The use of cooling and cold storage to stabilize and preserve fresh stone fruits

F.G. MITCHELL
POMOLOGY DEPARTMENT
UNIVERSITY OF CALIFORNIA AT DAVIS
DAVIS, CA 95616
USA

C.H. CRISOSTO
POMOLOGY DEPARTMENT
KEARNEY AGRICULTURAL CENTER
UNIVERSITY OF CALIFORNIA AT DAVIS
9420 SOUTH RIVERBEND AVENUE
PARLIER, CA 93648
USA

SUMMARY - Temperature management is a vital part of the postharvest handling system for stone fruits. Rapid cooling and low temperature holding are important for protecting the physiological health of these fruits, slowing the spread and growth of fruit rotting fungi, slowing the rate of water loss and thus delaying the onset of fruit shrivel, and minimizing the harmful effects of mechanical injuries on the fruits. The opportunities for long distance marketing of stone fruits in world markets requires that careful attention be given to good temperature management. Changes in fruit handling procedures, especially the trend toward bulk handling, have often rendered older cooling methods ineffective, but newer methods, including hydrocooling and forced-air cooling, can provide rapid cooling and good fruit temperature protection when used properly. Effective temperature management during cold storage includes attention to the refrigeration system and its controls, design and insulation of the storage structure, and management of the storage operations.

Key words: Stone fruits, postharvest, fruit quality, temperature management, hydrocooling, forced-air, deterioration, water loss, fruit rotting

RESUME *- "Utilisation du refroidissement et des chambres frigorifiques pour stabiliser et conserver les fruits frais à noyau". La gestion de la température est vitale dans le système de traitement des fruits à noyau après récolte. Pour protéger la santé physiologique de ces fruits, il est important de les refroidir rapidement et de les garder à basse température, ralentissant ainsi la propagation et la croissance de maladies cryptogamiques, ralentissant les pertes en eau et donc retardant l'apparition de fruits ratatinés, et minimisant les effets nuisibles des dommages mécaniques sur les fruits. La commercialisation à longue distance des fruits à noyau du fait de la mondialisation des échanges requiert une gestion rigoureuse de la température. Des changements dans les procédures de traitement de fruits, en particulier la tendance de les traiter en vrac, ont souvent rendu de vieilles méthodes de refroidissement inefficaces, mais des méthodes plus récentes, incluant l'hydrocooling et le refroidissement à air comprimé, peuvent procurer un refroidissement rapide et une bonne protection des fruits par la température lorsqu'elles sont employées correctement. Une gestion efficace de la température durant l'entreposage au froid repose sur une gestion adaptée du système de réfrigération et de son contrôle, de son type et de sa fonctionnalité, de sa localisation et enfin de la gestion des opérations d'emmagasinage.*

Mots-clés : *Fruits à noyau, post-récolte, qualité des fruits, gestion de température, hydrocooling, air comprimé, détérioration, perte d'eau, fruits pourris.*

The expansion of the stone fruit industries in California has resulted in many changes in temperature management practices. These changes have been in response to the advancing knowledge of temperature requirements and consequences of these fruits, to changes in the handling system that make some older procedures unsatisfactory, and to a desire to extend the postharvest life of these fruits to reach more distant markets. Much research attention has been given to the effects of temperature management on stone fruit deterioration, with emphasis on those problems that limit the postharvest life.

With the introduction of bulk handling methods in the fruit industries, attention was given to their impact on commercial cooling and cold storage practices; and new cooling methods were developed to accommodate these evolving handling systems. The acceptance of the developing information, and utilization of new handling procedures by the stone fruit industries has been based largely on their incentive to prolong the postharvest life of these fruits to achieve orderly marketing. This paper, drawing mostly upon recent stone fruit studies in California, discusses temperature management effects and describes cooling and storage methods that are useful for stone fruits.

