29

Postharvest Handling Systems: Small Fruits

I. Table Grapes

Carlos H. Crisosto and F. Gordon Mitchell

The table grape is a nonclimacteric fruit with a relatively low rate of physiological activity. The fruit is subject to significant water loss following harvest, which can result in stem drying and browning, berry shatter, and even wilting and shriveling of the berries. Gray mold, caused by the fungus *Botrytis cinerea*, requires constant attention and treatment during storage and handling. The bloom (natural wax) on the grape berry's surface is a primary appearance quality factor. Rough handling and rubbing destroys this bloom, giving the skin a shine rather than the more desirable luster appearance.

CULTIVARS

In California the major cultivars are Thompson Seedless (Sultanina) and Flame Seedless, marketed mostly during the summer months up to 8 to 10 weeks after harvest. Perlette is still important in the early production area of the Coachella Valley in California, and other seedless cultivars such as Ruby Seedless, Sugraone (Superior Seedless), and Crimson Seedless make up the bulk of the remaining production. There is also increasing production of recently introduced seedless cultivars including Autumn Royal and Princess. The seeded Redglobe cultivar is important for export in the mid-to-late season. Little is known about the specific postharvest requirements of these new cultivars.

MATURITY

Grapes are harvested when mature, based upon the soluble solids concentration of the berries. Titratable acidity and sugar to acid ratio are also used as maturity indices (e.g., Thompson Seedless, 18:1 sugar to acid ratio). The minimum requirements vary with cultivar and growing area. Cultivars other than green-colored ones also have minimum color requirements based on the percentage of berries in the cluster that show a certain minimum color intensity and coverage. Detailed information on maturity requirements according to cultivars is presented in chapter 23.

WATER LOSS

In general, cumulative water loss during postharvest handling results in weight loss, stem browning, berry shatter, and shriveling of berries. In all of the cultivars studied, there is a high correlation between cluster water loss and stem browning. The high rate of respiration of stems may also be a contributor to stem browning, as the respiration rate of the stems may be 15 times or more that of berries. When water loss reaches 2.0% or more for Perlette, Flame Seedless, Thompson Seedless, Ruby Seedless, and Fantasy Seedless, stems will show symptoms of browning approximately 7 days later in storage. A survey indicated that water loss ranged from 0.5 to 2.1%, based on the initial weight (measured at harvest) within the 8-hour period before cooling. The magnitude of the losses was directly related to the length of exposure, temperature during the delay before cooling, and type of box material. Even a few hours delay at high temperatures can cause severe drying and browning of cluster stems (fig. 29.1), especially on the hottest

Figure 29.1

Cumulative water loss during postharvest handling results in weight loss, stem browning, and shriveling of berries. Even a few hours delay at high temperatures can cause severe stem drying and browning, especially on the hottest days.

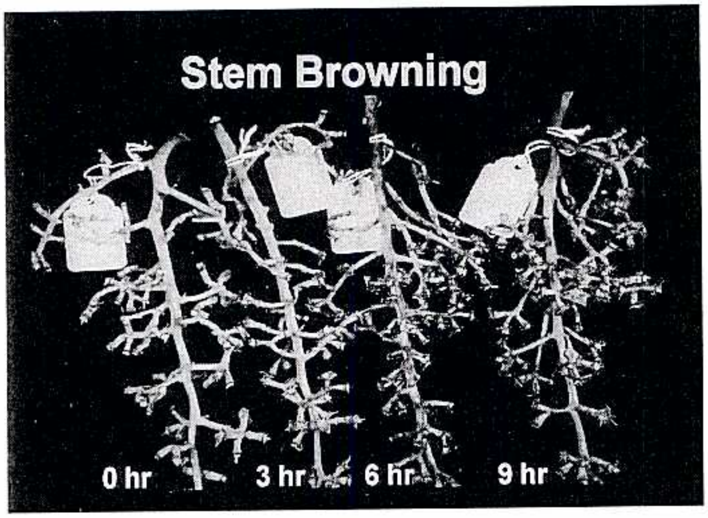
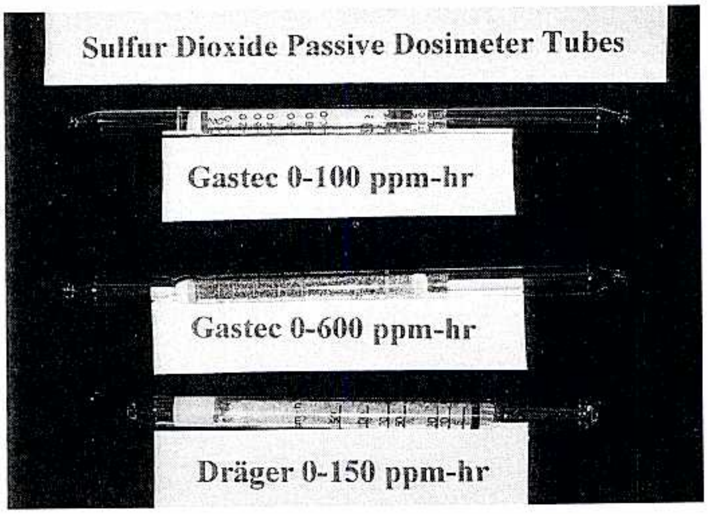


Figure 29.2

Sulfur dioxide dosimeter tubes used to monitor sulfur dioxide concentration during fumigation of table grapes.



days. Water loss during storage can reach 2.5% for plain packed grapes. (A box is "plain packed" when fruit is placed cluster to cluster in the box until the appropriate net weight is attained.) The use of cluster bags reduced water losses in all three of the containers tested during their postharvest life (Crisosto et al. 2001).

Because stems and fruit are susceptible to deterioration from water loss, grapes are normally forced-air cooled as soon as possible after harvest. Grapes do not tolerate the wetting associated with hydrocooling.

FRUIT ROTS

GRAY MOLD

Control of the fungus *Botrytis cinerea*, which causes Botrytis rot (gray mold), requires constant attention and treatment during storage and handling. Gray mold is the most aggressive postharvest disease of table grapes because of its ability to develop at temperatures as low as –0.5°C (31°F) and move by mycelial growth from berry to berry. Botrytis rot can be identified by the characteristic "slipskin" condition that develops, and later, by "nests" of decayed berries encased in white mycelium. Botrytis rot of grapes is not sufficiently avoided by fast cooling alone. It is standard practice in California and other production areas to fumigate with sulfur dioxide (SO_2) immediately after packing, followed by lower-dose SO_2 treatments weekly during storage. An exception is for grapes produced in the Coachella Valley, which are marketed soon after harvest. Formulas for calculating SO_2 fumigation dosages are available in the publications by Nelson (1985) and Luvisi et al. (1992). Because of the recent increased interest in the export market, there is a greater demand for the use of SO_2-generating pads, especially for long-distance transport. Sodium metabisulfite is incorporated into the pads, allowing the release of SO_2 during transit and marketing.

