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Stone Fruit

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INTRODUCTION

The term 'stone fruit' is used to cover fruits of the *Prunus* species, peaches, nectarines, plums, cherries and apricots. This chapter will concentrate on post-harvest issues relating to peaches, nectarines and plums. Owing to their close relationship peaches and nectarines will be considered together.

Peaches and nectarines

Peaches and nectarines are classified from the horticultural point of view as stone fruits or drupes. They are soft fleshed with a pit, contain a high level of antioxidant but are highly perishable with a limited market life potential (Lill *et al*. 1989). The total antioxidant capacities of peaches and nectarines are about 15% and 20% of the total antioxidant capacity relative to that of 100 ml of red wine and 100 ml of green tea, respectively (USDA 2007a). Potential opportunities for export marketing, combined with the desire to store some late-season cultivars to extend the marketing season, have increased interest in understanding fruit physiology and extending postharvest life.

Peach, *Prunus persicae*, is native to China and Persia (Iran); at one time it was called 'Persian apple.' Chinese literature dates its cultivation in China to 1000 BCE. Probably carried from China to Persia, the peach quickly spread from there to Europe. In the sixteenth century, it was established in Mexico probably by the Spanish missionaries who introduced the peach to California in the eighteenth century. Nectarine (*Prunus persicae* var. nectarina) has been reported for nearly as long as peach, but its origin is unknown. Because they may have arisen from peach seeds, most peach-growing areas world-wide have also introduced nectarine cultivars.

Plums

Plums (*Prunus salicina*) are mainly marketed for fresh consumption and not for drying. They are also used for canning, freezing and jam and jelly making. The Japanese plum is native to China, but was domesticated in Japan about 400 years ago. It was first brought to California from Japan in 1870 by John Kelsey. In 1885, Luther Burbank imported about 12 seeds from Japan, and used them to breed many cultivars. The plum industry has increased throughout California (mainly in the southern San Joaquin Valley) where most Japanese plums in the United States are grown. Prunes are cultivars of European Plum (*Prunus domestica*, L.) which can be dried whole. Like plums, prunes can be eaten fresh (if a very sweet fruit is desired); but they also have the high sugar content necessary for successful drying. The European plum, believed to have originated in the Near East, has been grown in parts of Europe for many centuries. Through its culture in France, the prune 'd'Agen' was introduced to California from France by Louis Pellier, a French horticulturist who had come to California seeking gold.

Plums (*Prunus salicina* Lindell) have the potential to contribute greatly to human nutrition because of their richness in fiber and antioxidants. These values can be found in the USDA Food Composition Database (USDA 2007b).

Crop Post-Harvest: Science and Technology, First Edition. Edited by Debbie Rees, Graham Farrell and John Orchard.

STONE FRUIT PHYSIOLOGY

Botanically, peach is a drupe. A drupe is a fleshy fruit with a thin, edible outer skin (epicarp) derived from the ovary, an edible flesh of varying thickness beneath the skin (fleshy mesocarp), and a hard, inner ovary wall that is highly lignified (endocarp) and is commonly referred to as the 'stone' or 'pit', which encloses a seed. Peaches have thin skins and soft flesh. The skin, as a protective layer, is composed of cuticle, epidermis and some hypodermal cell layers. The cuticle is a thin coating of wax and serves to reduce water loss and to protect the fruit against mechanical injury and attack by pathogens. The epidermis, consisting of heavy-walled cells, is responsible for most of the skin's mechanical strength. Surface chromosomes or hairs ('fuzz') of peach fruit are extensions of some epidermal cells. The flesh, which is the main edible portion of the fruit, consists mainly of storage parenchyma tissue composed of large, relatively thin-walled cells with high water content. On the basis of separation of stone from flesh, nectarine and peach varieties can be divided into two groups: freestone (where the stone does not adhere to the flesh) and clingstone (where the stone adheres firmly to the flesh).

Upon the completion of pollination and fertilization of the egg, the flower ovary begins to enlarge into a developing fruit. This is 'fruit set', and it marks the beginning of growth and development. Stone fruits have a double sigmoidal growth curve which includes three distinct stages of growth. Following fruit set, cell division continues for about 4 weeks, with cell enlargement beginning and proceeding rapidly (stage 1). Slow growth then occurs, during which lignification of endocarp (pit hardening) and growth of endosperm and embryo inside the seed take place (stage 2). Cell enlargement (expansion) resumes in the flesh (mesocarp) tissue. The fruit continues to increase in size until it reaches full maturity, after which growth slows markedly and finally stops (stage 3). The duration of each stage of growth depends upon variety, climactic conditions and some cultural practices (such as thinning or crop load per tree, soil moisture, girdling and nutrition). Fruit density (specific gravity) declines during Stage 1, increases during Stage 2, then declines again during Stage 3 (final fruit swell). During the pit hardening, the seed constitutes 25% of the fruit weight, and this value drops to 14% during final swell. From a postharvest standpoint, interest in Stage 3 is greatest, since maturation, ripening and senescence occur during this stage. Maturation is the time between final growth and the beginning of ripening. Maturity is the end point of maturation. An immature fruit may ripen off the tree, but it will be of poor quality. A mature fruit will attain good quality when ripened off the tree. Ripening involves changes that transform the mature fruit into one ready to eat. Changes associated with ripening include loss of green colour and development of yellow, red and other colours characteristic of a variety. As a fruit ripens, it softens, its starch is converted to sugars, its acidity declines and it produces certain volatile compounds that give it a characteristic aroma. Increased respiration and ethylene production rates are among the physiological changes associated with ripening. Once a fruit ripens, it begins senescence. Physical and chemical changes continue after 'optimum' ripeness is reached (from a flavour quality standpoint), including further softening and loss of desirable flavour. The final outcome of post-ripening changes is complete breakdown and death of the tissues.