Temperature effects on stone fruits

Temperature affects many processes in stone fruits and their environment. Detailed discussions of these effects are found in many publications, including Mitchell (1987; 1992), Mitchell and Kader (1989), Sommer (1989) and Kader (1992). The rates of physiological processes in the fruit, including respiration and ethylene evolution and action (as a ripening hormone), are temperature regulated, and are lowest just above the freezing point of the tissue. Thus the rates of fruit ripening and flesh softening, and the progression of senescent breakdown, are fruit temperature dependent; while the rates of water loss and fruit shrivel development (and cherry stem browning) result from vapor pressure differences between fruit and their environment, which are controlled by fruit temperature and the temperature, relative humidity and air velocity of the surrounding atmosphere.

Temperature will also influence other causes of fruit deterioration. The rates of growth and spread of fruit rotting organisms are temperature regulated in the same way as the physiology of the fruit, though various fruit rotting fungi vary, in their temperature response patterns. The temperature regime will influence the development of temperature related injury symptoms in the fruit, whether high temperature injury, chilling injury (internal breakdown), or freezing injury.

Mechanical injuries are temperature influenced in two ways. First, temperature can affect fruit sensitivity to impact and vibration injuries. Nectarine, peach and plum sensitivity is lowest at 10 to 20°C for vibration bruising, and about 30°C for impact bruising. Second, low temperature following an injury will minimize its effects on the deterioration and physiological activity (CO_2 and C_2H_4 production) of the fruit as well as minimizing the rate of growth of microorganisms invading any resulting wounds.

High temperature effects

The lethal temperature for stone fruits will depend on a number of factors, including cultivar, fruit maturity and duration of exposure to the temperature. Warm field temperatures (below the lethal level) will cause fruit to soften and lose water, and accelerate the growth and spread of fruit rotting fungi. Internal breakdown symptoms in sensitive cultivars may be aggravated by field exposure to temperatures between about 30 and 40°C following harvest. Protection at the time of harvest should include avoidance of direct sun exposure (dark colored fruit can warm many degrees above ambient air temperature) and rapid transfer from field to cooler.

Low temperature effects

In general, maximum postharvest life can be attained at just above the freezing point, which may be <-1°C for cultivars having a high soluble solids concentration (SSC). Stone fruits, with a short potential postharvest life, should be cooled to their desired holding temperature as soon after harvest as possible, especially for extended holding or marketing. Two potential problems when fruit are held at low temperatures are freezing injury (that may follow below freezing temperature exposure), and chilling injury (that may follow above freezing temperature exposure).

Freezing injury

All stone fruit tissues may be injured if cooled to below their freezing point. The freezing point is inversely related to the SSC of the fruit; the highest reported freezing point for stone fruits of about -0.8°C should correspond with about 8% fruit SSC. Because of SSC variability within the fruit tissue, a safety factor must be added. Short exposures to freezing temperatures may not cause tissue freezing and injury.

Chilling injury, or internal breakdown (IB)

This problem, sometimes also called 'wooliness', 'dry fruit', 'mealiness', 'internal browning', 'translucency', 'gel breakdown' or 'leathery fruit', occurs with many cultivars of all stone fruit species except cherry. Symptoms development usually occur when fruit are removed from low temperatures for ripening or marketing. In addition to the symptoms described by the various names of the disorder, fruit lose their flavor, and often lose their ability to ripen. Because of the delayed development of symptoms the problem is most frequently experienced by consumers rather than handlers, and this may severely affect future sales.

IB will develop at temperatures <10°C, but the most critical temperature range for severe symptoms development is between about 2 and 8°C, peaking at 5°C. While fruit held below this temperature range can still show symptoms, they will develop more slowly and be less severe. If fruit of susceptible cultivars are held near 5°C, their market life can be significantly reduced (Table 1).