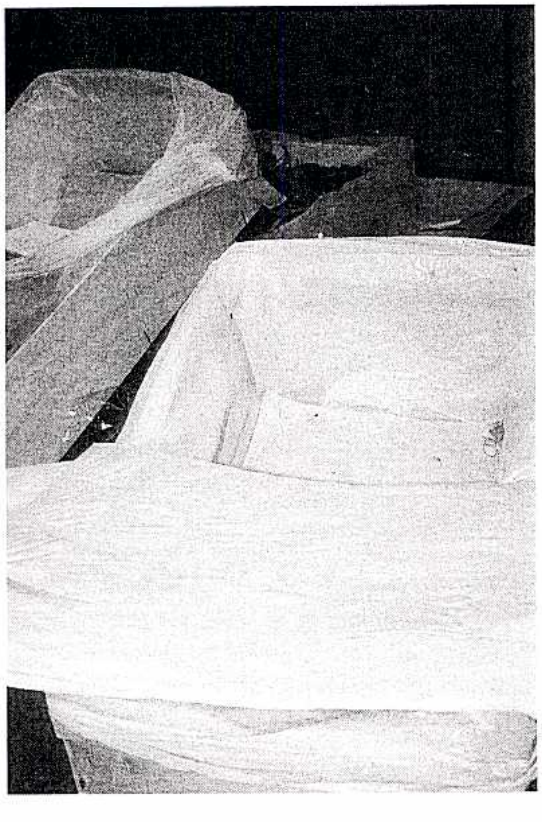
One problem associated with SO_2 fumigation of grapes is the constant potential for injury to the fruit and stems. Injured tissue first shows bleaching of color, followed by sunken areas where accelerated water loss has occurred. These injuries first appear on the berry where some other injury has occurred, such as a harvest wound, transit injury, or breakage at the cap stem attachment. Symptoms may also be seen around the cap stem, and slowly spread over the berry. Careful attention to SO_2 treatment procedures is necessary to minimize this damage. Another problem with SO_2 fumigation of grapes is the level of sulfite residue remaining at time of final sale. Sulfur dioxide was once included on the list of "Generally Recognized As Safe" (GRAS) chemicals, for which no registration is required. Heavy usage of sulfites in some other foods has caused a change in regulation, because some people are highly allergic to sulfites. Sulfite residues in grapes are currently limited to less than 10 ppm, and there are limits on the number of repeat SO_2 fumigations allowed, depending upon cultivar.

Recently it has been demonstrated that the amount of sulfur dioxide gas needed to kill *Botrytis* spores, or to inactivate exposed mycelium, is dependent on the SO_2 concentration and fumigation time. A cumulative concentration, calculated as the product of the concentration and exposure time, called the CT product, describes the sulfur dioxide exposure needed to kill *Botrytis cinerea*. A CT of at least 100 ppm-hour is the minimum required to kill spores and mycelium of *Botrytis* at 0°C (32°F), or approximately 30 ppm-hour at 20°C (68°F). The CT-100 dose can be obtained with an average concentration of either 100 ppm for 1 hour, 200 ppm for ½ hour, 50 ppm for 2 hours, or an equivalent combination of concentration and time. This finding was the basis for the development of the total utilization system.

The total utilization system differs from the traditional system in that there is no excess SO_2 fumigant at the end of the fumigation treatment, reducing both air pollution and sulfite residues in the fruit. It can be used with forced-air cooling for initial fumigation and in cold storage for subsequent periodic treatments. Total utilization typically uses about half as much SO_2 as the traditional method, and improves the uniformity and effectiveness of the SO_2 fumigant.

Figure 29.3

A slow-release SO_2-generating pad combined with a perforated or microperforated polyethylene box liner is used to control decay and reduce water loss during transport of table grapes.



THE TOTAL UTILIZATION SYSTEM

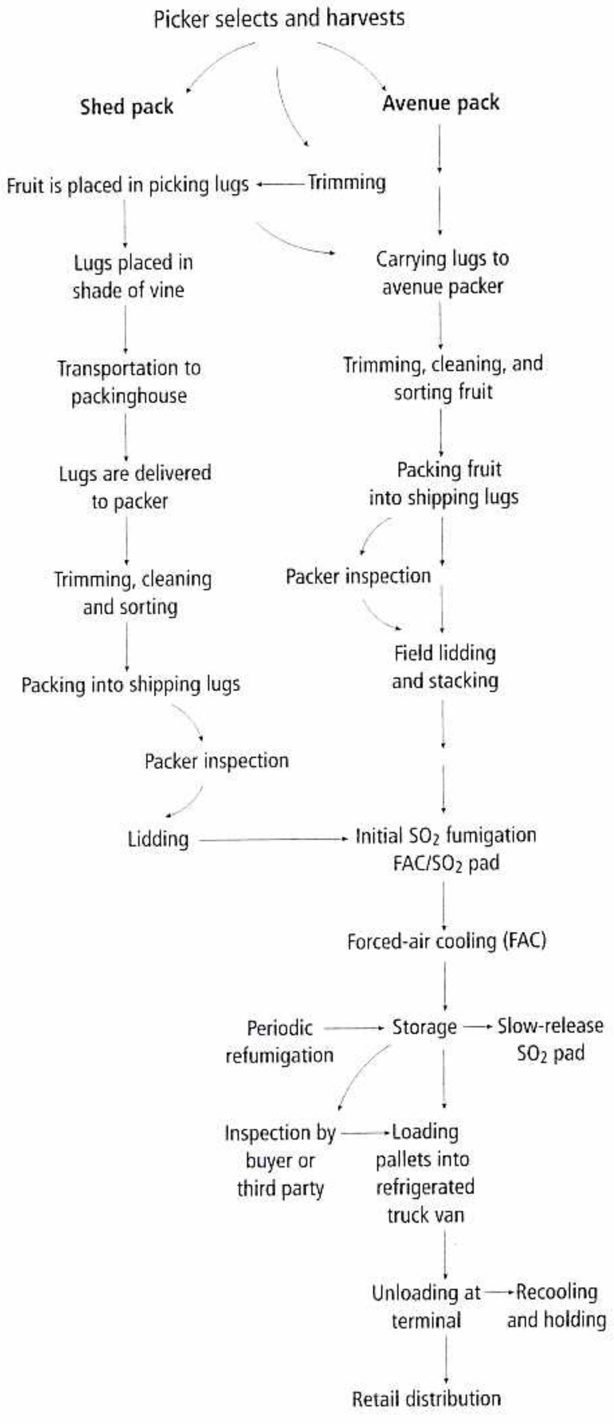
Initial fumigation. The first fumigation is done in conjunction with forced-air cooling. The forced air flows through the boxes and ensures good penetration of SO_2, even to the center boxes within a pallet. In most combinations of boxes and packs, this system produces over 80% penetration, measured as percentage of the room air CT product.

Passive fumigation. This fumigation process is applied every 7 to 10 days. After SO_2 application in the room, fans should run at high speed for over 3 hours so that nearly all of the SO_2 is absorbed by the fruit, packaging materials, and room surfaces. At the end of fumigation, the concentration of SO_2 in the room air should be less than 2 to 5 ppm and no venting or scrubbing is needed. In this system, each cold storage room should be calibrated to determine the amount of SO_2 to use. Center boxes within a pallet have lower SO_2 exposures than corner boxes, and pallets closest to the SO_2 inlet have higher fumigant exposures than those farthest away. To check fumigant penetration and distribution, inexpensive SO_2 dosimeter tubes are available. These dosimeters were originally designed for human safety monitoring. There is a large difference in SO_2 penetration according to box materials. For example, SO_2 penetration is higher in EPS boxes than wood-end and corrugated boxes; SO_2 penetration in corrugated is lower than in wood-end boxes.

Dosimeters designated for SO_2 fumigation doses at marked levels from 0 to 150, 0 to 100, and 600 ppm-hr are available (fig. 29.2). These dosimeter tubes work well for measuring the SO_2 CT product inside packed grape boxes. The glass dosimeter tubes are placed in the center of the boxes inside tissue wraps of cluster bags if these are present, and usually in boxes located in the center of the pallets. After fumigation the tubes are removed promptly and the ppm-hr exposure to SO_2 is

Figure 29.4

Postharvest handling of table grapes.



recorded. The tubes should be read promptly because some tubes can overestimate the dosage if examining their color reaction is delayed. A dose of 100 ppm-hr is the minimum adequate dose. This allows the operator to adjust the amount of fumigant applied to ensure that most boxes are adequately protected from decay but not exposed to fumigant levels that might cause excessive residues and bleaching. For details on this work see Luvisi et al. (1992).

Shipment. During ocean shipment for periods longer than 10 days or long retail handling in which SO_2 fumigation cannot be applied, the use of SO_2-generating pads in combination with a box plastic liner is advised (fig. 29.3). These SO_2-generating pads have sodium metabisulfite incorporated into them to allow a constant and slow release of SO_2 during shipment and marketing.

