Postharvest Handling Systems: Pome Fruits

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California is a major producer of apple and European pear fruit for U.S. and export markets. California produces a more limited volume of Asian pears and quince. The apple industry in California has increased greatly over the past 10 years. New plantings in the Central Valley, in addition to older plantings along the coast and in the foothills, have increased California's production such that it is generally the third largest producing state in the United States after Washington and Michigan. Granny Smith, Gala, and Fuji have dominated these new plantings. The pear industry in California is more than 90% Bartlett pear, with approximately half the volume diverted to processing, while the fresh volume remains substantial.

I. Apple

MATURITY

Maturity changes in apples include skin color, seed color, flesh firmness, soluble solids content, starch content, titratable acid content, respiratory rate, ethylene production, and production of other flavor and odor constituents. Suggested maturity indices have included all of these as well as time (days from full bloom), accumulated heat units (e.g., degree-days above 7°C [45°F]), fruit size, and various combinations of these.

Most possible maturity indices have limitations. For example, ethylene production and respiratory rate changes may occur too late or are too variable to be useful for timing of harvest. Some other changes are too subtle to be effective. Most commercial applications of maturity indices use days from full bloom as the rough guide, with fine tuning using mostly starch index and flesh firmness. Maturity standards must take into account whether fruit is to be stored (and for how long) or shipped immediately. The goal is to determine a reliable index that can predict the best harvest date for long-term controlled atmosphere storage or for short-term air storage. Harvesting immature fruit results in smaller fruit with greater susceptibility to water loss and storage disorders, such as bitter pit and scald. Overmature fruit have greater susceptibility to softening, mealiness, decay, and controlled atmosphere–related disorders.

Many apple-growing regions have developed maturity standards that guide the start of harvest. These standards may be voluntary or legally binding. In California, Granny Smith apples are released for harvest by county according to the California Granny Smith Starch Iodine Chart. Inspectors rate a 30-apple sample from the orchard for starch degradation pattern, and the average for the orchard must meet the minimum level of starch degradation (a score of 2.5 on the Starch Iodine Chart). A similar starch score is used to determine the start of Granny Smith harvest in New Zealand. While starch disappearance is also used to guide the start of Granny Smith harvest in Washington, the scale is quite different from that used in California and New Zealand. Unfortunately, the starch disappearance charts used in different apple growing regions are not uniform. Scales can range from 0 to 6, 0 to 7, or 0 to 10. The higher number always indicates more starch disappearance.

Starch is a useful index of harvest maturity because starch is degraded into sugars as the apple matures and begins to ripen. The

Starch Iodine Solution
(0.1% iodine, 1% potassium iodide)

Dissolve 10 grams (1 tsp) of potassium iodide crystals in 265 milliliters (1⅛ cup) clean water in a 1-l (1-qt) container. Gently swirl until the crystals dissolve. Add 2.5 grams (¼ tsp) iodine and swirl until iodine dissolves (this may take a while). Dilute this solution with clean water to make 1 l (1 qt). The solution is sensitive to light and should be stored in a dark container or wrapped in aluminum foil. Fresh solution should be made each season. These chemicals are available at most drug stores.

starch content is measured at the center cross-section of the apple. Starch disappearance is visualized by staining the cut surface of the apple with an iodine–potassium iodide solution (see recipe above). The iodine solution turns starch black and provides a view of the starch clearance pattern. Starch charts can be used to determine a starch score based on the percentage of the cross-section clear of staining.

HANDLING

Apple fruit are hand-picked into bags, gently transferred into field bins, and transported to the packing facility. Care must be taken during harvest of apples to avoid impact bruising. Solid-framed, padded picking bags into which pickers can place, rather than drop, harvested apples are ideal. Careful training and supervision of picking crews is essential to avoid excessive fruit bruising.

Apples, which are often stored in field bins to await later packing, may be drenched with a scald inhibitor and fungicide and are sometimes treated with calcium chloride for bitter pit control before storage.

Apple fruit can benefit from precooling prior to cold storage. Precooling can be accomplished by forced-air cooling or hydrocooling. While hydrocooling is faster than forced-air cooling, there is the potential to spread disease organisms from diseased fruit or soil to healthy fruit. If liquid chlorine is used to reduce the potential for disease spread, care must be taken to change the drench water daily to prevent a buildup of sodium, resulting in fruit burn. The same is true for dump tank water systems.

Fruit to be packed are unloaded from bins using water flotation dumps, washed, presized to eliminate undersized fruit, and sorted. Sorting is generally by a combination of electronic and human sorters. Electronic sorters for color and size are very common in larger packinghouses. Electronic sorting for defects is used to a very limited extent but will likely increase in the near future. Most defect sorting is by human sorters at this time. Fruit is often segregated into several fresh grades, as well as processing grades and by-product outlets.

