EMERGING POSTHARVEST TECHNOLOGIES TO ASSURE FRUIT QUALITY

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Abstract

Consumer quality has been defined based on several in-store consumer tests and it is mainly related to flavor at consumption time. Improvement on peach preconditioning ripening techniques, reduces incidence of cold storage disorders and assures fruit quality during storage and delivery to consumers. Recently, an intensive work has been carried out in new plant growth regulators such as 1-MCP to extend market life performances. The traditional use of 1-MCP was tested in several tree fruit cultivars with erratic results in peaches and nectarines and reliable results in plums. Shelf life was extended several days in most of plum and pluot cultivars tested. Our group has developed two new approaches on the use of 1-MCP in the tree fruit industry. The first, treated plum have been stored at 10˚C to reduce energy use and deliver 'ready to eat' fruit to consumers. The second, a fast and effective technique using forced-air cooling (FAC) which reduces the application time of 1-MCP from 24 to 6 hours. 1-MCP-FAC treated fruit behave in the same manner as the one treated per 24 hours. An in-store consumer test indicated that 1-MCP had no detrimental effects on low-acidity plums, but it reduced consumer acceptance of high acidity plums.

Keywords: chilling injury, cold storage disorders, consumer acceptance, postharvest losses, ripening, 1-MCP

Introduction

Immediately after harvest, fruits and vegetables begin to senesce, deteriorate and postharvest losses occur. As part of the fruit senescent process, fruits and vegetables start to lose weight, firmness, flavor, and become more susceptible to decay and physiological problems. It has been accepted that postharvest losses, depending on the commodity, reached approximately 5-25% in developed countries and 20-50% in developing countries. The U.S. Department of Agriculture's Economic Research Service estimates 57% of the weight of fresh fruits and 51% of the weight of fresh vegetables in 2005 were not consumed. The rate of losses is mainly related to temperature, time of this temperature exposure and commodity genetic makeup. Temperature controls the biological processes associated with fruit and vegetable deterioration, but the relationship between temperature and rate of deterioration is not linear. Thus, rate of deterioration is 3-, 7.5-, 15-, and 22-fold faster at 10, 20, 30, and 40˚C than at 0˚C (Kader, 2000; Table 1). These differences in deterioration rate at different temperatures are important to consider during postharvest handling management. Environmental conditions such as high temperature, atmosphere environment, air velocity, relative humidity, vapor pressure deficit, ethylene, light and other factors surrounding commodities will affect fruit deterioration mainly by accelerating the biological processes. Commercial storage conditions (0-5 ˚C and 80-95% RH) may reduce respiration and deterioration rate, and delay the softening process, but may also lead to the development of storage disorders, reducing storage life and consumer acceptance of stone fruit. The first step to assure high quality produce for the consumer is to maximize orchard quality. Thus, improving understanding of genotypes and the pre-harvest factors influencing fruit quality will help to satisfy consumers and increase consumption. In addition, proper postharvest handling strategies of stone fruit should be adopted, to avoid storage disorders. This brief article provides an update in postharvest technology to preserve fruit quality during storage and delivery to consumers with emphasis on peaches and Japanese plums.

Table 1. Effect of temperature of respiration and deterioration rate

Temperature (°C)	Relative velocity of deterioration or respiration	Relative shelf life (%)	Loss per day (%)
0	1	100	1
10	3	33	3
20	7.5	13	8
30	15	7	14
40	22	4	25

Cold storage disorders of peaches

Many peach (*Prunus persica* (L.) Batsch) cultivars can develop a physiological disorder called chilling injury (CI) or internal breakdown (IB). This disorder, triggered by exposure to cold storage temperatures, affects several organoleptic attributes, such as texture and flesh color and juiciness. The presence of chilling injury is a frequent source of complaints by peachconsumers and wholesalers of peach. Externally, fruit with chilling injury appear sound, so the problem is usually not noticed until the fruit reaches retailers and consumers. A high frequency of affected fruit reduces consumer satisfaction, limits development of long distance markets, and reduces peach consumption. The major symptoms of CI are flesh mealiness (M), flesh leatheriness (FL), flesh browning (FB), flesh bleeding (FBL), loss of flavor, and development of off-flavors. Mealiness (M) is a fruit flesh textural disorder, where affected ripe fruit have a dry grainy feel when chewed. In simple terms, mealy fruit are dry and soft when ripe, while leathery fruit are dry and firm when ripe, or remain firm because of a failure to ripen. Desirable, non-mealy fruit are juicy, with a soft, melting texture, or are juicy and firm (Lurie and Crisosto, 2005).