The slow-release SO_2-generating pad combined with a perforated polyethylene box liner (6.5 mm hole, 7.5 cm center, or ¼ in. hole, 3 in. center) reduces water loss and assures *Botrytis* control without enhancing bleaching (SO_2 phytotoxicity). This perforated box liner did not interfere with the initial fumigation (Crisosto et al. 1994, 2000). Initial fumigation is essential to control *Botrytis* during long-term storage or shipping. Water loss in the field and during storage or shipping was greatly reduced using this perforated box liner.

PACKING SYSTEMS

The two methods of handling table grapes in California are summarized in figure 29.4. Most California table grapes are packed in the field. In contrast to South Africa and Chile, few grapes are shed-packed.

FIELD PACKING

The most common field-packing system is the "avenue pack" (fig. 29.5). The fruit is picked and placed into shallow plastic picking lugs. Usually, the picker also trims the cluster. The picking lug is then transferred a short distance to the packer, who works at a small, shaded portable stand in the avenue between vineyard blocks. It is common for the packer and several pickers to work as a crew. Packing materials are located at the packing stand, which also shades the packer. With many packing stands around the vineyard, supervision is more difficult than in a packing shed. Lidding is done in the field. Substandard fruit can be accumulated in field lugs for transport to wineries or other processors.

SHED PACKING

Shed-packed fruit is harvested by pickers and placed in field lugs without trimming,

Figure 29.5

"Avenue pack" of table grapes.

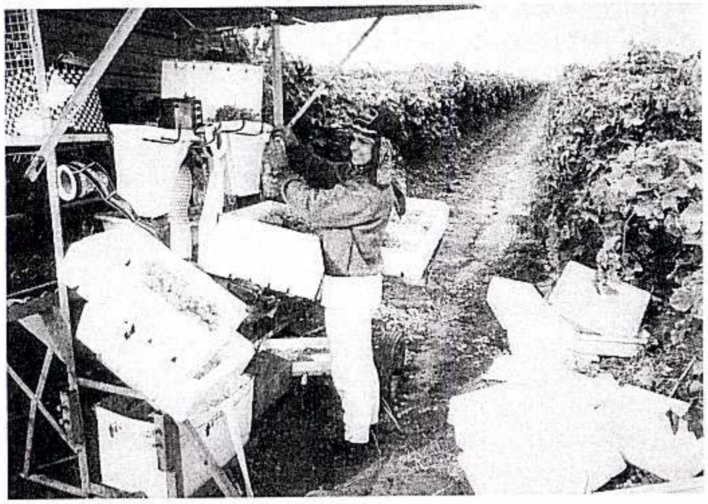


Table 29.1. Advantages and disadvantages of corrugated, wood-end, and foam boxes for packing table grapes

	Type of box*		
Attribute	**Wood-end**	**Corrugated**	**Foam**
Historical identification as a grape box	+++	+	+
Pleasant appearance and presentation of the fruit	+++	+	+++
Most favorable cost	+	+++	++
Ease of storing empty boxes and logistics of transporting to field	+	+++	+
Ease of packing	+	+	+
Protection against heat gain in the field	+	+	++
Protection of the fruit against shatter	+	+	+++
Protection of the fruit against bruising and splitting	+	+	+++
Stability of columns of boxes prior to palletizing	+++	+	++
Firmness of interlock for stability in the pallet	+	+	+++
Penetrability of palletized boxes to circulating air and fumigant	++	+	+++
Light weight during handling and shipping	+	++	+++
Conservation of storage and shipping space due to small bulk of box	+++	+++	+
Stability of the box in multiple pallet stacks	+++	+	++
Stability of the box during high humidity cold storage	+++	–	+++
Perceived (by receivers and public):			
Environmental acceptability	++	+++	–
Potential for recycling	+++	+++	+++
Actual amount of recycling (1995)	–	++	–

Source: Luvisi et al. 1995.

Note: *+++ = most or best attribute; ++ = intermediate attribute; + = average attribute; – = negative attribute.

then placed in the shade of the vines to await transport to the shed. At the packing shed the field lugs are distributed to packers, who select, trim, and pack the fruit. Generally, there are two grades packed simultaneously by each packer to facilitate quality selection. In some operations, trimming, color sorting, and a first quality sorting may have occurred in the field.

In all of the systems, grapes are nearly always packed on a scale to facilitate packing to a precise net weight, whether field or shed packed. In general, mid- and late-season grapes are packed in plastic bags or wrapped in paper. For early-season grapes, bulk pack is mainly used. In all cases, packed lugs are subject to quality inspection and weight checking.

PACKAGES

Three types of box materials are available to the California industry: corrugated, the technical Kraft Veneer (TKV, or wooded end), and the expanded polystyrene (EPS or Styrofoam). The advantages and disadvantages of these materials are summarized in table 29.1. In general, the use of corrugated has increased, especially for earlier cultivars and for fruit that are not stored for long periods. The use of the EPS container is becoming more popular for late cultivars and long storage periods. The choice of box material is often influenced by factors other than maintaining the quality of packed fruit (see table 29.1), such as the preferences of the receiver, environmental issues (recycling), cost, cold storage humidity conditions, storage length period, box weight, etc. TKV and foam boxes are mainly used for long storage periods because they maintain their structural integrity in high humidity conditions better than corrugated boxes. Approximately 0.1% of the total grape production is packed in clamshell containers.

Mainly due to retail pressures to use the 100 by 120 cm (40 by 48 in) pallet, the range of box sizes is diversified well beyond the standard LA lug (14 by 17.5 in). Since 1994, the MUM (35 by 40 cm, or 14 by 16 in), metric (40 by 50 cm, or 16 by 20 in), and shoe box (30 by 50 cm, or 12 by 20 in) containers have been used by the California industry. Detailed studies of the relationship between pack volume and packing height in the box versus grape quality have been carried out for the different box materials and sizes (see Luvisi et al. 1995).

In the last 6 years, different inner-packaging styles have been developed, driven mainly by retailers. During the 1998–99 season, approximately 70% of the total crop was packed using plastic cluster bags, approximately 20% was plain-packed (no inner packaging), and approximately 7% was wrap-packed. Plastic cluster bags provide consumer-size units and reduce the drop of loose berries onto produce department floors. The use of the plastic cluster bags has been reported to greatly reduce fruit damage during marketing (Luvisi 1992). Recent work has developed a cluster bag ventilation system (patented in 2000) that restricts water loss and slows drying and shriveling of the fruit and stems (Crisosto et al. 2001). In general, the use of the plastic cluster bag has been increasing, especially for mid- and late-season cultivars and for fruit that will be stored for long periods.

PALLETIZATION

After packing and lidding, grapes are palletized on disposable or recycled pallets. Some strapping in the field before loading is necessary in grapes packed in shoe-box boxes. Often, loaded pallets coming from the field pass through a "pallet squeeze," a device that straightens and tightens the stacks of containers. These pallet loads are unitized, usually by strapping or netting.

In shed-packing operations, some palletizing glue is used. This glue bonds the corrugated containers vertically on the pallet so that only horizontal strapping is required.

COOLING AND STORAGE OPERATIONS

After palletization is complete, the pallets are moved either to a fumigation chamber for immediate SO_2 treatment, to a forced-air cooler combined with fumigation, or to a forced-air cooler, where fumigation is done at the end of the day's packing. In any case, cooling must start as soon as possible and SO_2 applied within 12 hours of harvest. Many grape forced-air coolers in California are designed to achieve seven-eighths cooling in 6 hours or less. After cooling is completed, the pallets are moved to a storage room to await transport. Ideally the storage room operates at –1° to 0°C (30° to 32°F) and 90 to 95% RH, with a moderate airflow 20 to 40 cfm per ton of stored grapes. The constant low temperature, high RH and moderate airflow are important to limit the rate of water loss from fruit stems. Fruit should be stored at –0.5° to 0°C (31° to 32°F) pulp temperature throughout its postharvest life.