Most fresh-market apples are tray-packed, while lower grades may be volume filled. Bagging of apple fruit is used more frequently, not only for smaller apples but also for large fruit destined for consumer warehouse stores. Bruising continues to be a concern for bagged fruit, but newer machine designs have reduced this problem somewhat.

Packed cartons are segregated by fruit size and stacked onto unitized pallets. Final cooling of these pallet loads occurs after packing. Cooling may involve forced-air or static room cooling. Most apple cartons used today are not ventilated or are inadequately ventilated, a situation that seriously impedes cooling after packing.

A flow diagram for the handling of apples (fig. 27.1) shows the steps involved in fresh-market handling.

STORAGE

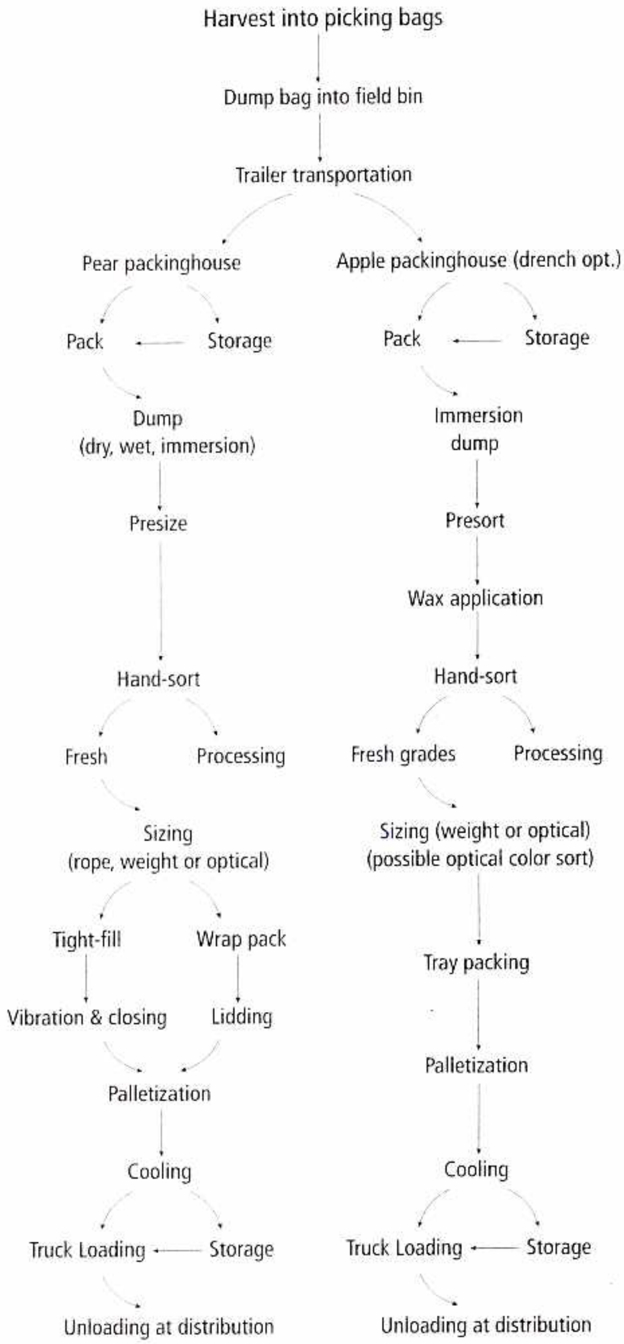
TEMPERATURE MANAGEMENT

As a general rule, pome fruits respond best to rapid cooling and storage at as low a temperature as possible without danger of freezing or low-temperature injury. Many apple varieties can be safely stored at 0°C (32°F); however, there are exceptions, some of which are shown in table 27.1. Low-temperature injury can be manifested as internal flesh browning. Specific recommendations for varieties may require confirmation under localized conditions. For example, California-grown Yellow Newtown apples are recommended to be stored at 3.5° to 4.5°C (38° to 40°F), while Yellow Newtown apples from other growing areas have been safely stored at 0°C (32°F).

Cooling delays are associated with shortened storage life, flesh softening, increased physiological disorders, and diseases. Thus, fruit should be cooled as soon after harvest as possible. However, for fruit with severe

Figure 27.1

Postharvest handling of apples and Bartlett pears.



watercore, cooling delays can reduce the severity of the disorder. The importance of cooling speed can vary with cultivar. For example, Gala apples often soften significantly in storage, and rapid cooling can greatly extend the storage life. When antioxidants such as diphenylamine are used to delay storage scald development, a cooling delay of up to 1 day may be required for maximum scald control. Rapid cooling of the fruit after this delay becomes even more important.

While some apples are packed immediately after harvest, the majority are stored for a period of time in either regular cold storage or in controlled atmosphere storage. During the packing operation, fruit can warm considerably, and recooling after packing is important to maintain fruit quality. The lack of adequate ventilation on most apple boxes greatly slows the recooling process after packing. Boxes should be designed with at least 5% venting on all four sides to allow for air passage when boxes are cross-stacked.