PEACH AND NECTARINE POST-HARVEST HANDLING SYSTEMS

Fruit deterioration factors

Water loss

Fruit shrivelling occurs when fruit lose approximately 5–8% of the fruit's water content, based on weight at harvest. This loss is sufficient to cause visual shrivel in peaches and nectarines (Ceponis *et al*. 1987). While there is a large variability in susceptibility to water loss among cultivars, all peaches and nectarines must be protected to assure the best post-harvest life. Fruit waxes that are commonly used as carriers for post-harvest fungicides can reduce the rate of water loss when brushing has not been overdone. Mineral oil waxes can potentially control water loss better than vegetable oil and edible coatings. Because fruit shrivel results from cumulative water loss throughout handling, it is important to maintain low temperature and high relative humidity throughout harvesting, packing, storage, transport and distribution. Short cooling delays, efficient waxing with gentle brushing, fast cooling followed by storage under constant low temperature and high relative humidity are the main ways of limiting water loss.

Chilling injury (CI) or internal breakdown (IB)

The major physiological cause of deterioration for peaches and nectarines is a low-temperature or chilling injury (CI) problem generically called 'internal breakdown' (IB) (Plate 10.1) The genetic disorder can manifest itself as dry, mealy, woolly or hard-textured fruit (not juicy), flesh or pit cavity browning and flesh translucency usually radiating through flesh from the pit. In all of the cases, flavour is lost before visual symptoms are evident. However, there is large variability in CI susceptibility among peach and nectarine cultivars (Tables 10.1

Table 10.1 Effects of Storage Temperature on Storage and Shipping Potential of peach cultivars[a].

		Fruit type			Storage and shipping potential (weeks)	
Cultivar	Plant breeding program	Flesh–stone adhesion	Flesh texture	Flesh color	0°C	5°C
Autumn Flame	Doyle	Freestone	Melting	Yellow	1	0
Autumn Lady	Merrill	Semifreestone	Melting	Yellow	2	1
Autumn Rose	Richards	Freestone	Melting	Yellow	1	1
Brittney Lane	Zaiger	Clingstone	Melting	Yellow	5	5
Carnival	Merrill	Freestone	Melting	Yellow	2	1
Country Sweet	Zaiger	Clingstone	Melting	Yellow	5	5
Crimson Lady	Bradford	Clingstone	Nonmelting	Yellow	5	5
Elegant Lady	Merrill	Freestone	Melting	Yellow	4	1
Fairtime	USDA	Freestone	Melting	Yellow	3	1–2
Fay Elberta	NA	Freestone	Melting	Yellow	4	3
Flavorcrest	Weinberger	Freestone	Melting	Yellow	4	2
Ivory Princess	Bradford	Clingstone	Melting	White	5	3
June Lady	Merrill	Cling	Melting	Yellow	4	1
Kaweah	Zaiger	Freestone	Melting	Yellow	2	1
Last Chance	Sprague	Freestone	Melting	Yellow	2	1
May Sweet	Zaiger	Clingstone	Melting	Yellow	5	5
O'Henry	Merrill	Freestone	Melting	Yellow	3	2
Parade	Merrill	Freestone	Melting	Yellow	1	<1
Rich May	Zaiger	Clingstone	Melting	Yellow	4	3
Ryan Sun	Chamberlin	Freestone	Melting	Yellow	4	1–2
Saturn	Bailey	Freestone	Melting	White	5	3
September Flame	Burchell	Clingstone	Melting	Yellow	2	1
September Snow	Zaiger	Freestone	Melting	White	4	2
September Sun	Chamberlin	Freestone	Nonmelting	Yellow	3	1–2
Snow Fire	Zaiger	Freestone	Melting	White	5	2
Snow Kist	Zaiger	Clingstone	Melting	White	5	2
Spring Snow	Zaiger	Clingstone	Melting	White	5	5
Sugar Giant	Zaiger	Freestone	Melting	White	5	2.5
Sugar Lady	Zaiger	Freestone	Melting	White	3	2
Sugar Lady	Zaiger	Freestone	Melting	White	4.5	3
Summer Lady	NA	Freestone	Melting	Yellow	5	3
Summer Sweet	Zaiger	Freestone	Melting	White	4.5	2
Sunlit Snow	Zaiger	Clingstone	Melting	White	5	5
Super Rich	Zaiger	Clingstone	Melting	Yellow	5	5
Sweet Dream	Zaiger	Clingstone	Melting	Yellow	1	0
Sweet Scarlet	Zaiger	Freestone	Nonmelting	Yellow	4	2
White Lady	Zaiger	Freestone	Melting	White	4	2

[a] Information was obtained from personal communications with Gary Van Sickle, Kevin Day, and David Ramming, from Brooks and Olmos (1972), Whealy and Demuth (1993), Okie (1998), nursery catalogues and US patents.

Table 10.2 Effects of Storage Temperature on Storage and Shipping Potential of Nectarine Cultivars[a].

Cultivar	Plant breeding program	Fruit type: Flesh–stone adhesion	Fruit type: Flesh texture	Fruit type: Flesh color	Storage/ shipping potential (weeks): 0°C	Storage/ shipping potential (weeks): 5°C
Arctic Jay	Zaiger	Freestone	Melting	White	5	5
Arctic Snow	Zaiger	Freestone	Melting	White	5	2
Arctic Star	Zaiger	Clingstone	Melting	White	5	5
Arctic Sweet	Zaiger	Clingstone	Melting	White	5	3
August Glo	Zaiger	Clingstone	Melting	Yellow	3	1
August Red	Bradford	Clingstone	Melting	Yellow	5	3
Diamond Bright	Bradford	Clingstone	Melting	Yellow	5	5
Diamond Ray	Bradford	Clingstone	Melting	Yellow	5	5
Fire Pearl	Bradford	Clingstone	Melting	White	5	2
Grand Pearl	Bradford	Clingstone	Melting	White	2	1
Honey Blaze	Zaiger	Semifreestone	Melting	Yellow	5	5
Kay Sweet	Bradford	Clingstone	Nonmelting	Yellow	5	5
Ruby Diamond	Bradford	Freestone	Melting	Yellow	5	3
Ruby Pearl	Bradford	Clingstone	Melting	White	5	5
Ruby Sweet	Bradford	Clingstone	Melting	Yellow	5	5
September Free	USDA	Freestone	Melting	Yellow	3	1
September Red	Bradford	Clingstone	Melting	Yellow	4	1
Spring Red	Anderson	Freestone	Melting	Yellow	5+	3
Summer Blush	Bradford	Clingstone	Melting	Yellow	5	1
Summer Bright	Bradford	Clingstone	Melting	Yellow	5	3
Summer Fire	Bradford	Clingstone	Melting	Yellow	5	3
Summer Grand	Anderson	Freestone	Melting	Yellow	5+	5
Zee Glo	Zaiger	Clingstone	Melting	Yellow	3	3