Fumigation is commonly repeated every 7 to 10 days during storage. Grapes should be regularly monitored during storage for physiological deterioration, fruit rot, SO_2 injury, and stem drying. When grapes are loaded for transport or shipment they may receive an additional SO_2 fumigation before loading to assure a longer market life because fumigation is seldom available in receiving markets. Unless SO_2 fumigation is available, the receiver must order grapes for immediate needs and must complete distribution and marketing within a reasonable time after arrival. An exception would be when SO_2-generating pads are placed in the container before shipment.

REFERENCES

Cappellini, R. A., M. J. Ceponis, and G. W. Lightner. 1986. Disorders in table grape shipments to the New York market, 1972–1984. Plant Dis. 70:1075–1079.

Crisosto, C. H., J. L. Smilanick, and N. K. Dokoozlian. 2001. Illustrating the importance of water loss during cooling delays for California table grapes. Calif. Agric. 55(1): 39–42.

Crisosto, C. H., J. L. Smilanick, N. K. Dokoozlian, and D. A. Luvisi. 1994. Maintaining table grape post-harvest quality for long distant markets. In Proc. International Symposium on Table Grape Production, June 28 and 29, 1994. Davis, CA: American Society for Enology and Viticulture. 195–199.

Crisosto, C. H., J. Smilanick, and A. A. Gardea. 1995. Uso de dióxido de azufre para controlar botrytis durante el manejo postcosecha de uva de mesa. Horticultura Mexicana 3(1): 33–40.

Harvey, J. M., and W. T. Pentzer. 1960. Market diseases of grapes and other small fruits. USDA Handb. 189. 37 pp.

Luvisi, D. A., H. Shorey, J. Smilanick, J. Thompson, B. Gump, and J. Knutson. 1992. Sulfur dioxide fumigation of table grapes. Oakland: Univ. Calif. Div. Ag. and Nat. Res. Bulletin 1932. 21 pp.

Luvisi, D., H. Shorey, J. Thompson, T. Hinsch, and D. Slaughter. 1995. Packaging California grapes. Oakland: Univ. Calif. Div. Ag. and Nat. Res. Publ. 1934. 16 pp.

Nelson, K. E. 1985. Harvesting and handling California table grapes for market. Oakland: Univ. Calif. Div. Ag. and Nat. Res. Bull. 1913. 72 pp.

Reynaud, E., and P. Ribereau-Gayon. 1971. The grape. In A. C. Hulme, ed., The biochemistry of fruits and their products. Vol. 2. New York: Academic Press. 172–206.

Ryall, A. L., and W. T. Pentzer. 1982. Handling, transportation and storage of fruits and vegetables. Vol. 2. Fruits and tree nuts. 2nd ed. Westport, CT: AVI. 257–262, 529–542.

Winkler, A. J., J. A. Cook, W. M. Kliewer, and L. A. Lider. 1974. General viticulture. Berkeley: Univ. Calif. Press. 710 pp.

II. Strawberries and Cane Berries

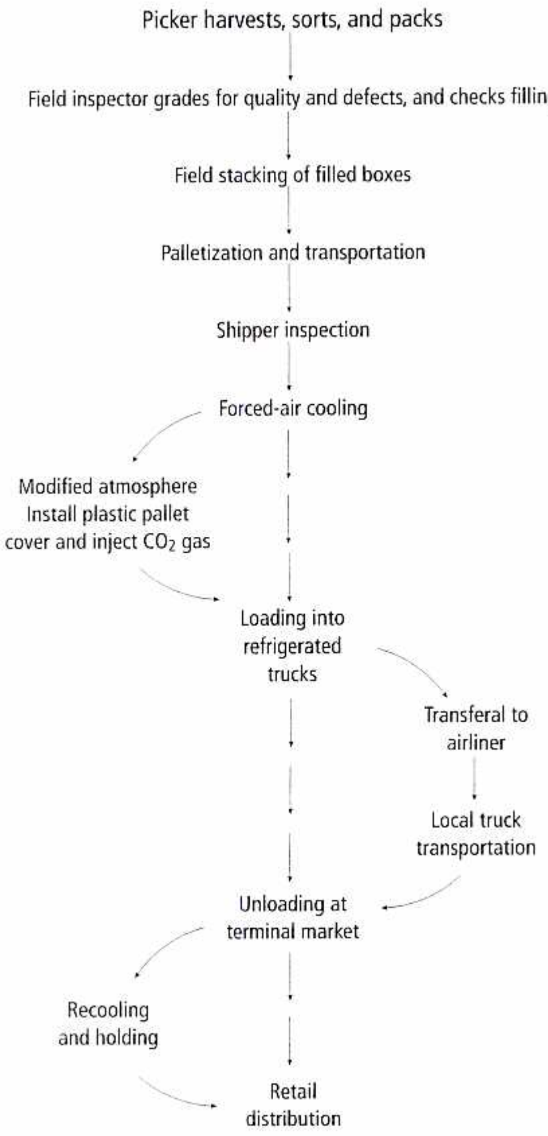
Elizabeth J. Mitcham and F. Gordon Mitchell

STRAWBERRIES

Strawberries are one of the most perishable fresh fruits, yet worldwide they are being successfully marketed in increasing volume. Because much of the marketing is at a great distance from the growing sites, effective handling procedures are required to prevent excessive deterioration. In California, a large fresh strawberry industry exists based largely on fruit delivery to markets up to 5,000 km (2,000 to 3,000 mi) away. California strawberry production begins in late winter in the south and continues through late fall in the north. Fresh market is the primary outlet, followed by freezing and jam manufacturing markets.

Figure 29.6

Postharvest handling of strawberries.



The primary market for fresh strawberries extends across the United States and into southern Canada. Some fruit are exported overseas by air to markets such as Japan and Australia. Most domestic shipments move by surface transport (highway trucks). Surface-transported strawberries must have a 5- to 7-day market life when shipped to cities in the eastern United States.

HARVESTING AND FIELD HANDLING

Strawberry growers and harvesters play a key role in determining fruit quality and deterioration throughout marketing and distribution. Important factors in the field include preharvest disease control and field sanitation; maturity selection; avoiding injuries while harvesting and packing fruit into crates; grading to eliminate injured, diseased, and defective fruit; protection from warming; and prompt movement from field to cooler (fig. 29.6).

Field disease control may include fungicidal treatment (when needed and following label instructions on the proper use of the chemical), removal of all diseased fruit from the plants at each harvest, and avoiding fruit contact with damp soil.

Harvest should be as frequent as needed to avoid overmature fruit, and any overripe berries encountered should be diverted to processing or discarded. Fruit color should be within a fairly narrow range when harvested (normally at least three-fourths red color) so that all berries will perform and respond to handling conditions in a similar manner. Fruit should be sorted carefully to remove even small lesions and all injuries (cuts, finger bruises, torn or removed calyx, etc.), and care should be taken to avoid wounding the fruit during the harvest and packing operations. Harvesting, grading, and packing are done simultaneously by the pickers in the field. The crates are usually placed into a picking cart or stand, which keeps the crate off the ground and facilitates easy packing of the crate by the picker during harvest (fig. 29.7).

Figure 29.7

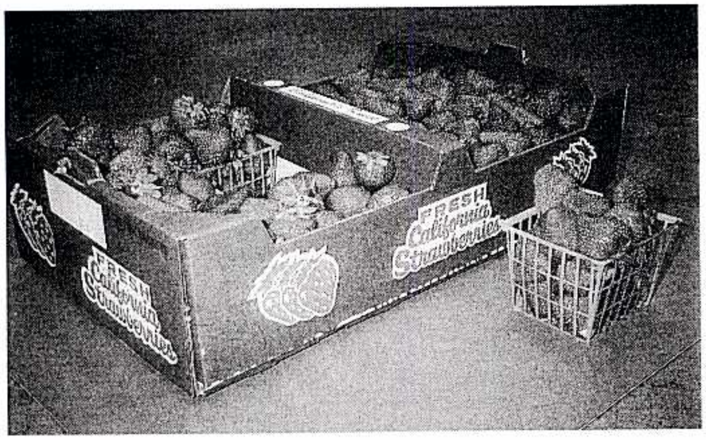
A strawberry harvest operation. Picking from only half the bed on each side of the picker eliminates excessive reaching and simplifies selection, sorting, and placement of the berries into trays on the wheeled cart.