Table 1. Percent of marketable stone fruit after two different temperature regimes

Variety	Percent Juicy Fruit	
	0°C for 6 weeks	5°C for 3 weeks
Peaches		
Spring Lady	80	17
Springcrest	95	35
Flavorcrest	85	42
Redtop	42	27
O'Henry	67	14
Fairtime	67	23
Nectarines		
Juneglo	100	100
Sparkling J	86	100
Fantasia	91	40
September Red	49	13
Fairlane	50	9

Other factors influencing symptoms development are cultivar, maturity (low maturity fruit are more susceptible), cultural practices, environment (more severe in fruit grown in cool climates), the temperature and duration of field exposure after harvest (uncontrolled delays before cooling can aggravate subsequent symptoms development), and the duration of storage exposure within the critical temperature range. Various cultivars have a postharvest life of 1 to 6 weeks at 0°C (Table 2). While fruit do not develop IB at 10°C or above, they would be quickly destroyed at such temperatures due to flesh softening, fruit rotting and shrivel.

Various treatments have been reported to reduce or delay the development of IB. These include warm temperature holding before cooling, intermittent warming periodically during storage, warm temperatures with controlled atmospheres, and controlled atmosphere storage or transport. While some have had limited commercial usage, all have shown inconsistent performance. When fruit under any of these treatments were subsequently held near 5°C (as would occur in transport) no treatment benefits remained. Good temperature management remains\the one tool that has given consistent commercial benefits in delaying the onset of IB.

Table 2. Postharvest performance rating of different stone fruit cultivars grown in California (Modified and updated from Mitchell and Kader, 1989)[†]

Variety	Internal Breakdown 5°C[††]	Market Life 0°C[†††]	Variety	Internal Breakdown 5°C[††]	Market Life 0°C[†††]
Nectarine					
August Red	M	3	Mayfire	L	6
Autumn Grand	H	2-3	May Grand	L	6
Fairlane	H	3	Red Free	L	6
Fantasia	M	4-6	Red Grand	M	3-5
Flamekist	M	3	Royal Giant	M	4
Flaming Red	M	3	September G.	M	3-4
Flavortop	L	4-5	September R.	M	3
Independence	L	5-6	Sparkling R.	M	5
July Red	L	6	Spring Red	L	6
Juneglo	L	6	Summer G.	L	5
May Diamond	L	6	Summer Red	M	5
Mayglo	L	4			
Peach					
Autumn Gem	H	1	Lacey	M	6
Belmont	H	1	Merrill G.	L	6
Cal Red	H	2	O'Henry	M	4
Carnival	H	2	Parade	H	3
Cassie	H	2	Red Cal	H	2
Early Fairtime	H	2	Redtop	L	4
Early O'Henry	H	4	Regina	L	3
Elegant Lady	H	4	Sparkle	M	3
Fairtime	H	2	Springcrest	H	3-4
Fire Red	H	2	Springold	H	3
Flamecrest	L	3	Spring Lady	L	5
Flavorcrest	H	4	Summer Lady	H	5
June Lady	M	3	Suncrest	M	2
Kings Lady	H	2	Windsor	H	2
Plum					
Ambra	H	2	Moyer	L	5
Angeleno	M	8-10	Nubiana	H	2
Black Beaut	L	3	President	L	3
Casselman	M	5-6	Queen Ann	M	4
Catalina	L	6	Queen Rosa	M	4
El Dorado	M	3-5	Red Beaut	H	1-2
French Prune	L	>8	Red Rosa	H	4
Friar	M	3-4	Rosemary	L	4
Frontier	H	>4	Royal D.	M	6
Grand Rosa	H	3	Roysum	M	4
July Santa Rosa	H	3	Santa Rosa	L	3-5
Kelsey	H	2	Simka	M	3
Laroda	L	4	Spring Beaut	L	2
Late Santa Rosa	L	3	Wickson	L	4

[†] Rankings are summarized from detailed test results
[††] Internal breakdown ratings: L=low, M=moderate, H=high susceptibility
[†††] Market life is the length of time fruit could be stored with at least 85% of fruit remaining marketable. Market life varies according to initial maturity, orchard influence, and conditions during growing season and storage period.