On a cellular level, metabolism of the pectin component of the cell wall is altered in mealy fruit. A gel is formed as pectins in intercellular spaces absorb free water, intercellular adhesion is reduced, and cells form loose clumps rather than rupturing to release juice. Flesh browning (FB) is often seen in mealy fruit, although it can also occur in the absence of mealiness. Flesh browning occurs when enzymes such as polyphenol oxidase act on phenolic substrates when they are brought into contact. Flesh bleeding (FBL) is caused by the movement of water-soluble red pigments, probably anthocyanins, through the fruit flesh during cold storage or after subsequent ripening. It can be present at harvest or develop as fruit ripen and senesce on the tree. The progression of M and FB symptoms is associated with reduced perception of normal flavor and with development of off-flavors. In most cultivars tested, flavor loss ('hidden damage') is perceived prior to lack of juice or mealiness, and FB is generally the last visual symptom of CI damage to develop. The documented sensory damage underscores the effect of CI complex damage on consumer preference and fruit consumption and its commercial importance. In addition, more attention should be focused on obtaining cultivars with genetic tolerance/resistance or in developing postharvest innovations to control the early stages of chilling injury (flavor loss) rather than later aspects such as FB development. Several treatments have been attempted as a short-term solution. Controlled atmosphere, warming exposures, and preconditioning have been used commercially to mitigate CI in peach fruit. Among these treatments, preconditioning is widely used commercially and, when properly applied, delays CI symptom expression for 10 to 12 days, enough to improve the quality of some peach cultivars on arrival. Unfortunately, the benefits of these treatments have been erratic, and when postharvest life has been extended, the time of extension has been too short to have a commercial impact. An early review of orchard factors affecting peach CI such as nitrogen fertilization, deficit irrigation regimes, maturity, canopy position, crop load, fruit size, environmental conditions, season factor, and genotypes concluded that genotype was the most important factor among them. In general, clingstone nectarine cultivars were less susceptible to CI than peach cultivars and non-melting flesh cultivars have reduced endoPG activity and less CI than melting flesh cultivars. The variation in CI susceptibility among commercial cultivars and selections when stored at either 0´IC or 5´IC indicated that CI is genetically controlled. Clingstone non-melting flesh (CNMF) peaches, which are primarily used in canning but are also popular in the European and South African fresh markets are largely free of CI, although the physiological basis for this resistance has not been addressed. Melting flesh (MF) cultivars vary in susceptibility to CI, with some varieties exhibiting symptoms in all fruit after only one week of cold storage even at 0˚C, while others appear resistant, withstanding six weeks of cold storage before eventually ripening and senescing. To provide a long-term solution to CI, genetic resistance to this disorder is desirable for new MF peaches destined for the fresh market. This may be achievable by phenotypic selection for resistance in breeding program progeny. However, the inheritance of symptoms has not been quantified, and strategies for genetic improvement through breeding would be greatly aided by knowledge of the underlying mechanisms of genetic control.

A novel approach on plum handling using 1-Methylcyclopropene (1-MCP)

Japanese plum (*Prunus salicina* Lindl.) is a highly perishable temperate fruit and cold storage at 0 ˚C is recommended to extend fruit postharvest life and maintain quality. Commercial storage and transportation conditions (0-5 °C and 80-95% relative humidity) delay the softening process, reduce weight loss and disease development, but may also lead to the development of cold storage disorders (Crisosto et al., 2009). Most plum cultivars are susceptible to postharvest disorders, such us chilling injury (CI) symptoms after prolonged cold storage and express symptoms during ripening at room temperature (Manganaris et al., 2008). The cold storage disorder symptoms include flesh browning, gel breakdown, mealiness, flesh translucency, red pigment accumulation (bleeding), over-ripening, and loss of flavor. The onset of these cold storage symptoms determines the postharvest storage/shipping potential because CI development reduces consumer acceptance. Susceptibility of fruit to CI mainly varies according to genetic background and storage temperature (Crisosto et al., 2009).