Figure 29.8

Package design holding eight 0.45-kg (1-lb) clamshell baskets made of clear thermoformed plastic.

Figure 29.9

Common package design holding 4 to 5 kg (9 to 11 lb) of fruit in twelve 0.55-l (1-dry-pt) polypropylene mesh baskets.



Strawberries in California are shipped in corrugated fiberboard crates holding a variety of baskets. Clear, thermoformed plastic clamshell baskets in quart and pint (0.9 and 0.5 l) sizes are most commonly used (fig. 29.8). This basket can be placed directly on the retail display without repackaging or adding a cover. Open mesh plastic baskets are also used (fig. 29.9), and the crate holds 4 to 5 kg (9 to 11 lb) of fruit. These plastic baskets can be capped or uncapped, but the crate is not lidded for subsequent handling.

Trays are grouped together in a two-high stack with wires at both ends of the trays. The wires protrude above the top tray and fit into slots in the tray stacked above. Fiberboard tie sheets are placed on top of the sixth, tenth, and top tray layers. Wires and tie sheets stabilize the pallet load and protect the fruit so that pallet wraps or strapping are typically not necessary.

Berries are picked with the caps (calyxes) attached. Some special "stem-grade" fruit are picked by pinching the stem about 5 cm (2 in) from the calyx. The fruit must be loosely held in the hand without squeezing. Any squeezing of the fruit will cause bruising injury and discoloration. Strawberries should be placed into the crate, not dropped into it. While the crates need to be well filled for marketing, they should not be filled so full that berries will be crushed when crates are subsequently stacked. Often, berries are cut by the basket rim on the open-mesh baskets as a result of being packed over the tops of the baskets. Other overpackaged fruit are injured by abrasion against the corrugated crate. Injuries from this type of packing cause both a direct loss from physical damage as well as an increased risk of Botrytis rot (gray mold), which can spread to nondamaged berries. The lidded baskets eliminate this type of damage.

Any berries that show rot, sunburn, insect feeding, irregular shape, softness, or overripeness should be removed from the plant and discarded. If the calyx has been accidentally removed during picking, that fruit should also be discarded.

PREPARING HARVESTED STRAWBERRIES FOR MARKET

Temperature management

Good temperature management, including rapid cooling and maintenance of low pulp temperatures, is the single most important factor in protecting strawberries to minimize decay and over-ripening and to maximize their postharvest life. Both exposure temperature and duration are important to the amount of deterioration that will occur. Because of this relationship, constant circulation of delivery trucks to and from the field is required, and frequent, small loads must be delivered to the cooler. Arriving fruit should be moved promptly to the cooler without delays for inspection or other processing.

Because of the harmful effects of cooling delays it is recommended that cooling begin within approximately 1 hour of picking to prevent decreases in the percentage of marketable fruit (fig. 29.10). All strawberries in California are forced-air cooled in order to remove field heat and cool the fruit to storage temperature as soon as possible. Forced-air cooling is a specific method of cold air management in which pallets of fruit are positioned so that cold air must pass through package openings and around individual berries (see chapter 11 for more details). The design of the strawberry crates commonly used in California, with their large side ventilation openings, allows large volumes of air to move across packed berries with only modest air pressure differences, and berry cooling can be quite rapid. Approximate airflow characteristics needed for cooling strawberries in standard corrugated crates with mesh baskets are shown in table 29.2. Cooling rates for mesh baskets and pint-sized clamshells are similar, but quart clamshells take slightly longer to cool. The amount of venting on the clamshell baskets should be close to 13% of the side surfaces.

Figure 29.10

Strawberries should be cooled as soon as possible after harvest. Delays beyond 1 hour reduce the percentage of marketable fruit.

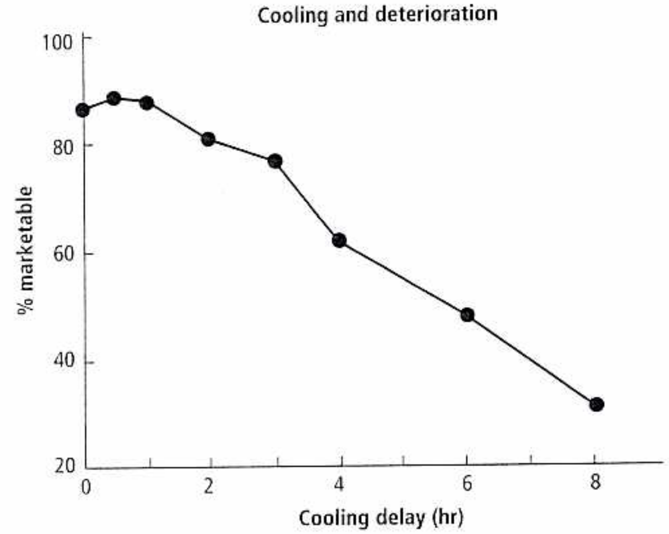


Table 29.2. Airflow characteristics and time to cool strawberries

Hours to seven-eighths cool warmest fruit	1.5	2	3	4
Airflow (l.sec/kg or cfm/lb berries)	2.0	1.4	0.8	0.5
Static air pressure (in) across pallet*	0.40	0.20	0.08	0.04

Note: *Static air pressure in × 0.2487= kPa.

Seven-eighths cooling time is the time required to cool the berries seven-eighths of the difference between their initial temperature and the temperature of the cold air. A 24°C (75°F) strawberry in –1°C (30°F) air would be seven-eighths cool when it reaches 2°C (about 36°F). These values are based upon the warmest fruit in the pallet (on the downstream position, inside the tunnel). The pallet furthest from the fan will usually contain the warmest fruit.

Refrigerated holding

Depending upon their handling and harvest maturity, strawberries may have a market life of from 1 to 2 weeks. Strawberry coolers and holding facilities should be maintained as close to 0°C (32°F) as possible with minimum temperature fluctuation. The highest freezing point that has been reported for strawberries is –0.8°C (30.6°F), but this is dependent upon their soluble solids concentration (higher soluble solids would result in a lower freezing point). Maintaining high RH in storage areas minimizes water loss.

Carbon dioxide treatment

Many strawberries are shipped with elevated CO_2 treatment, sometimes called modified atmosphere transport. This may be useful in slowing the physiological activity of the berries, thus slowing their rate of deterioration. It can also reduce the spread and development of rots (especially gray mold). This effect on gray mold development is measurable at transport temperatures above about 2°C (36°F), when growth and spread of the rot are more active. The value of CO_2 treatment will depend upon the transport time and temperature and upon the decay potential of the fruit. The greatest benefit would be expected for berries harvested

Figure 29.11

A pallet bag is placed over a pallet of thoroughly cooled strawberries; the bag will be sealed to the plastic pallet liner under the fruit.

Figure 29.12

With the plastic bag and pallet liner carefully taped together, a nozzle pierces the bag to exhaust some air and then replace it with CO_2. Tape will cover the point of injection in order to maintain the gas seal.

after periods of cool, moist, or foggy weather when free water might collect on berries in the field, and when gray mold spread would be expected to be most severe.

The standard method of CO_2 treatment is to completely enclose pallet loads of cold berries in sealed plastic bags, pull a slight vacuum, then add CO_2 to create a 12 to 15% CO_2 atmosphere within the pallet bag and around the fruit (figs. 29.11 and 29.12). It is important that the fruit be thoroughly cold, since the plastic pallet cover will impede further cooling, and condensation can form on the plastic when the berries are not fully cooled. All preparation and treatment should occur inside the refrigerated holding rooms, and pallet covers should be applied just prior to truck loading.

TRANSPORTING FRESH STRAWBERRIES TO MARKET

The period during which fresh strawberries are in transport is a major portion of their total postharvest life. Thus, assuring good conditions, including maintenance of low fruit temperatures during loading and transport, is critical to the successful marketing of fresh strawberries.