Water loss and shrivel

Fruit shrivel and cherry stem drying result from the accumulated water loss that occurs throughout the postharvest handling of the fruit. Visual symptoms usually appear when fruits have lost 3 to 5% of their initial weight. Even though lesser amounts of water loss may not cause visible shrivel at that time, the fruits may be conditioned to quickly shrivel as they progress through marketing. Thus water loss prevention must be continuous from harvest through marketing.

Water moves from fruit to the surrounding atmosphere as water vapor. Water evaporating from fruit cells will saturate the open intercellular spaces within the fruit (which are thus nearly 100% relative humidity [RH]). Water vapor then migrates from this area of high concentration (high water vapor pressure [VP]) to the surrounding atmosphere which is at a lower concentration (a lower VP). How rapidly it migrates depends partly upon natural barriers created by the fruit epidermis (skin) and waxy cuticle, and partly upon the vapor pressure difference (VPD) between the internal and external atmospheres. Water vapor leaving the fruit will create a high RH microclimate immediately around the fruit, and slow further water loss. If high air velocity passes over the fruit during storage, it can sweep away that microclimate and increase the rate of water loss.

Field handling

While fruits are held in the field following harvest, rapid water loss will occur because of the relatively high temperatures of both fruit and surrounding air. While the fruit internal atmosphere is near saturation (with a high VP), the surrounding dry air will have much less water vapor than it is capable of holding (thus a lower VP). The resulting VPD will cause rapid water vapor migration from the fruit. Depending on climatic conditions, water loss in the field can be at 30 to 40 times the rate during prolonged cold storage.

Cooling

During air cooling, when warm fruit (at high VP) first enter the cold air of the cooler (at low VP), the VPD between fruit and environment will be quite high, and rapid water loss will continue. However the VPD will continually decline as fruit cool, because the atmosphere within the cold fruit will hold much less water vapor (thus having a lower VP). Because rapid cooling will speed the lowering of the VPD in the system, it will slow the rate of water loss and fruit shrivel.

Storage

During storage, both fruit and storage atmosphere are at low temperature, and thus both have a low VP. The storage atmosphere, however, will be at a lower RH (and VP) than the fruit internal atmosphere, resulting in a small VPD and continued water vapor migration from the fruit. Because the storage period is normally much longer than field or cooling exposures, this small VPD can still result in substantial cumulative water loss from the fruit. The maintenance of a high RH and low temperature during storage can minimize the VPD in the system, and slow the development of fruit shrivel. Slowing the velocity of air circulation in the storage facility, to the point that fruits are just protected from warming, will also help to maintain the water vapor transition zone (microclimate) around the fruit.

Estimating water loss differences

The VPD is the difference between the VP of the fruit at its temperature (TF) (with its saturated internal atmosphere) and the VP of the surrounding atmosphere under its temperature T_A and RH ([saturation VP at T_F of fruit] - [saturation VP at T_A of air x RH/100]). Because warmer air will hold more water vapor, it will have a higher saturation VP than cold air. As an example, assume 25°C field and 0°C storage conditions (air has a saturation VP of 23.8 mm Hg at 25°C, and 4.6 mm Hg at 0°C). If the T of fruit and air were the same, the VPD in the field at 25°C and 40% RH would be: (23.8 [VP of fruit] - [23.8 x .40] [VP of air]) = 14.28 mm Hg; while the VPD in storage at 0°C and 90% RH would be: (4.6 [fruit] - [4.6 x .90] [air]) = 0.46 mm Hg. Under these conditions, fruit in the field would lose water at (14.6/0.46) = 32 times the rate during subsequent storage. The cumulative effect of two different handling regimes on water loss is shown in Table 3.