Plum storage or transport at temperatures higher than 7.5 ˚C to avoid CI symptoms development has been tested in several cultivars with successful control of cold storage disorders, but over-ripening, senescence and softening overcame the benefits (Crisosto and Garner, 2008). In previous studies of our group (Palou and Crisosto, unpublished data), untreated 'Fortune' plums stored at 0 to 5 ˚C had higher firmness retention for up to two weeks of storage, but exhibited up to more than 50% of mealy fruit after three days of ripening at 20 ˚C, while fruit stored at 10 ˚C did not show any CI symptom, but softened too fast, resulting in a short postharvest market life. Furthermore, a combined approach using controlled atmosphere (CA) to reduce softening when plum are exposed to temperatures higher than 7.5 ˚C has also been also unsuccessfully tested (Crisosto and Garner, 2008) because of softening and 'off-flavor' problems due to low oxygen (3-5%) and/or high CO_2 (10-15%) toxicity after long storage periods of storage. Therefore, the use of 1-Methylcyclopropene (1-MCP), which inhibits ethylene and prevents ethylene-dependent responses such as softening and senescence of vegetative and fruit tissues (Sisler and Serek, 1997), and its active role in plum ripening inhibition is well demonstrated (Abdi et al., 1998; Martinez-Romero et al., 2003), could be a promising approach to store plums above chilling temperatures ranges without undesired softening. 1-MCP is registered as SmartFresh™ (AgroFresh®, Rohm and Haas, Spring House, PA) for postharvest chemical fumigation in sealed rooms or tents on a number of fruit and vegetable crops including apple, avocado, banana, broccoli, kiwifruit, melon, persimmon, tomato, pear, Asian pear, peach, nectarine, plum, apricot and plumcot (Watkins, 2006). The standard application recommended by AgroFresh® for the stone fruit is 0.5 µL L^{-1} for 24 h in a sealed room or tent at 0 °C. Our previous work using cultivars growing in California indicated that the benefit of using 1-MCP in peaches and nectarines is cultivar dependent and sometimes erratic. However, our results have been effective and consistent on maintainaining plum cultivars postharvest life (Crisosto, unpublished). Although the effect of 1-MCP postharvest application on plum is promising on reducing softening during storage, transportation, and retail handling, it may interfere with their ability to ripen normally after storage and/or produce storage disorder symptoms (Dong et al., 2002). Several research papers state that 1-MCP treatment does not affect sugars, but maintains higher titratable acidity (TA) levels, which might affect fruit's final sensory quality (Salvador et al., 2003). The storage of fruit in above chilling temperatures, but still cold storage temperatures (7.5-10.0 ˚C) after the 1-MCP application could provide significant energy and cost savings while maintaining adequate post-storage plum quality by avoiding or delaying the development of CI symptoms and improving ripening recovery for consumers. This hypothesis was tested by exposing different Japanese plum (*Prunus salicina* L.) cultivars to 0.5 L L^{-1} 1-MCP at 0 °C for 24 h. Following 1-MCP treatment, fruit were stored at 0 or 10 ˚C for 10, 20, or 30 d, respectively. After those periods of cold storage, fruit were moved to ripen at room temperature (20˚C, RH 90%) for 0, 2, 4 and 6 d and their quality were evaluated. Ethylene production, respiration rate, tissue firmness, soluble solids content (SSC), titratable acidity (TA), skin and flesh color were evaluated during each ripening period. In general, 1-MCP treated fruit stored at 10 °C had similar ripening behavior as the untreated ones stored at 0 °C after 10 and 20 d of storage. In both cultivars, 1-MCP treatment was able to inhibit ethylene production and significantly delay significantly plum softening during ripening after 10 and 20 d of storage at 10 °C compared to control fruit. 1-MCP did not affect SSC, but it delayed color change, TA, and firmness drop at both storage temperatures.