Refrigerated loading. Refrigerated holding rooms or loading docks for strawberries should be equipped with sealed loading doors that allow berries to remain under refrigeration while they are loaded into transport vehicles.

The transport vehicle should be thoroughly inspected to assure that the refrigeration system and airflow system are operating properly, and that the vehicle and any contents have been completely cooled before strawberry loading begins.

Experience suggests that damage to strawberries during transport is least when fruit are placed near the front and center of the vehicle. There the tractor axle under the load is often equipped with air-ride suspension (for driver comfort), whereas the rear trailer axles most commonly have normal spring suspension.

Past studies have shown that considerable heating of fruit can occur through trailer walls, with strawberries loaded against side walls warming substantially during cross-country transport. To resolve this problem, the California strawberry industry pioneered the use of "center loading" of pallets, using dunnage blocks along the sides (between walls and pallets) to stabilize the load. This assures space for airflow between the trailer wall and the pallets.

Setting the thermostat. The vehicle thermostat should be set at as low a temperature as possible without danger of freezing the strawberries. If the freezing point is near –0.8°C (30.6°F) (depending on the soluble solids concentration of the fruit) and if the accuracy of the thermostatic control equipment of the vehicle is ± 1.5°C (± 3°F), then a 1°C (34°F) setting may be possible. Any produce to be loaded with strawberries should be compatible.

Air transport. Most strawberries transported by air are destined for export markets. Strawberries for air transport should receive the same preparation and protection as strawberries for surface transport. Berries should be cooled and loaded as discussed above, and the fruit should be kept cold as long as possible before being staged for air cargo handling. Efforts should be made to minimize exposure of strawberries (pallets or air freight containers) to open sunlight, especially on hot tarmac staging areas. Reflective pallet covers with cold packs may help reduce warming. Tests have shown that even though strawberries may warm during transport, it is better to provide cooling whenever possible than not to cool at all. Upon arrival at destination, pallet covers should be removed and the fruit should be promptly returned to refrigeration, using forced-air (if possible) to recool them to near 0°C (32°F) as quickly as possible.

CARE OF STRAWBERRIES IN DISTRIBUTION AND RETAILING

Receiving. Cold fruit in refrigerated vehicles should be unloaded directly into the 0°C (32°F) warehouse whenever possible. If the fruit are warmer than about 2°C (36°F) they will benefit from being recooled and held at 0°C (32°F). If inspection indicates the presence of decay and reconditioning is required, the fruit should still be placed at cold temperatures and small lots removed momentarily for sorting.

Handling bagged pallets. Strawberries in pallets that have been bagged and treated with CO_2 will warm somewhat during transport as a result of their own respiration. The bags do not allow cold air to flow through the boxes within the pallets to remove this respiratory heat. Because of handling abuses to the pallets during loading and unloading, it is likely that some of the plastic pallet covers will have been punctured, and the high-CO_2 atmosphere will have been lost. It is thus important that these plastic bags be removed and the berries cooled thoroughly upon receipt.

Refrigerated holding. Strawberries in distribution should be held between 0° and 2°C (32° and 36°F) under reasonably high (90 to 95%) RH. In low-RH air, the fruit will readily lose water, and this can quickly cause those fruit to shrivel and appear old. Loss of vitamin C has also been observed when strawberries were stored under low-RH air. Because fruit shrivel is a result of cumulative water loss, fruit that appear sound may be approaching the stage at which shrivel becomes visible at the time of arrival in the distribution market.

Loading for retail store distribution. Because of their high perishability, strawberries should receive special handling in their final distribution. They should not be allowed to accumulate in warm staging areas where individual store orders may be assembled. They should not be loaded into warm distribution vehicles awaiting assembly of other products to complete the load. Whenever possible, strawberries should be kept cold until the delivery trucks are ready to depart, and only then placed into the load for final movement to retail outlets.

Many of the principles that apply to handling of strawberries also apply to handling of other fresh caneberry fruit.

RASPBERRIES AND BLACKBERRIES

Raspberries and blackberries grow on cane bushes and are harvested by hand for the fresh market when fully ripe. Some processed raspberries are machine-harvested. Raspberries should be fully red, and blackberries should be fully black and easily separate from the core at harvest. Harvesting will be necessary at least every other day to prevent development of overripe fruit. Berries should be handled gently as they bruise very easily. Fruit should be harvested into small containers and quickly transported to a shaded area for packing.

- Strawberries and caneberries are among the most perishable fruits.
- Berry deterioration is caused by injuries from harvesting and handling, decay, and self-destruction (natural senescence).
- Reducing berry losses must start with picker training and supervision.
- Careful grading at harvest to prevent packing of overripe, injured, or diseased berries is essential to prevent the spread of disease to healthy berries.
- Good temperature management is the single most important factor in minimizing deterioration and maximizing strawberry and caneberry shelf life.

The packing process involves sorting for defects, including damaged, decayed, and overripe fruit; placing fruit into small cardboard or plastic baskets; and overwrapping with cellophane or into clamshell thermoformed plastic containers.

Rapid cooling is very critical for the highly perishable raspberry and blackberry. Fruit should be cooled to 0°C (32°F) using forced-air cooling. Avoid leaving the fruit on the forced-air cooler beyond the time needed to seven-eighths cool to prevent excessive dehydration. Carbon dioxide treatment, as described for strawberries, can equally benefit these berries by reducing decay development.

BLUEBERRIES

Blueberries are more hardy than raspberries and blackberries but still require careful and expedited handling for successful marketing. Blueberries for fresh market are nearly always harvested by hand, while those destined for processing may be machine-harvested. The ability to resist damage during the harvesting operation varies considerably among varieties. Berries of some varieties may be picked soon after they turn dark blue, but those of other varieties are not ripe even though they have turned dark blue. These fruit should be picked after they develop good flavor, but while they are still firm enough for successful marketing.

As with the other berries discussed, handling of blueberries should be minimized to reduce fruit damage. Fruit should be harvested into small containers or directly into small cardboard or plastic baskets. Baskets are overwrapped with cellophane. Cool fruit to 0°C (32°F) as quickly as possible after harvest.

CRANBERRIES

Cranberries grow on small shrubs. Berries can be harvested by hand, with a scoop (tines and bucket), or by machine in a dry field. Alternatively, the field can be flooded (bog) and a machine can be used to water-rake the fruit off the shrubs. The berries float and are collected onto elevators using wind to move the fruit. The water system results in greater yields but causes more injury to the fruit. Water-harvested fruit also have greater decay, particularly if held in the water up to 24 hours. If the fruit are held in the water more than 12 hours, a physiological breakdown of the berry occurs after harvest. The incidence of this breakdown increases with increasing time in the water and varies with variety.

Rapid cooling after harvest is important to maintain fruit quality. However, cranberries are chilling-sensitive and should not be stored at temperatures lower than 3°C (37.4°F).

REFERENCES

Ceponis, M. J., and A. W. Stretch. 1983. Berry color, water-immersion time, rot and physiological breakdown of cold-stored cranberry fruits. HortScience. 18:484–485.

Dale, A. E., J. Hanson, D. E. Yarborough, R. J. NcNeil, et al. 1994. Mechanical harvesting of berry crops. Hort. Rev. 16:255–382.

Kader, A. A. 1991. Quality and its maintenance in relation to the postharvest physiology of strawberry. In A. Dale and J. J. Luby, eds., The strawberry in the 21st century. Portland, OR: Timber Press. 145–152.

Manning, K. 1993. Soft fruits. In G. B. Seymour et al., eds., Biochemistry of fruit ripening. London: Chapman and Hall. 347–377.

Miller, W. R., and R. E. McDonald. 1988. Fruit quality of rabbiteye blueberries as influenced by weekly harvests, cultivars, and storage duration. HortScience. 23:182–184.

Mitchell, F. G., E. Mitcham, J. E. Thompson, and N. Welch. 1996. Handling strawberries for fresh market. Oakland: Univ. Calif. Div. Ag. and Nat. Res. Publ. 2442. 14 pp.