Table 3. Estimated weight loss in nectarines under two different handling regimes (adapted from Mitchell *et al.*, 1972)

Handling step and conditions	Weight Loss %	
	Typical	Expedited
Field handling at 26.7°C and 30% RH: 8-hour *vs* 2 hour delay	2.0	0.5
Cooling - 12 h forced-air: 2.2°C and 70% RH *vs* 0°C and 95% RH	0.6	0.4
Storage - 7 days at 0°C: 70% RH and 30 m/min *vs* 95% RH and 8 m/min	3.0	0.5
Transport - 3 days at 4.4°C and 80% RH: fruit loaded at 4.4°C *vs* 0°C	2.4	1.5
Cumulative weight loss through system:	8.0	2.9

Fruit cooling methods

Detailed discussions of the cooling methods discussed here are found in Mitchell *et al.* (1972); Mitchell (1989; 1992) and Kasmire and Thompson (1992). While several cooling methods are used for various horticultural commodities, only three basic methods, along with some design variations within these methods, are useful for stone fruits. The oldest of these, the so-called 'room cooling' method, is generally too slow to afford protection when used with modern handling procedures and long distance marketing of stone fruits. Another, 'hydrocooling', cools quite rapidly, but is usually only useful to remove field heat prior to the final packaging of the fruit. The third, 'forced-air cooling', cools relatively rapidly, and can be used before and/or after packing. All three methods have been widely used around the world for stone fruits.

In the discussions that follow, some typical cooling times are noted for the various cooling methods. These are only for general comparison, and more specific data will depend upon many factors of container design, venting, packing and packaging materials, etc. These can be easily determined by anyone engineering the system.

Room cooling

This method involves passing cold air over stacks of either field or shipping containers of fruit. The stacks are placed to achieve cold air flow over and around them, thus removing heat from their surfaces (ideally at least 15-20 cm between rows and 10 cm between stacks within the rows). Small packages on pallets will cool better by this method if individual packages are stacked with about 2-3 cm spaces around them. Air flow should be at least 60 to 120 m/minute, and containers should be placed so that all surfaces are contacted by the flowing air. The high velocity will maximize surface heat removal, but cooling is slowed by heat conduction from the centers to the surface of containers or pallets. It is best suited to cooling fruit in small packages that are spaced to minimize the path of heat conduction to package surfaces. Typical 7\8 cooling times (cooling 7\8 of the distance from the initial fruit temperature to the temperature of the coolant, in this case the cold air) are about 30-60 hours.

The faster cooling methods have generally replaced room cooling as the fruit industries have changed to large field bins and to palletization of smaller packages. Both of these create large unit sizes with limited surfaces for air flow; and the path for heat conduction from center to surfaces is quite long. Thus it is difficult to achieve cooling in the centers of these units. The stone fruit industries have also adopted faster cooling methods in their effort to lengthen the holding period of the fruits in order to reach more distant markets. Added to these is the advancing knowledge of the quality benefits accrued from rapid cooling and low temperature protection of these fruits.

Hydrocooling

This method, which cools fruit by contact with flowing cold water, is the oldest rapid cooling method in use. The most common hydrocoolers convey open field containers of fruit through a vertical flow of water; with the effluent water being re-cooled to near 0°C and pumped to an overhead drip pan to recirculate over the fruit. With this hydrocooler design water flows of 600 to 1000 $l/min/m^2$ of drip pan surface area are desired. The fruit containers need bottom ventilation (at least 5-6% of area) to allow water drainage. This is the fastest cooling method available, and large peaches can be 7/8 cooled in about 35-40 minutes.

Because of their susceptibility to stem shrivel and browning from water loss, cherries respond very well to hydrocooling. Due to their small size, they will 7/8 cool in as little as 7 to 10 minutes, which allows hydrocoolers to be installed as part of the packing line. The bulk cherries typically pass through the hydrocooler after they have been cleaned, separated, graded and prepared for packaging, and will be completely cold as they are packaged and move to cold storage. Such in-line hydrocoolers are impractical for other stone fruits , because their larger size greatly prolongs their hydrocooling time.

Stone fruits are generally tolerant of the wetting that is associated with hydrocooling. Care must be taken to maintain sanitation and avoid the spread of fruit rotting organisms. This includes frequent water filtering, draining, cleaning and refilling of the hydrocooler, and the use of chlorine or another fungistat as allowed by pesticide regulations. Care must be taken to assure that the cultivars to be packed are tolerant of any fungistat that is used.