[a] Information was obtained from personal communications with Gary Van Sickle, Kevin Day, and David Ramming, from Brooks and Olmos (1972), Whealy and Demuth (1993), Okie (1998), nursery catalogues and US patents.

and 10.2). In general, peach cultivars are more susceptible to CI than nectarine cultivars. In susceptible cultivars, CI symptoms develop faster and more intensely when fruit are stored at temperatures between about 2°C and 7°C than when similar fruit are stored at 0°C or below, but above freezing point (Mitchell 1987; Table 10.3). At the shipping point, fruit should be cooled and held near or below 0°C if possible. During transportation if CI susceptible cultivars are exposed to approximately 5°C, it can significantly reduce their post-harvest life.

Several treatments to delay and limit development of this disorder have been tested. Among them, preconditioning treatment before storage is being used commercially in the United States, Chile and other countries. The success of the controlled-atmosphere treatment in ameliorating CI is dependent on cultivar market life potential, fruit temperature, shipping time and fruit size.

Post-harvest treatments to reduce deterioration

Controlled atmosphere (CA)

Most studies of CA storage of peaches and nectarines have found that lowering O_2 and raising CO_2 in the storage atmosphere conferred benefit on the fruit and delayed or prevented the appearance of mealiness, internal reddening and flesh browning (Zhou *et al*. 2000; Crisosto *et al*. 1995; Lurie 1992; Retamales *et al*. 1992). The CO_2 component appears to be critical for delaying the onset of CI (Wade 1981; Kajiura 1975; Anderson *et al*. 1969). Exposure to 10% CO_2 + 10% O_2 for 6 weeks has been reported to

Table 10.3 Relationship between Stone Fruit Soluble Solids Content (SSC) and the Freezing Point.

SSC	Safe Freezing Point	
(%)	(°F)	(°C)
8.0	30.7	–0.7
10.0	30.3	–0.9
12.0	29.7	–1.3
14.0	29.4	–1.4
16.0	28.8	–1.8
18.0	28.5	–1.9

prevent CI in the nectarine cultivars 'Fantasia', 'Flavortop; and 'Flamekist' (Lurie 1992). It has been demonstrated that 'Fantasia' nectarines stored in air plus 10 to 20% CO_2 were juicy and had good flavour after 5 weeks at 0°C storage (Burmeister & Harmon 1998). CA conditions of 6% O_2 + 17% CO_2 have been reported to be beneficial for peaches and nectarines shipped from Chile (Retamales *et al*. 1992; Streif *et al*. 1992). In California, the major benefits of CA during storage/shipment are retention of fruit firmness and ground colour, and reduction of flesh browning development. CA conditions of 6% O_2 + 17% CO_2, the best combination, at 0°C have shown a limited benefit for reduction of mealiness during shipments for yellow flesh cultivars (Crisosto *et al*. 1999b) and white flesh cultivars (Garner *et al*. 2001). As mealiness is the main CI symptom rather than flesh browning, the use of CA technology in California cultivars has been limited. The CA efficacy is related to cultivar (Mitchell & Kader 1989), preharvest factors (Crisosto *et al*. 1997; Combrink 1996; Von Mollendorff 1987), temperature, fruit size (Crisosto *et al*. 1999a), marketing period and shipping time (Crisosto *et al*. 1999b).

The use of the modified atmosphere packaging (MAP) technique has been tested on several peach cultivars without success. Despite high CO_2 levels that were reached during cold storage, flesh mealiness and flesh browning development limited the potential benefits of this technology. In some commercial cases when box liners (MAP) were used, the incidence of decay increased because of lack of proper cooling and condensation during transportation.

Preconditioning treatment

A commercial controlled delayed cooling or preconditioning treatment was developed to extend peach (*Prunus persica*) market life of the most popular California peach cultivars. A 48 h cooling delay at 20°C was the most effective treatment for extending market life of CI susceptible peaches without causing fruit deterioration (Crisosto *et al*. 2004a). This treatment increased minimum market life by up to 2 weeks in the cultivars tested. Weight loss and softening occurred during the controlled delayed cooling treatments, but did not reduce fruit quality. Fruit must be cooled down and fruit temperature should be maintained near 0°C during their post-harvest handling.

Post-harvest fruit diseases

Post-harvest loss of peach and nectarine to decay-causing fungi is considered the greatest deterioration problem. Worldwide, the most important pathogen of fresh stone fruits is Botrytis rot, caused by the fungus *Botrytis cinerea* (Plate 10.2). It can be a serious problem during wet, spring weather. It can occur during storage if fruit have been contaminated through harvest and handling wounds. Avoiding mechanical injuries and good post-harvest temperature management are effective controls.

Brown rot is caused by *Monilinia fructicola* with infections beginning during flowering. It is the most important post-harvest disease of peaches in California (Plate 10.3). Rhizopus rot is caused by *Rhizopus stolonifer* and can occur in ripe or near-ripe peaches kept at 20°C to 25°C. Cooling and keeping fruit below 5°C are part of an effective control. Good orchard sanitation practices and proper fungicide applications are essential to reduce these problems. It is also common to use a post-harvest fungicidal treatment against these diseases. A Food and Drug Administration (FDA) approved fungicide(s) is often incorporated into a fruit coating or wax for uniformity of application. The regulation on the use of fruit coatings varies according to country. Careful handling to minimize fruit injury, sanitation of packinghouse equipment and rapid, thorough cooling to 0°C as soon after harvest as possible are also important for effective disease suppression.