Morris, J. R., and W. A. Sistrunk. 1991. The strawberry. In N. A. M. Eskin, ed., Quality and preservation of fruits. Boca Raton, FL: CRC Press. 181–206.

Perkins-Veazie, P. 1995. Growth and ripening of strawberry fruit. Hort. Rev. 17:267–297.

Perkins-Veazie, P., J. K. Collins, J. R. Clark, and J. Magee. 1994. Postharvest quality of southern highbush blueberries. Proc. Fla. State Hort. Soc. 107:269–271.

Robbins, J. A., and J. K. Fellman. 1993. Postharvest physiology, storage and handling of red raspberry. Postharv. News and Info. 4:53N–59N.

Talbot, M. T., J. K. Brecht, and S. A. Sargent. 1995. Cooling performance evaluation of strawberry containers. Proc. Fla. State Hort. Soc. 108:258–268.

III. Kiwifruit

Carlos H. Crisosto and
F. Gordon Mitchell

Approximately 2,100 hectares (5,200 acres) of kiwifruit (mainly of the cultivar Hayward) are grown in California, producing approximately 10 million to 11 million 3.6-kilogram (8-lb) boxes of fruit valued at $40 million to $43 million. Most production in California is located in the San Joaquin and Sacramento Valleys. Because of the hot, dry climate, kiwifruit must be well irrigated, but under these conditions kiwifruit develop very high soluble solids and mature earlier than in cooler climates. Most of the production area is relatively free of heavy winds so wind scarring of fruit is minimal, but care must be taken to avoid sunburn.

PHYSIOLOGY

Kiwifruit have an initial high starch content throughout the flesh before ripening, which is converted into sugars with time in storage. Consequently, soluble solids content (SSC) increases sharply in kiwifruit after harvest and may more than double during the first 1 to 2 months of storage. Meanwhile, titratable acidity decreases by as much as 50%. Most dramatic of all changes during early storage is a reduction in flesh firmness. Flesh firmness typically declines by 30 to 50% during each month of air storage at 0°C (32°F), until the fruit is fully ripe (near 0.9 kgf using an 8-mm tip, or 2 lbf using $\frac{5}{16}$ in tip).

Both CO_2 and ethylene production rates show a slight increase during early storage, then level out and continue at a fairly constant rate through a long period of storage. This small early peak in respiratory activity may be a response to handling injuries (even the wound caused by picking the fruit), rather than a real acceleration in physiological activity related to ripening. Respiration and ethylene production increase concurrently, and respiration almost always peaks 1 or 2 days before ethylene production. The climacteric rise of both ethylene-treated and control kiwifruit began only when fruit soften to 0.7 kilogram-force(1.5 lbf), well after the fruit were soft enough to eat (1.3 kgf, or 2.9 lbf) (Ritenour et al. 1999).

MATURITY

Kiwifruit exhibit little change in appearance and density as they approach maturity. They reach nearly full size well in advance of maturity. Although there is a large size variation among fruit on the vine, this appears unrelated to fruit maturity. For these reasons, any maturity standard must be based upon a single harvest of all fruit.

Several physical and chemical characteristics have been studied in kiwifruit, such as surface color, flesh color, soluble solids content (SSC, which is mostly sugars), titratable acidity (TA), SSC:TA ratio, starch disappearance, seed color change, and flesh firmness. Surface and flesh color change little over long periods of fruit development. Acid composition changes somewhat with development, but the level of titratable acids declines only after a period of storage. Starch disappearance is not easily measurable until ripening begins. Soluble solids content (SSC) taken at harvest time has been the most widely used maturity index to predict a minimum quality and storage performance. A 6.5% minimum SSC level of freshly harvested kiwifruit is commonly used as a standard in California. Because much of the starch conversion into sugars occurs after harvest, an initial SSC measure is valid only if taken immediately after harvesting the fruit because monitoring the SSC of fruit after packing or after any other delays that allow for starch conversion to sugar will result in higher SSC levels.

PHYSICAL INJURY

Flesh softening occurs as fruit mature on the vine, thus, flesh firmness measurements may help growers determine how late they can delay the harvest. The variability among fruit from a given location increases as softening on the vine continues and especially when flesh firmness drops below about 6.5 kilogram-force (14 lbf). Thus, there would be softer fruit if harvest occurs when flesh firmness drops below this level. To avoid possible increased fruit-handling injuries, harvest should not be delayed beyond an average flesh firmness of 6.5 kilogram-force (14 lbf).

When firm fruit (>6 kgf, or 13 lbf) are impacted, a light, whitish bruise results. The white color results from failure to convert starch to sugar in the injured cells. When the fruit softens to about 3 kilogram-force(6.6 lbf), a translucent bruise results. This injured flesh no longer contains starch. At intermediate firmness between about 6 and 3 kilogram-force(13.2 and 6.6 lbf), no visual bruising symptoms appear. Kiwifruit injured at above 6 kilogram-force (13.2 lbf) flesh firmness do not show a physiological response in either elevated CO_2 or ethylene production. However, below that firmness, there is a sharp increase in ethylene production, which persists for more than 2 weeks after injury. This is another reason for completing fruit harvest before flesh firmness drops below this level.

Vibration bruising of kiwifruit usually results in only minor signs of surface injury, but it could cause severe internal flesh injury. Such injury occurs when fruit soften to about 2.3 kilogram-force(5 lbf). Concurrent with the injury is a sharp increase in ethylene production that persists for at least a week. Opportunity for vibration bruising can be expected during transport from storage to distribution market. This provides a compelling reason for attempting to market kiwifruit at firmness above 2.3 kilogram-force(5 lbf).

Late-harvested kiwifruit retain their flesh firmness during storage better than early harvested fruit. Even though these fruit are less firm at harvest, they will emerge after 4 to 6 months storage at 0°C (32°F) firmer than earlier harvested fruit. Thus, growers should not rush to harvest fruit destined for long storage. A good rule for kiwifruit storage management appears to be "last harvested-last marketed." It is also known that kiwifruit with higher SSC levels will store better than ones with lower levels. Thus, late harvest is recommended to assure high kiwifruit quality after a long storage period in California.

QUALITY

In-store consumer acceptance tests were carried out for three consecutive seasons on the relationship between ripe soluble solids concentrations (RSSC) and/or ripe titratable acidity (RTA) on Hayward kiwifruit (Crisosto and Crisosto 2000). Based on test results, kiwifruit with RSSC that ranged from 11.6% to greater than 13.5% were always liked by consumers but with different degrees of liking. A 12.5% RSSC is being proposed as a minimum quality index for early-marketed Hayward kiwifruit. RTA played a significant role in consumer acceptance only on kiwifruit that had RSSC less than 11.6% with RTA equal to or greater than 1.17% ("sour"). These data confirm recommendations from New Zealand that ripe Hayward kiwifruit should have a minimum of 12.5% SSC to achieve consumer acceptance.

TOTAL SOLIDS

A total solids determination measured at any time during kiwifruit postharvest life should predict final SSC (ripeness) and fruit quality. Percent total solids is the dry weight (after removing all of the water) divided by the fresh weight of the tissue. There is a highly significant correlation between total solids and ripe soluble solids concentration (Slaughter and Crisosto 1998). To speed up the total solids determination, the drying period has been shortened to about 52 minutes by using a microwave oven. However, this procedure is a destructive method and it involves careful fruit sample preparation for its determination, making it difficult to use.

NIR SPECTROSCOPY

A nondestructive quick method, NIR spectroscopy technique, can be used to determine fructose, glucose, SSC, and total solids (dry weight). The reliable measurement of total solids any time during postharvest handling can be used as a quality index. Because of its potential for high-speed measurements, this optical technique may be suitable for quality segregation in the packing shed (Slaughter and Crisosto 1998).

ORCHARD FACTORS

Fruit from certain vineyards maintain firmness during storage better than fruit from other vineyards consistently from year to year. A survey of numerous vineyards within California production areas indicated that vineyard nutrition was related to these differences (Johnson et al. 1997). Fruit with a high nitrogen concentration softened more rapidly in storage. Potassium and calcium were also positively correlated with fruit storage ability but less consistently than nitrogen.