Some stone fruits can show surface discoloration as a result of water immersion. Some reports have associated these problems with prior surface injuries and/or the presence of metal ions (such as Fe ions) in the hydrocooling water. Care should be taken to avoid unnecessary heights of water dropping onto fruits, especially softer fruits. When hydrocooling cherries, which are soft fleshed and easily bruised, the height of the water dropping onto the fruit must be kept as low as possible.

Forced-air cooling (pressure cooling)

Forced-air cooling was developed specifically as a rapid air-cooling substitute for room cooling. While slower than hydrocooling, it will typically cool fruit in 1/6 to 1/8 of the time required for room cooling, and fruit are not wetted. Cooling times can approach those of hydrocooling if a very large volume air flow is used, but the high cost may not be justified.

Forced-air cooling is a way of managing the cold air so that it passes through containers and around individual fruit, cooling them by sweeping heat from their surfaces. The method can be designed into new installations; or often existing room cooling facilities can be modified to accommodate it (depending upon the size of the cooling coils and the refrigeration capacity available to the room). Essentially forced-air cooling places the containers of fruit so the cold room air cannot return to the refrigeration coils except by passing through those containers and around the fruit. In stone fruit forced-air coolers, typical air flows range between 30 and 60 $m^3/min/T$ of fruit, and typical 7/8 cooling times are 4 to 6 hours. While shorter cooling times are possible, energy costs can become excessive.

Forced-air cooling is only efficient if air is able to pass through containers and around the fruit. For side-to-side cooling, this requires that container sides (in line with the air flow) have about 5 to 6% of their area vented. If packages are to be cooled by end-to-end air flow, then package ends must be so vented. A few large vents spaced over the surface are preferable to many small vents, and the cold air must be able to reach those vents. Care must be taken that internal packing materials do not block air flow through the containers, or irregular and incomplete cooling will result. If fruit are packed in trays within the containers, the vents must be placed to allow air flow across each level of tray.

Considerable back pressure may be created when the desired air flow is moved through containers, and air supply blowers must be rated to meet these requirements. The back pressures will vary with container design and desired air flow volume, but typical static pressure requirements for 4 to 6 hour stone fruit forced-air cooling are 1 to 2 cm of water. This is in addition to the static pressure requirement to move air through the refrigeration system. Three designs of commercial forced-air coolers are discussed here.

Forced-air cooling tunnel

This is the most commonly used forced-air cooling design. The fork-lift driver constructs a tunnel by placing one row of stacked field bins or pallets of packages on each side of an exhaust blower. Pallets or stacks of bins are placed tightly together within the row, but a space the width of the blower (usually about 1 m) is allowed between rows.

A cover that is fastened over the blower, usually fabric with stiffener rods sewn in at about 1/2 m intervals, is then rolled out over the space between the two rows and allowed to drop to the floor at the far end. That cover should be designed to provide about 1/3 m overlap of the top of the bins or packages along each side. If 4-way entry pallets are used (pallets that are open to air cross flow), then those pallet openings must be blocked along the outside edge of the tunnels, usually with a narrow strip of fabric. With the blower operating, air is exhausted from the covered plenum (the tunnel), creating a slight vacuum, and cold air from the room will flow through vent openings and around individual fruit in order to reach the low pressure area.

With this design, cooling will first occur on the room side of the tunnel (upstream of the air flow), and fruit that are inside the tunnel (downstream of the air flow) will remain warmest. For this reason accurate evaluation of cooling will require that temperatures be monitored inside the tunnel plenum. Some space must be allowed on the room side of the tunnels for cold air from the room to reach the side vents. Thus if multiple tunnels are used, additional space must be allowed between adjacent tunnels. If cooling becomes slower with distance from the blower, then the space between rows in the tunnel may be too narrow. A practical limit for the length of such tunnels is about 10-12 m. If cooling is slower near the floor, then the width of the supply plenum (the space between adjacent tunnels) may be too narrow.