Physical damage

Stone fruits are susceptible to mechanical injuries including cuts, impact, compression and abrasion (vibration) bruising. Careful handling during harvesting, hauling and packing operations to minimize such injuries is important because the injuries result in reduced appearance quality, accelerated physiological activity, potentially more inoculation by fruit decay organisms and greater water loss. Incidence of impact and compression bruising has become a greater concern as a large part of the peach and nectarine industry is harvesting fruit at more advanced maturity (softer) to maximize fruit flavour quality. Several surveys carried out in south-eastern Fresno County (California, United States) indicated that most impact bruising damage occurs during the packinghouse operation and long transportation from orchard to packinghouse. Critical impact bruising thresholds (the minimum fruit firmness measured at the weakest point to tolerate impact abuse) have been developed for many of the commercially important peach and nectarine cultivars.

Abrasion damage can occur at any time during post-harvest handling. Protection against abrasion damage involves procedures to reduce vibrations during transport and handling by immobilizing the fruit. These procedures include: installing air suspension systems on axles of field and highway trucks, using plastic film liners inside field bins, using plastic bins, installing special bin top pads before transport, avoiding abrasion on the packing line and using packing procedures that immobilize the fruit within the shipping container before they are transported to market. In situations when abrasion damage occurs during harvesting on fruit that have heavy metal contaminants, such as iron, copper and/or aluminium, on their skin, a dark discolouration (inking or peach skin discolouration) is formed on the surface of peaches and nectarines. These dark or brown spots or stripes on the fruit are a cosmetic problem and a reason for discard. Heavy metal contaminants on the surface of the fruit can occur as a consequence of foliar nutrients and/or fungicides sprayed within 15 days or 7 days before harvest, respectively. Pre-harvest intervals that have been developed for several approved fungicides in California should be followed. Light brown spots or stripes are also produced on the surface of white flesh peaches and nectarines as a consequence of abrasion occurring mainly during harvesting and hauling operations.

Temperature management and optimum storage conditions

Optimum temperature is –1°C to 0°C. The freezing point varies, depending on SSC, from –3°C to –1.5°C (Table 10.3). Relative humidity (RH) should be 90–95% with a low air velocity during storage (Thompson *et al*. 1998). Fruit can be cooled in field bins using forced-air cooling or hydro-cooling. Hydro-cooling is normally done by a conveyor-type hydro-cooler or *in situ*. Fruit in field bins can be cooled to intermediate temperatures of 5–10°C provided packing will occur the next day or pack immediately. If packing is to be delayed beyond the next day, then fruit should be thoroughly cooled in the bins to near 0°C. In IB-susceptible cultivars, fast cooling within 8 hours and maintaining fruit temperature near 0°C are traditionally recommended.

Peaches and nectarines in packed containers should be cooled by forced-air cooling to near 0°C. Even peaches that were thoroughly cooled in the bins will warm substantially during packing and should be thoroughly re-cooled after packing. A new technique to delay IB symptoms and pre-ripen fruit has been successfully introduced to the California and Chilean industries. This technique consisted of a ≈48-hour controlled cooling delay. Forced-air cooling is normally indicated after packing.

Stone fruit storage and overseas shipments should be at or below 0°C. Maintaining these low pulp temperatures requires knowledge of the freezing point of the fruit, of the temperature fluctuations in the storage system and equipment performance. Holding stone fruits at these low temperatures minimizes both the losses associated with rotting organisms, excessive softening, water losses and the deterioration resulting from CI in susceptible cultivars.

Horticultural maturity indices

The maturity at which stone fruits are harvested greatly influences their visual quality, ultimate flavour and market life (Crisosto 1994). Harvest maturity affects the fruit's flavour components, physiological deterioration problems, susceptibility to mechanical injuries, resistance to moisture loss, susceptibility to invasion by rot organisms, market life and ability to ripen. Peaches and nectarines that are harvested too soon (immature) may fail to ripen properly or may ripen abnormally. Immature fruit typically soften slowly and irregularly, never reaching the desired melting texture of fully matured fruit. The green ground colour of fruit picked immature may never fully disappear. Because immature fruit lack a fully developed surface cuticle, they are more susceptible to water loss than properly matured fruit. Immature and low-maturity fruit have lower soluble solids concentrations and higher acids than properly matured fruit, all of which contribute to inadequate flavour development. Low-maturity fruit are more susceptible to both abrasion and the development of flesh browning symptoms than properly matured fruit. Over mature fruit have a shortened post-harvest life, primarily because of rapid softening and they are already approaching a senescent stage at harvest and developing a mealy texture. Such fruit have partially ripened, and the resulting flesh softening renders them highly susceptible to mechanical injury and fungus invasion. By the time such fruit reach the consumer, they may have become overripe, with poor eating quality including off-flavours and mealy texture.

In several countries, harvest date is determined by skin ground colour changes from green to yellow in most cultivars. A colour chip guide is used to determine maturity of each cultivar, except for white flesh cultivars. A three-tier maturity system is used in California and a similar system is used on other countries: (1) U.S. Mature (minimum maturity), (2) Well-Mature and (3) Tree Ripe. Measurement of fruit firmness is recommended in cultivars where skin ground colour is masked by full red colour development, especially nectarines, before maturation. In these cases, a maximum maturity index can be applied. Maximum maturity is defined as the minimum flesh firmness (measured with a penetrometre with an 8 mm tip) at which fruit can be handled without bruising damage. Bruising susceptibility varies widely among cultivars. The optimum maturity for stone fruit harvest must be defined for each cultivar. The highest maturity at which a cultivar can be successfully harvested is influenced by post-harvest handling and temperature management procedures. Maturity selection is more critical for distant markets than for local markets, but does not necessarily mean lower maturity. Because of the availability of new cultivars that adapt well to harvesting more mature (softer), the increase in popularity of high-quality, less firm fruit (more mature) and the use of more sophisticated packinghouse equipment, a large proportion of stone fruits are being picked at a more advanced maturity stage.