POSTHARVEST DISEASE MANAGEMENT

Most kiwifruit decay problems are a result of infection by *Botrytis cinerea*. This organism grows and spreads slowly at 0°C (32°F) storage, but because of the long storage duration (up to 6 months) for kiwifruit, it is a major cause of fruit loss. Botrytis rot can invade the fruit directly, but it also enters through wounds, invades dead floral parts or other organic matter on the fruit, and spreads from infected fruit to healthy surrounding fruit (nesting). It is important to maintain cleanliness in the vineyard, to avoid fruit injuries during handling, to brush the fruit to remove dead floral parts and other material on the fruit surface, to avoid contamination (such as juice from soft fruit), to cool the fruit rapidly, and to maintain a constant 0°C (32°F) storage temperature. A preharvest fungicide spray is recommended when high Botrytis pressure is detected. Because Botrytis rot is associated with soft fruit, any practices that maintain flesh firmness during storage decrease the fruit-rotting problem.

During long-term storage, some individual kiwifruit become rotted, particularly from *Botrytis cinerea*. Fruit infected with Botrytis rot produce ethylene at a higher rate, and this can affect flesh softening of healthy fruit. Even a single soft, decayed kiwifruit in the center of a flat can speed the softening of surrounding fruit. Fruit farthest from the rot can soften more rapidly than fruit in trays that are rot-free.

Sampling fruit from vineyards 4 months after fruit set and recording the incidence of *Botrytis* colonization in sepals or stem ends is being used as a field-monitoring method to predict the incidence of kiwifruit Botrytis gray mold after 3 to 5 months in cold storage. Spraying a registered fungicide 1 or 2 weeks before harvest significantly reduced postharvest gray mold after 5 months storage only in vineyards with more than 6% gray mold prediction. Preharvest spray is not recommended when predicted gray mold is below 6%. This prediction method can be successfully used by growers to make decisions about preharvest sprays, sorting, repacking, and shipping (Michailides and Morgan 1996).

STORAGE CONDITIONS

Kiwifruit flesh softening is rapid during the first few weeks of storage, even at 0°C (32°F). Exposure to ethylene during any cooling delay can substantially accelerate flesh softening during subsequent 0°C (32°F) air storage. The greater the ethylene concentration and the longer the cooling delay period, the greater the effect on fruit softening. Advancing fruit maturity also increases the sensitivity of freshly harvested fruit to ethylene exposure. The best protection of kiwifruit quality after harvest is forced-air cooling to near storage temperature within 6 hours of harvest, avoiding any ethylene exposure, and storing at 0°C (32°F). We determined a reduction in Botrytis incidence on kiwifruit exposed to an ethylene–free delayed cooling period under specific environmental conditions ("curing"). A period of 48 hours curing at 15°C, 95% RH, and high air velocity (2 m/sec, or 6.5 ft/sec) around the kiwifruit are recommended for a successful treatment.

Avoid ethylene exposure during harvest, transport, and storage. Even very low ethylene levels (5 to 10 ppb) will induce fruit softening. Continuous ventilation during air storage helps to assure low ethylene levels. This method works very well in the Central Valley of California when the outside air is ethylene-free. However, during burning days, we found that air ethylene levels increase to dangerous concentrations.

Extensive studies have been conducted on the potential benefits of controlled atmosphere (CA) storage for kiwifruit. The major benefits are a delay in flesh softening during storage and reduction in Botrytis rot problems. Best results have been obtained in a CA atmosphere of about 5% CO_2 and 2% O_2. The fruit must be promptly cooled and placed under the CA conditions as soon after harvest as possible. There is little benefit if delays in establishing CA conditions exceed 1 week. Upon removal from CA conditions the fruit are firmer and retain a greater market life. Ethylene accumulation must be avoided in CA storage as in air storage. Ethylene at low levels causes rapid flesh softening, and a fruit injury problem involving an ethylene-CO_2 interaction has been identified. Avoiding ethylene contamination is therefore important, and only CA generating equipment that does not produce ethylene should be used. It is possible that ethylene scrubbing may be required during CA storage, but no reliable commercial CA storage system for kiwifruit has been critically monitored.

We found that the rate of kiwifruit softening stored in either ethylene-free air or 5% CO_2 and 2% O_2 at 0°C (32°F) during the 16-week cold storage period was related to fruit size and storage conditions. However, soluble solids concentration accumulation was independent of the fruit size and the storage conditions. Under both storage conditions, large size (approximately 101 g, or 3.5 oz) fruit had a slower rate of softening than medium (93 g, or 3.2 oz) and small size (81 g, or 2.9 oz) kiwifruit. Air-stored kiwifruit softened approximately 2.5 times faster than CA-stored fruit. Kiwifruit are more susceptible to physical damage during packaging when they soften below 1.8 kilogram-force(4 lbf). Under air conditions large, medium, and small kiwifruit reached 1.8 kilogram-force fruit firmness by 11, 12, and 13 weeks, respectively. Large, medium, and small kiwifruit under CA conditions reached 1.8 kilogram-force fruit firmness by 25, 35, and 57 weeks, respectively. Thus, the length of the bin cold storage period prior to packaging depends on fruit size and storage conditions.

KIWIFRUIT RIPENING

For general information on management of fruit ripening, see chapters 16 and 21. Kiwifruit ripening protocols for packers, shippers, buyers, handlers, and receivers have been developed. The *Ripening Guidelines for Kiwifruit Handlers and Receivers* are available from the California Kiwifruit Commission or from Dr. Carlos Crisosto.

REFERENCES

Arpaia, M. L., F. G. Mitchell, and A. A. Kader. 1994. Postharvest physiology and causes of deterioration. In J. H. Hasey, R. S. Johnson, J. A. Grant, and W. O. Reil, eds., Kiwifruit growing and handling. Oakland: Univ. Calif. Div. Ag. and Nat. Res. Publ. 3344. 88–93.

Arpaia, M. L., F. G. Mitchell, A. A. Kader, and G. Mayer. 1985. Effects of 2% O_2 and varying concentrations of CO_2 with or without C_2H_4 on the storage performance of kiwifruit. J. Amer. Soc. Hort. Sci. 110:200–203.

Crisosto, C. H., and G. M. Crisosto. 2001. Understanding Consumer acceptance of early harvested 'Hayward' Kiwifruit. Postharv. Biol. Technol. 22:205–213.

Crisosto, C. H., D. Garner, G. M. Crisosto, and R. Kaprielian. 1997. Kiwifruit preconditioning protocol. Acta Hort. 444: 555–560.

Crisosto, C. H., D. Garner, R. S. Johnson, and J. P. Zoffoli. 1992. Maturity indices for kiwifruit. Sacramento: California Kiwifruit Commission.

Johnson, R. S., F. G. Mitchell, C. H. Crisosto, W. H. Olson, and G. Costa. 1997. Nitrogen influence storage life. Acta Hort. 444:285–290.

Michailides, T., and D. P. Morgan. 1996. New technique predicts gray mold in stored kiwifruit. Calif. Agric. 50(3): 34–40.

Mitchell, F. G. 1990. Postharvest physiology and technology of kiwifruit. Acta Hort. 282: 291–307.

Mitchell, F. G., G. Mayer, W. Biasi, and D. Golli. 1990. Estimating kiwifruit maturity through total solids measurements. Sacramento: California Kiwifruit Commission.

Ritenour, M. A., C. H. Crisosto, D. T. Garner, G. W. Cheng, and J. P. Zoffoli. 1999. Temperature, length of cold storage and maturity influence the ripening rate of ethylene-preconditioned kiwifruit. Postharv. Biol. and Technol. 15:107–115.

Slaughter, D. C., and C. H. Crisosto. 1998. Nondestructive internal quality assessment of kiwifruit using near-infrared spectroscopy. Semin. in Food Anal. 3:131–140.