 + 20 kPa CO_2, or 1 kPa O_2 + 0.03 kPa CO_2) were characterized by complete ethylene inhibition; however, in apricots stored in 1 kPa O_2, the ethanol concentration increased after one week storage, leading to off-flavors and rendering the fruits unsuitable for consumption (Pretel et al., 1999).

CA or MA conditions for 'Aprikoz' apricots provided better external appearance and taste than other storage conditions (Koyuncu et al., 2010). Active MA replacing the initial atmosphere of the bags with an atmosphere enriched with 20 kPa CO_2 did not modify the gas composition at equilibrium, although it shortened the time necessary for equilibrium to be reached. In 'Beliana' apricots, a slight decrease in ethylene concentration was observed inside bags with an active MA below that of bags with a passive MA (Pretel et al., 2000). A study on the effect of several packaging materials on postharvest performance of 'Tom Cot' apricot fruits indicated that the biodegradable film used can successfully store apricot fruits up to 21 days under passive MAP conditions (Peano et al., 2015). Although storing 'Goldrich' fruit under MA and CA at 1°C was better at preventing fruit softening, 1-MCP was more effective at limiting the incidence of decay, while the accumulation of CO_2 inside the Xtend packaging induced internal browning disorders (Gabioud Rebeaud et al., 2015).

Despite the fact that apricot is highly perishable, the number of studies on the efficacy of CA/MAP technologies in maintaining apricot fruit quality is limited and further studies are warranted. Such studies should additionally consider the genotype effect (slow-softening versus fast-softening cultivars); particular attention should be provided to novel apricot cultivars being launched into the market.

Comments

It is of prime importance to understand the specific conditions and limitations of using CA/MAP when marketing different stone fruit types. Furthermore, there are few or no cost/benefit analyses on whether these technologies will allow growers access to long-distance markets with high-quality fruit and low transportation costs. Postharvest technologies like CA/MAP have been tested to increase stone fruit market life by reducing cold storage disorders and senescence changes, including softening, with sometimes contrasting results. Optimal atmospheric modifications may vary greatly not only among species, but also among commercially important cultivars of the same species.

CA efficacy is greatly affected by cultivar, preharvest factors, temperature, fruit size, marketing period, and shipping time, as measured by the incidence and intensity of chilling-related disorders. As responses to atmospheric modification vary greatly among cultivars and market conditions, it is important to develop very specific information about the benefits and limitations of these techniques for marketing commercially important cultivars, particularly those destined for distant markets.

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