Quality characteristics and criteria

In California the minimum ripe soluble solids concentration (RSSC) needed to reach high consumer acceptance for peach and nectarine was determined by using ‘in-store’ consumer tests of low and high ripe titratable acidity (RTA) melting flesh cultivars as a part of our program to develop minimum quality indexes (Crisosto and Crisosto, 2005). There is high consumer acceptance of peaches with high soluble solids content (SSC). Titratable acidity (TA) and SSC:TA are currently used as an important predictor of consumer acceptance but it is accepted that volatile, flavour and texture are also important components of flavour. For these moderate/low-acid and high-acid cultivars, consumer acceptance was closely related to RSSC, but maximum consumer acceptance was attained at different RSCC levels depending on the cultivar. The fact that these cultivars reached high consumer acceptance with different RSSC levels indicates that a single generic RSSC quality index would not be reliable to assure consumer satisfaction across all cultivars. For most of the midseason peaches, a minimum of 11% SSC with a TA ≤0.7% is required to satisfy about 80% of consumers. Our ‘in-store’ consumer tests indicated that high consumer acceptance is attained with mid- and late-season cultivars when peaches are free of chilling injury and ‘ready to eat’ prior to consumption. Within these cultivars, a large population of the fruit will be highly accepted by the consumers. Traditionally, the lack of flavours has been associated with early-season fruit or mid-late CI damaged fruit. These early cultivars have low flavour quality potential and generally are consumed mature and ‘not ripe’. However, lately a group of new cultivars that ripen early in our season (late April–mid-June) is becoming available. The ones that have been tested had high SSC, moderate to low acidity levels, were aromatic and had a high consumer acceptance when consumed at the ‘ready to eat’ stage. As production of new cultivars with diverse flesh colours, flavours, soluble solids concentrations (SSC), and titratable acidities (TA) is increasing in California and the rest of the world, we tested the concept of cultivar segregation according to the sensory perception of organoleptic characteristics. We were able to consistently segregate peach and nectarine cultivars into groups (balanced, tart, sweet, peach or nectarine aroma and/or peach or nectarine flavour) with similar sensory attributes. Based on this information, we suggest that cultivars should be clustered in organoleptic groups and development of a minimum quality index should be attempted within each organoleptic group rather than proposing a generic minimum quality index based on ripe SSC. This organoleptic cultivar classification may help to match consumer or ethnic preferences and enhance the current promotion and marketing programs.

Harvesting and packaging handling

Fruit are hand-picked using bags, plastic baskets or totes. Fruit are dumped in bins that are on the top of trailers between rows in the orchard. If fruit are picked into totes, the totes are usually placed directly inside the bins. Baskets are placed on racks within modified trailers. Fruit picked at advanced maturity stages and white flesh peaches or nectarines are most commonly picked and placed into baskets or totes. Fruit can be hauled for short distances by these trailers, but they are designed principally for transport within orchards. If the transport distance is longer than 5–10 km, bins are loaded on a truck or semi-truck and trailer for transportation to packinghouses. Harvest crews usually consist of 15 to 25 labourers including a foreman, who is responsible for ensuring uniformity of harvest, adherence to maturity and fruit size criteria and general supervision. Depending on the cultivar and orchard, a labourer can usually harvest 1½ to 3 bins (400–450 kg per bin) of fruit per day. Early-season cultivars are usually picked every 2–3 days, and by mid- to late season the interval can stretch to as much as 7 days between harvests. Tree heights are commonly 3.7–4.7 m, and workers require ladders to reach the uppermost fruits. Ladders are made of aluminium and are 3.7–4.0 m in length. Either four or six rows

Table 10.4 Incidence of Bruising (Impact + Vibration) within Three Ranges of Fruit Firmness in Packages of Tray Packed Yellow Flesh Peaches, Volume-Filled White Flesh Peaches, and Volume-Filled Yellow Flesh Nectarines after a 30-Minute Vibration Treatment.

	Percentage of bruised fruit at different levels of fruit firmness		
Packaging scenario or bruise location	<2.3 Kg-force	2.3–4.5 Kg-force	>4.5 Kg-force
Tray packed yellow flesh peach	35.1	2.7	0.0
Volume filled white flesh peach	55.2	13.6	–
Volume filled yellow flesh nectarine	43.9	9.8	4.4

are harvested at a time with an equitable number of pickers distributed in each row as conditions warrant. Labourers pick an entire tree and leap-frog one another down the rows. The foreman is responsible for moving the pickers between rows to maintain uniformity. Picking platforms have been tried in the past, but are not an economical way of reducing reliance upon ladders due to their cost and the vast differences in tree and labourer variability. When full, the bins are taken to a centralized area and unloaded from the bin-trailers to await loading by forklift onto flatbed trailers for delivery to the packing facility. Full bins are typically covered with canvas to prevent heat damage, and loading areas are usually bordered by large shade trees that serve to help reduce fruit exposure to the sun. In instances where the orchard is close to the packing plant, the fruit can be conveyed there directly on the bin-trailers.

At the packinghouse the fruit are dumped (mostly using dry bin dumps) and cleaned. Here trash is removed and fruit may be detergent washed. Peaches are normally wet-brushed to remove the trichomes (fuzz), which are single cell extensions of epidermal cells. In the case of nectarines, the brushing operation can usually be omitted. Waxing and fungicide treatment may follow in both types of fruit. Water-emulsifiable waxes are normally used, and fungicides may be incorporated into the wax. Waxes are applied cold and no heated drying is used.

Sorting is done to eliminate fruit with visual defects and sometimes to divert fruit of high surface colour to a high-maturity pack. Attention to details of sorting line efficiency is especially important with stone fruits where a range of fruit colours, sizes and shapes can be encountered. Sizing segregates fruit by either weight or dimension. Sorting and sizing equipment must be flexible to efficiently handle large volumes of small fruit or smaller volumes of larger fruit. Most yellow-flesh peaches are packed into two-layer (tray) boxes. Small-sized, yellow-flesh peaches are generally volume-fill packed. Most white-flesh and tree-ripe peaches are packed into one-layer (tray) boxes. Limited volumes of high-maturity fruit are 'ranch packed' at the point of production. In a typical tree-ripe operation, high-maturity and/or high-quality fruit are picked into buckets or totes that are carried by trailer to the packing area. Packers work directly from buckets to select, grade, size and pack fruit into plastic trays. In these cases, the fruit are not washed, brushed, waxed or fungicide treated. In other cases, fruit are picked into buckets or totes but then dumped into a smooth-operating, low-volume packingline for washing, brushing, waxing, sorting and packaging. Because of less handling of the fruit, a higher maturity standard can be used, and growers can benefit from increased fruit size, red colour and greater yield. High-quality fruit can also be produced by managing the orchard factors properly and picking firm fruit. In this case, ripening at the retailer will be essential to assure good flavour quality for consumers.