The other potential barrier for the use of 1-MCP treatment is the 24-h application period recommended for stone fruit which delays the storage, packaging, and interrupting the current operation flow. Fast cooling is a commercial practice used worldwide during stone during the stone fruit postharvest handling to reduce disease development, softening, and weight loss of fresh fruit. Forced-air cooling is a powerful tool to market perishable produce over long distances because of its ability to cool produce quickly after harvest; thereby it became the primary method of cooling of fresh fruits and vegetables in California prior to cold storage (Thompson et al., 2002). Thus, we propose a 1-MCP application during the forced air cooling operation (˝6-9 h) that does not interrupt the current plum postharvest operation, and it should be easily adapted by the stone fruit industry. In order to make the 1-MCP pre-storage application easier for the growers, we probed the potentiality of applying 1-MCP during the forced air cooling operation (FAC), reducing the application time from 24 h to 6 h, without losing its efficacy. An application of 1-MCP during forced air cooling (FAC) was compared to the standard 24 hour treatment in different plum cultivars. Fruit were treated with 1-MCP (0.5 µL L^{-1}, 0°C, 24 h) in sealed 330 L volume aluminum tanks or applied with 1-MCP (0.5 µL L^{-1}, 0 °C, 6 h) in a forced air cooler (1 Ls^{-1} kg^{-1}) fitted in a 4000 L volume tend (Figure 1). Following treatments fruit were stored at 0 °C or 10 °C and 90% RH for 10 and 20 d. After the storage period, fruit were ripened at room temperature (20 °C, RH 90%) for up to 14d. Ethylene emission, respiration rate, tissue firmness, soluble solids content (SSC), titratable acidity (TA), skin and flesh color were evaluated during the ripening period. The efficacy of the FAC 1-MCP application was similar to the conventional for all the cultivars tested. Both1-MCP treatments improved postharvest performance of plums, protecting them from fast softening process during the ripening period (Figure 2). The results from this work demonstrate that fruit treated with 1-MCP-FAC (6h) and subsequently stored at 10 ˚C, exhibit similar storage performance and ripening behavior than the untreated fruit stored at the recommended temperature for stone fruit (0 ˚C) for up to 20 d. Furthermore, our results showed that with this protocol, fruit might have an extra two to three days of market life compared to the untreated fruit stored at the normal temperature for plums (0 ˚C), and it would be less likely to suffer from bruising damage during postharvest retail handling. Therefore, the implementation of the use of 1-MCP to store fruit at 10 ˚C as a new combined approach could be a solution to avoid chilling injury and improve consumer acceptance. The energy usage estimation for the 1-MCP pre-storage treatment followed by storage at 10 ˚C is 35 kWh/ton versus the 54 kWh/ton needed for the regular storage at 0 °C for up to 20 d in the Californian climate conditions (Thompson and Singh, 2008). In summary, our new proposed protocol would provide a 35% reduction in energy usage compared to the regular storage, and therefore a significant reduction in costs from 8.10$ to 5.25$ per ton of fresh fruit (Thompson et al., 2010). Reduction of energy consumption and/or more efficient energy use are current challengestoward reducing CO_2 output and to saving costs. The 1-MCP-FAC application protocol can be easily adopted in the tree fruit industry, because of the significant reduction of the application time (6 h compared to the 24 h), the considerable energy savings and the avoidance of any additional operations, since FAC is already applied from by the majority of the industry.

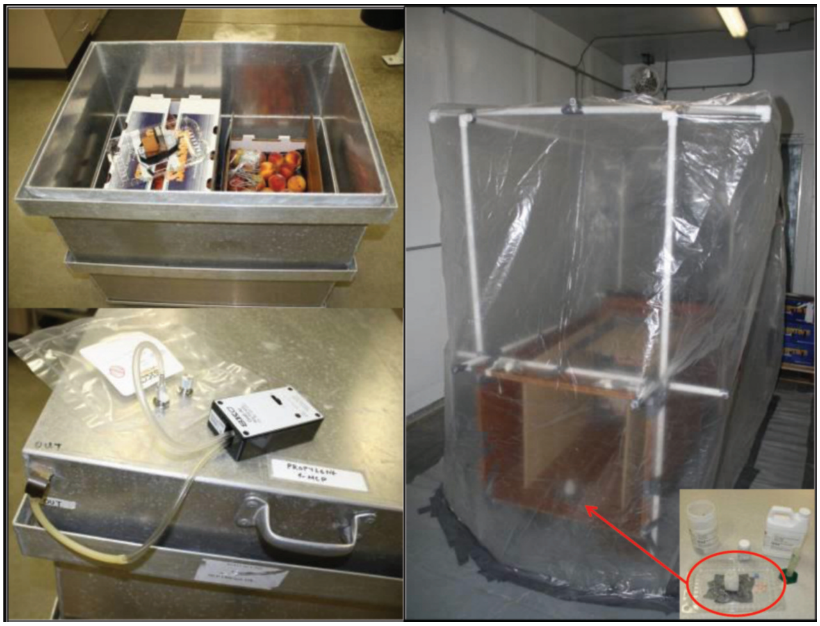

Figure 1. Standard recommended application of 1-MCP (0.5 µL L^{-1}, 0 °C, 24h) in a sealed 330 L volume aluminum tank (left), and the novel application technique, in a forced air cooler (0.5 µL L^{-1}, 0 °C, 24h) fitted in a 4000 L volume tend (Right).