Cold wall forced-air cooling

In this design, the air return plenum is a permanent structure, usually built along both sides of a cold room. The cold wall consists of a false wall spaced away from the insulated wall of the room, through which air can be returned to the refrigerated coils and recirculated to the room. Dampered openings are built into this false wall to accommodate individual pallets of packed fruit. Ventilation, air flow and temperature monitoring requirements are similar to those for the forced-air tunnel. By constructing shelves, multi-layers of pallets can be accommodated, but only one pallet can be placed against each opening in the wall.

Because of the dampers in the wall, each pallet of fruit will cool independently; cooling need not await completion of an entire tunnel of fruit. This design is used in some large scale operations where warm fruit is constantly entering the cooler from the packing line. It is also used in some small, mixed-commodity operations, because each pallet can be handled as an individual lot, and pallets of different size can be accommodated.

Serpentine forced-air cooling

This design can be used to cool fruit in field bins with or without side ventilation, provided the bin bottoms are vented. It uses a cold wall plenum which is designed to accept the field bins, with dampered slot openings located to coincide with every other fork-lift slot on a stack of bins. When bins are placed tightly against the cold wall the dampers are opened. Bins can be stacked tightly both within and between rows for about 4 to 6 stacks from the wall. On the room side, the fork lift slots that are open to the wall plenum are covered, and the alternate slots left open. Cold air from the room will enter through the open slots and flow vertically down or up through the fruit to reach the air return slots in the cold wall. If the bins are equipped with side vents, then air will enter through all openings and channel to the air return slots. As with cold walls, the ventilation, air flow and temperature monitoring requirements of serpentine coolers are similar to those for the forced-air tunnel.

This is the only forced-air design that can be used with bins without side vents. It allows bins to be tightly stacked, both within and between rows, thus making efficient use of cold room space. Cooling is fairly uniform throughout the bins. Stacks can be as tall as the facility is designed to receive, depending on the lifting capacity of the fork-lift equipment. The air flow requirements are similar to the other forced-air systems. The length of the air flow path (4 to 6 bins out from the wall) is restricted by the narrow fork-lift slots in the bins, which become the air supply and air return plenums. For this reason, this design works best in fairly narrow cooling rooms, with cold walls constructed along each side of the room.

Cold storage

In most cases stone fruits are not "stored" in the true sense of long term holding, but are rather held for short periods after harvest in order to facilitate orderly marketing. Even so, the storage requirements are quite specific if the fruits are to reach consumers in satisfactory condition. Because most cold storage facilities are designed to maintain temperature, with only limited cooling capability, the fruit must be cooled to near their desired holding temperature (near 0°C) before entering storage.

The storage facility should be capable of maintaining the desired storage temperature within a narrow range, ideally +/-0.5°C of set temperature. This will depend upon the accuracy of temperature monitoring and control equipment, the amount of insulation in storage room walls and ceiling, the amount and pattern of heat introduced into storage rooms by equipment, doors, leaks and warm fruit, and by fruit movement in and out of storage.

Because of the need to minimize water loss throughout the postharvest handling of these fruits (to delay onset of fruit shrivel), the storage facility should be capable of maintaining a high RH, ideally between 90 and 95%. It is desirable to have capability of varying the velocity of air flow in the storage facility, so that higher air flows (30-45 m/min) can be used at the start of storage to facilitate *limited* cooling and to adjust fruit temperatures, and then the air flow can be lowered to about 18-25 m/min to minimize water loss. When lowering air flows, fruit temperatures should be carefully monitored to assure that no "hot spots" develop (where the air flow is inadequate to remove heat entering the storage, or heat produced by fruit respiration).

The potential postharvest life of most stone fruits, even under ideal storage conditions, is limited to a few weeks (see Table 1), often because of internal breakdown or senescent breakdown of the fruit. This potential postharvest life includes the total time from harvest to consumption, and thus the time the fruits are held in cold storage will reduce their subsequent market life. Only a few stone fruit cultivars appear capable of greater than about 6 weeks total postharvest life (typically high SSC fruits that are stored at about -1°C). Many cultivars with internal breakdown sensitivity are limited to 1 to 4 weeks postharvest life, even under ideal holding conditions.