Our transportation bruising damage work on white and yellow flesh peaches and nectarines indicated that packaging system and fruit firmness influence bruising damage occurring during transportation. In general, tray packed fruit tolerate transportation better than volume filled (Table 10.4). Fruit with firmness between 2.3 and 4.5 kilos-force on the weakest fruit position only had between 3% (white flesh) to 10% (yellow flesh) damage, respectively (Crisosto et al., 2001; Valero et al 2006).

Handling at the receiving end

Peaches and nectarines are usually harvested when they reach a minimum or higher maturity, but are not completely ripe ('ready to eat'). Initiation of the ripening process must occur before consumption to satisfy consumers (Crisosto 1999). The ripening process can be initiated at the distribution centres (receivers) or at harvest immediately after packaging (preconditioning). In general, fruit < 27 to 36 N

(2.7 to 3.6 Kg-force) measured on the fruit cheek have high consumer acceptance and with 9 to 13.5 N (0.9 to 1.4 Kg-force) flesh firmness are considered ready to eat.

PLUM POST-HARVEST HANDLING SYSTEMS

Fruit deterioration factors

Chilling injury (CI) or internal breakdown (IB)

Chilling injury (CI) is a concern with most plum and fresh prune cultivars. It is expressed as flesh translucency and is associated with flesh browning (Plate 10.4). In previous publications from South Africa, flesh translucency, specifically in some plum cultivars, has been called 'gel breakdown' (Dodd 1984). In the United States, these symptoms are reported as 'internal breakdown' or CI (Crisosto *et al.* 1999b; Mitchell & Kader 1989). CI symptoms normally appear after placing fruit at ripening temperatures (20°C to 25°C) following cold storage at 2°C to 8°C. Postharvest life varies among cultivars and it is strongly affected by temperature management. Most plum and fresh prune cultivars are most susceptible to chilling injury when stored at 5°C. Market life of 'Blackamber,' 'Fortune' and 'Angeleno' plums at 0°C was > 5 weeks. 'Showtime,' 'Friar' and 'Howard Sun' plums developed chilling injury symptoms within 4 weeks, even when stored at 0°C. In all plum cultivars, a much longer market life was achieved when stored at 0°C than at 5°C (Table 10.5). However, market-life potential is affected by several other factors such as orchard conditions and maturity. For example, the role of maturity in market-life potential is well illustrated in our 'Blackamber' plum work (Table 10.6).

Pit burning symptoms are similar to internal browning but this is a heat damage problem that originates before harvest of 'Italian' and other cultivars of prunes and plum. It is associated with high temperatures during fruit maturation and can delay harvest (LaRue & Johnson 1989).

Post-harvest treatments to reduce deterioration

Controlled atmosphere (CA)

The major benefits of CA during storage and shipment are retention of fruit firmness and delay of changes in ground colour. Decay incidence can be reduced by CA of 1 to 2% O_2 + 3 to 5 % CO_2. Currently, CA has a limited use for storage for greater than 1 month with some cultivars such as Angeleno, Casselman, Santa Rosa, Laroda and Queen Ann (Kader & Mitchell 1998; Truter *et al.* 1994; Ben & Gaweda 1992; Streif 1989; Eksteen *et al.* 1986; Mitchell *et al.* 1981; Couey 1960, 1965).

The influence of modified atmosphere packages (MAP) on quality attributes and shelf life performance of 'Friar' plums was studied on 'Friar' plum (Cantín *et al.* 2008). Flesh firmness, soluble solids concentration (SSC), titratable acidity

Table 10.5 Effects of Storage Temperature on Market Life Potential of Plum Cultivars[a].

			Storage/shipping potential (weeks)	
Cultivar	Plant breeding program	Fruit type	0°C	5°C
Angeleno	Garabedian	Semi-free to freestone	5+	5
Betty Anne	Zaiger	Clingstone	5	5
Blackamber	Weinberger	Freestone		
Earliqueen	Zaiger	Clingstone	3	2
Friar	Weinberger	Freestone	5	3
Flavorich	Zaiger	Clingstone	5	5
Fortune	Weinberger	Semi-clingstone	5+	3
Hiromi Red	Zaiger	Clingstone	5	3
Howard Sun	Chamberlin	Freestone	4	1
Joanna Red	Zaiger	Freestone	5	5
October Sun	Chamberlin	Semi-clingstone	5	5
Purple Majesty	Bradford	Clingstone	5	3
Showtime	Wuhl	Freestone	5	3

[a] Information was obtained from personal communications with Gary Van Sickle, Kevin Day, and David Ramming, from Brooks and Olmos (1972), Whealy and Demuth (1993), Okie (1998), nursery catalogues and United States Patents.

(TA), and pH were not affected by the MAP liners. Fruit skin colour changes were repressed on plums packed in box liners that modified gas levels and weight loss was reduced by the use of any of the box liners. Plums packed without box liners (bulk packed) had approximately 6% weight loss. High CO_2 and low O_2 levels were measured in boxes with MAP box liners. Percentage of healthy fruit was not affected by any of the treatments during the ripening period (shelf life) following 45 days of cold storage. After 60 days of cold storage, fruit from the MAP box liners with higher CO_2 and low O_2 levels had a higher incidence of flesh translucency, gel breakdown and 'off flavour' than fruit from the other treatments.

Physical damage

Our previous work on impact bruising damage during harvesting and packaging (Crisosto *et al*. 2001) demonstrated that most plum cultivars with flesh firmness greater than 1.4 Kg-force tolerated very well impact forces up to 245 G (simulating impacts occurring during rough packingline operations) (Table 10.7). During transportation, our experience with plums suggested that plums will be even less susceptible to bruising damage during transportation than yellow flesh peach and nectarine. At retail, bruising potential was measured by placing an IS-100 recording accelerometer in the centre of the top layer of a two-layer tray packed box. Accelerations (G) ranging from 19.1 G to 44.9 G were measured during box handling – removal from the pallet and boxes and dropped from different heights. Thus, accelerations measured were lower than critical bruising thresholds for many plums with firmness equal to or higher than 1.4 Kg-force.