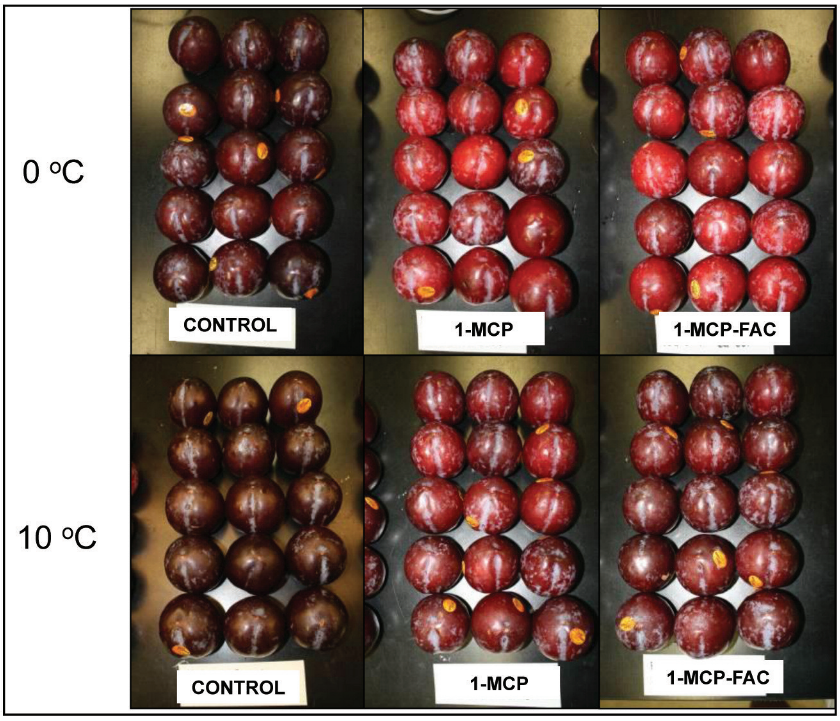

Figure 2. External appearance of 'Fortune' plums, untreated (Control) and treated with 0.5 µL L^{-1} 1-MCP for 24 h (1-MCP) or 6 h (1-MCP-FAC) after 10 days of storage at 0 °C or 10 °C plus 6 days ripening at 20 °C.

Besides the beneficial effects of 1-MCP on slowing down fruit ripening processes, it is critical that the fruit treated with 1-MCP reach a high consumer quality prior to consumption. For this reason, fruit were presented to the consumers (N=140) at the same ripening stage regardless of treatment (1-MCP treated or untreated) to make sure that any differences detected by consumers were due to the treatment with 1-MCP, and not to the different fruit ripening stages. This data confirmed our ongoing tree fruit sensory work indicating that ripening is needed to reach a maximum potential flavor perception. 1-MCP treatment had no detrimental effect on consumer acceptance of low-acid plums ripened properly prior to consumption. Consumer acceptance was significantly reduced on untreated and treated high-acid plums. 1-MCP treated ripe plums with high acidity had lower liking score than untreated, but they were still accepted by consumers. These results support the recommendation that use of 1-MCP in plum should be integrated in a more holistic strategy taking into consideration its beneficial effect on ripening inhibition and the factors affecting consumer acceptance, especially in high acid plum cultivars. Thus, 1-MCP use on plum should avoid cultivars with high acidity and/or plums picked early when fruit have titratable acidity of 0.9% or more. 1-MCP–FAC treatment followed by storage at 10 ˚C is a promising new methodology to avoid chilling temperatures and provide considerable energy saving without reducing postharvest life and consumer quality of low-acid plums. Our results encourage testing this new technology at the commercial scale to accurately quantify energy savings and consumer reactions for specific operations and markets.

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