Temperature management of stone fruit

The need for low temperatures to protect stone fruits during marketing has long been recognized. However, many changes have occurred in commercial stone fruit handling procedures and in our understanding of stone fruit responses to temperature (especially as they affect deterioration problems). New market opportunities sometimes make it desirable to transport these fruits to distant markets. These factors have stimulated the adoption of changes that will improve stone fruit temperature management practices.

The rapid cooling methods that have been introduced in response to these handling changes are an important factor in improving temperature management. When coupled with protection from warming, rapid handling, proper storage temperatures, and good supervision throughout the handling system, these newer cooling procedures can help to maximize the postharvest life potential for stone fruits. Transport conditions have not been addressed here, but the same factors that are involved during storage continue in importance throughout distribution.

References

Kader, A.A. (1992). Postharvest biology and technology: an overview. In: *Postharvest Technology of Horticultural Crops,* Pub. 3311, Kader, A.A. (ed.). Univ. Calif. Div. Agric. and Natural Resources, Chap. 3, pp. 15-20.

Kasmire, R.F. and Thompson, J.F. (1992). Selecting a cooling method. In: *Postharvest Technology of Horticultural Crops,* Pub. 3311, Kader, A.A. (ed.). Univ. Calif. Div. Agric. and Natural Resources, Chap 8 (III), pp. 63-68.

Mitchell, F.G. (1987). Influence of cooling and temperature maintenance on the quality of California grown stone fruit. *Rev. Int. Froid,* 10 (Mars): 77-81.

Mitchell, F.G. (1989). Cooling. In: *Peaches, Plums and Nectarines - Growing and Handling for Fresh Market,* Pub. 3331, LaRue, J.H. and Johnson, R.S. (eds). Univ. Calif. Div. Agric. and Natural Resources, Chap. 27, pp. 209-215.

Mitchell, F.G. (1992). Cooling horticultural commodities. In: *Postharvest Technology of Horticultural Crops,* Pub. 3311, Kader, A.A. (ed.). Univ. Calif. Div. Agric. and Natural Resources, Chap. 8, pp. 53-63.

Mitchell, F.G. and Kader, A.A. (1989). Factors affecting deterioration rate. In: *Peaches, Plums and Nectarines - Growing and Handling for Fresh Market,* Pub. 3331, LaRue, J.H. and Johnson, R.S. (eds). Univ. Calif. Div. Agric. and Natural Resources, Chap. 23, pp. 165-178.

Mitchell, F.G. and Kader, A.A. (1989). Storage. In: *Peaches, Plums and Nectarines - Growing and Handling for Fresh Market,* Pub. 3331, LaRue, J.H. and Johnson, R.S. (eds). Univ. Calif. Div. Agric. and Natural Resources, Chap. 28, pp. 217-222.

Mitchell, F.G., Guillou, R. and Parsons, R.A. (1972). Commercial cooling of fruits and vegetables. Manual 43, Univ. Calif. Div. Agric. and Natural Resources, p. 44.

Sommer, N.F. (1989). Suppressing postharvest disease with handling practices and controlled environments. In: *Peaches, Plums and Nectarines - Growing and Handling for Fresh Market,* Pub. 3331, LaRue, J.H. and Johnson, R.S. (eds). Univ. Calif. Div. Agric. and Natural Resources, Chap. 24, pp. 179-190.

Source:

Calidad post-cosecha y productos derivados en frutos de hueso/Qualité post-récolte et produits derivés chez les fruits à noyau/Post-harvest quality and derived products in stone-fruits. Vendrell, M. and Audergon, J.M. (eds.). 1995.Proceedings of the CIHEAM/IRTA Seminar on "Calidad post-cosecha y productos derivados en frutos de hueso/Qualité post-récolte et produits derivés chez les fruits à noyau/Post-harvest quality and derived products in stone-fruits", Lleida, 17-18 October 1994. Ajuntament de Lleida, Lleida. 216pp.