Post-harvest fruit diseases

Brown rot is caused by *Monilinia fructicola* and is the most important post-harvest disease of plums in California. Infection begins during flowering. Fruit rot may occur before harvest, but most often is expressed during post-harvest handling (Wells *et al*. 1994). Pre-harvest fungicide application, prompt pre-cooling after harvest, and orchard sanitation to minimize infection sources are control strategies. Post-harvest fungicide treatments are used to limit decay.

Grey mould is caused by *Botrytis cinerea*. This rot can be serious during years with wet spring weather. It can occur during storage if fruit have been contaminated during harvest and if wounding has occurred. Avoiding mechanical injuries, effective temperature management and post-harvest fungicide treatments are effective control measures.

Rhizopus rot is caused by *Rhizopus stolonifer*. This rot can occur in ripe or near-ripe plums kept at 20°C to 25°C. Pre-cooling and storing fruit below 5°C is effective in controlling this fungus.

Temperature management and optimum storage conditions

Plums and fresh prunes can be cooled in field bins using forced-air cooling, hydro-cooling, or room-cooling prior to packing. Packed plums and fresh prunes should be cooled by forced-air cooling to near 0°C. A storage temperature of –1.1°C to 0°C with 90 to 95% RH should be used. The freezing point varies from –2°C to –1°C depending on SSC. In late season plums and in fresh 'French' and 'Moyer' prunes, delays in flesh breakdown (IB) development have been attained by storing IB-susceptible cultivars at –1.1°C. However, to store plums at this low a temperature, high SSC and excellent thermostatic control are essential to avoid freeze damage.

Horticultural maturity indices

In most of the plum cultivars grown in California, harvest date is determined by skin colour changes that are described for each cultivar. A colour chip guide is used to determine maturity for some cultivars. Firmness, measured by squeezing

Table 10.6 Market Life of 'Blackamber' Plums Harvested on Four Different Dates, Then Stored at 0°C or 5°C.

Harvest date	Firmness (Kg-force)	SSC	TA[a]	SSC/TA	Maximum market life[b] (weeks at 0°C)	Minimum market life (weeks at 5°C)
6/20/02	7.0	10.3	0.78	13.2	2[2,3]	<2[3,4]
6/26/02	5.1	10.8	0.47	22.9	5[3]	2[3,4]
7/2/02	4.8	11.7	0.43	27.2	5[3]	3[1,3,4]
7/8/02	2.8	12.3	0.33	37.3	5[3]	2[1,3,4]

[a] Titratable acidity measured after ripening (0.4–0.7 Kg-force).

[b] End of market life based on chilling injury (CI) determined when ≥25% of the fruit became mealy[1] or leathery[2], or had flesh bleeding/browning[3] or gel breakdown/translucency[4]. Superscript indicates limiting condition.

Table 10.7 Minimum Flesh Firmness (Measured at the Weakest Point on the Fruit) Necessary to Avoid Commercial Bruising at Three Levels of Physical Handling.

	Drop Height[z]			
Cultivar*	(1 cm) ~66 G	(5 cm) ~185 G	(10 cm) ~246 G	Weakest position
Plums				
Blackamber	0	0	3[z]	Tip
Fortune	0	0	0	Shoulder
Royal Diamond	0	0	0	Shoulder
Angeleno	0	0	0	Shoulder
Peaches (yellow flesh)				
Queencrest	0	4	9	Tip
Rich May	0	0	9	Tip
Kern Sun	2	6	9	Tip
Flavorcrest	3	5	6–9	Tip
Rich Lady	6	10	11	Shoulder
Fancy Lady	3	7	11	Shoulder
Diamond Princess	0	0	9	Shoulder
Elegant Lady	3	5	6–9	Shoulder
Summer Lady	0	0	8	Shoulder
O'Henry	3	5	6–9	Shoulder
August Sun	3	4	9	Shoulder
Ryan Sun	0	0	10	Shoulder
September Sun	0	4	9	Shoulder
Nectarines (yellow flesh)				
Mayglo	4	8	11	Tip
Rose Diamond	6	7	8	Suture/Shoulder
Royal Glo	0	9	11	Shoulder/Tip
Spring Bright	6	10	10	Shoulder
Red Diamond	6	7	11	Shoulder
Ruby Diamond	4	9	9	Shoulder
Summer Grand	2	5	6	Shoulder
Flavortop	3	6	6	Tip
Summer Bright	0	6	8	Shoulder
Summer Fire	0	0	9	Shoulder
August Red	2	12	12	Shoulder
September Red	0	0	10	Shoulder

Note: Fruit firmness measured with an 8 mm tip and express as Kg-force.

[a] Dropped on 1/8″ PVC belt. Damaged areas with a diameter equal to or greater than 2.5 mm were measured as bruises.

fruit in the palm of the hand ('spring'), is also a useful maturity index for a few cultivars, especially those that achieve full colour several weeks prior to harvest. A two-tier maturity system is currently used in California: U.S. Mature (minimum maturity), and California Well-Mature. Measurement of fruit firmness is recommended for plum cultivars where skin ground colour is masked by full red or dark colour development before maturation. Flesh firmness, measured using a penetrometer (8 mm tip), can be used to determine a maximum maturity index, which is the stage at which fruit can

Table 10.8 Proposed Harvest Maturity Indexes Based on Firmness (8.0 mm Tip) and Minimum SSC for Different Plum Cultivars.

Cultivar	Firmness (Kg-force)	Minimum SSC (%)
Blackamber	3.2–4.0	10–12[z]
Fortune	3.2–4.07–9	11
Friar	3.2–4.0	11
Royal Diamond	3.2–4.0	11
Angeleno	2.7–4.0	12
Betty Anne	3.2–4.0	12

[a] Blackamber plums with TA ≤0.60% after ripening have a high consumer acceptance. If plums have ≥ 12.0% SSC, TA does not play a role.

be harvested without suffering bruising damage during postharvest handling. Plums are less susceptible to bruising than most peach and nectarine cultivars at comparable firmness. Fresh prunes are picked on the basis of colour, at least 50% of the fruit surface is red or purple and SSC is at least 16% in 'Moyer' and 19% in 'French' prunes.

Quality characteristics and criteria

High consumer acceptance is attained for most fruit with high SSC. Fruit TA, SSC:TA and phenolic content (astringency) are also important factors in consumer acceptance. However, there is no established minimum quality standard based on these factors. Consumer acceptance of most traditional plums is related to SSC except for plums with high titratable acidity (TA) at consumption as in some 'Blackamber' lots (> 0.7% TA). In 'Blackamber' plums consumer acceptance and market life were highly dependent on harvest date (Crisosto *et al*. 2004b). For plums within the most common industry ripe soluble solids concentration (RSSC) range (10.0–11.9%), ripe titratable acidity (RTA) played a significant role in consumer acceptance. Plums within this RSSC range combined with low RTA (≤0.60%) were disliked by 18% of consumers, while plums with RTA ≥ 1.00% were disliked by 60% of consumers. Plums with RSSC ≥12.0% had ~75% consumer acceptance, regardless of RTA. This work also pointed out that ripening before consumption decreased TA by approximately 30–40% from the TA measured at harvest (HTA). In some cases, this decrease in TA during ripening may increase the acceptability of plums that would otherwise be unacceptable. Using 'in-store' consumer tests, we have proposed harvest maturity indexes based on firmness and minimum SSC for selected plum cultivars (Table 10.8).

Harvesting and packaging handling

Japanese plums and the closely related interspecific plum-type fruits including Pluots® and plumcots, are harvested entirely by hand. Maturity is determined by fruit colour, fruit pressure or a combination of both, and is cultivar dependent. Soluble solids concentration, while important from a consumer satisfaction standpoint, is not commonly used as a measurement of field or harvest maturity. As most plum cultivars are well adapted to a late-harvesting system, increase of SSC can be achieved without jeopardizing the crop (Table 10.6). We suggest the use of firmness as an indicator of how late to harvest ('Tree Ripe') without inducing bruising, thereby maximizing orchard quality. But the decision of when to harvest should also take into account other factors such as fruit drop, environmental conditions, hand labour availability, market prices, distance to market, potential transportation damage and temperature management at the receiving location.

As with other fruit trees, plum fruits ripen from top of the tree to the bottom, a consequence of light environment. Lower fruit can be delayed in maturity by as much as 10–14 days compared to well-exposed fruit at the top of the tree. Consequently, harvests are multiple – generally two to four in number – and frequently complex in logistical determination. Unlike for peaches and nectarines, the first harvest in plums is commonly the largest pick. Since many plum cultivars develop full colour up to several weeks before commercial harvest and usually soften relatively slowly, it is important to develop a method by which field labourers can easily determine fruit maturity. In such full colour cultivars this is commonly done by limiting harvest to only a portion of the tree – usually segregated by light exposure, such as the top third of the tree in the first harvest, the middle third in the second and so on – so that labourers can proceed more quickly.

The logistics of harvesting are very similar to that described for peaches and nectarines. Fruits are harvested into picking bags that can hold up to ~20 kg of fruit. The pickers dump the fruit into bulk bins that contain about 400–450 kg of fruit. The bulk bins are transported in the orchard on tractor-pulled trailers that hold four or five bins. Usually two tractors and bin-trailers are required for each harvest crew. When full, the bins are taken to a centralized area and unloaded from the bin-trailers to await loading by forklift onto flatbed trailers for delivery to the packing facility.

Sorting is done to eliminate fruit with visual defects and sometimes to divert fruit of high surface colour to a high-quality pack. Sizing segregates fruit by either weight or dimension. In general, plums and fresh prunes are packed into 12.6 kg volume-filled containers.

Table 10.9 Ripening Rates of Plums at 10°, 20° and 25°C Measured with a UC Firmness Tester (8.0 mm Tip).

	Rate of softening (kg per day)		
Cultivar	10°C	20°C	25°CF
Plums			
Black Beaut	0.3	0.3	0.3
Santa Rosa	0.1	0.3	0.4
Blackamber	<0.1	0.3	0.32
Fortune	0.18	0.4	0.6
Friar	0.14	0.3	0.6
Simka	0.36	0.55	0.77
Royal Diamond	0.14	0.23	0.5
Casselman	0.06	0.23	0.3
Angeleno	0.0.045	0.0.18	0.0.23
Average	0.18	0.1.54	0.45

Table 10.10 Titratable Acidity of Plums at Harvest (Mature), and After Ripening at 20°C Until the Firmness of the Flesh Was Less Than 1.4 Kg-force (Ripe).

	Titratable Acidity (% malic acid)		
Cultivar	Mature	Ripe	Change (%)
Plums			
Black Beaut	0.61	0.49	–19.7
Santa Rosa	1.12	0.45	–59.8
Blackamber	0.61	0.59	–3.3
Fortune	1.11	0.43	–61.3
Friar	0.98	0.41	–58.2
Simka	1.31	0.41	–68.7
Royal Diamond	0.54	0.34	–37.0
Casselman	0.70	0.46	–34.3
Angeleno	0.42	0.33	–21.4
Average	0.82	0.43	–40.4

Retail outlet display considerations

Generally, if fruit firmness is greater than 2.3 kg-force, fruit should be displayed on a dry table. If fruit firmness is less than 2.3 kg-force, plums should be displayed on a cold table.

Retail ripening

Ideal plum ripening conditions are different than conditions for other tree fruits. In general, plums have a significantly slower rate of flesh softening than peaches and nectarines (Table 10.9). At 10°C, plum ripening was slow enough to be considered negligible for many cultivars, and the rate of softening is still slow at 20°C for most cultivars. The best plum ripening can be accomplished when exposed to 25°C. During ripening, plum TA decreased, but the amount varied from cultivar to cultivar (Table 10.10). In general, plum TA tended to decrease approximately 40% when reaching the ripe stage (0.9–1.4 kg force).

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