CONTROLLED ATMOSPHERE STORAGE

Controlled atmospheres (CA) are often used when apples are stored longer than 3 months; however, Gala apples have been shown to benefit from CA storage for as short as 1.5 months, and this has been used commercially. Most fruits are CA-stored in field bins, often with unsorted, field-run fruit. However, some apples are dumped, sorted, sized, and refilled into their bins before moving to CA storage. Maintenance of the proper levels of O_2 and CO_2 for each variety is critical to the success of CA storage as is proper harvest maturity. In general, fruit harvested earlier in the harvest season is a better candidate for long-term CA storage than later harvested fruit. Fruit with advanced maturity can be more susceptible to developing CA-related storage disorders. General CA recommendations by variety are shown in table 27.1.

RELATIVE HUMIDITY

Warm fruits lose water faster than cold fruits, especially if the RH of the air is less than 95%. Loss of water is loss of saleable weight and can result in fruit shrivel and loss of gloss. Water loss is cumulative from the time the fruits are harvested until consumption. Visible shrivel is not apparent until a critical amount of water is lost, usually 3 to 5% of the original weight. Rapid transport of fruits from the field to the cooler, rapid cooling and maintenance of 90 to 95% RH in storage are essential to reduce fruit water loss. Use of polyethylene film bin liners can reduce water loss in storage, particularly at less than 95% RH. The liner should have an open or highly perforated bottom if apples will be drenched or hydrocooled. The disadvantage of the liner is a significant reduction in

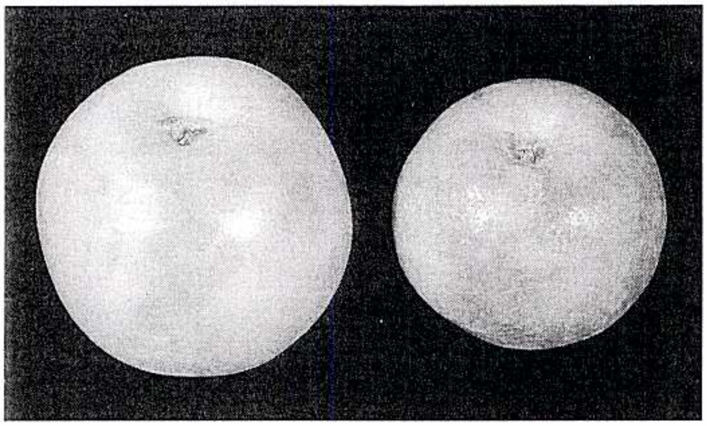
Table 27.1. Recommended temperatures and CA for storage of selected apple varieties

Cultivar	Temperature °C (°F)	O_2 concentration	CO_2 concentration	Storage life (months)
Braeburn	0–1 (32–34)	1.5–2.0	≤1.0	6–9
Fuji	0–1 (32–34)	1–2	≤1.0	7–9
Gala	0–1 (32–34)	1.5–2.0	1–2	4–6
Golden Delicious	0–1 (32–33)	1–2	1–3	7–10
Granny Smith	0–2 (32–35)	1–2	≤1.0	7–11
McIntosh	2–3 (36–38)	1.5–2.5	1.5–4	5–8
Mutsu	0–1 (32–34)	1.5–2.0	1–3	6–9
Pink Lady	0 (32)	1.5–2.0	1	9
Red Delicious	0–1 (32–34)	1–2	1–3	7–11

Source: Kupferman 1997.

Figure 27.2

Storage scald on Granny Smith apples.



cooling rate if room cooling or forced-air cooling are used. A RH of 90 to 95% is considered ideal for apples, but it is difficult to maintain using large-surface cooling coils alone. Supplemental humidification, especially with fog spray nozzles, is now widely used. Unfortunately, the water added in such a system increases the coil defrost problem.

PHYSIOLOGICAL DISORDERS

STORAGE SCALD

A number of physiological disorders can cause serious losses in apples, especially after prolonged storage. Apple storage scald is most severe on less mature fruits, but on highly susceptible varieties, such as Granny Smith and Red Delicious, scald occurs even on fruit harvested at optimal maturity. Fruit grown in hot, dry climates, such as California, are more susceptible. The disorder appears as brown patches on the fruit surface that may not develop until the fruit are warmed after storage (fig. 27.2). In very severe cases, browning will be seen on the fruit in cold storage and will intensify when the fruit are warmed after storage. Thorough cooling and maintaining a low storage temperature are important in scald control. Often, an antioxidant such as diphenylamine (DPA) is applied as a bin drench (fig. 27.3), according to label directions, before storage to reduce the incidence and severity of scald. Controlled atmosphere storage can significantly delay scald development. Very low O_2 concentrations in CA storage (less than 1%) can provide control similar to DPA in some cases, although care must be taken to avoid low-O_2 injury to the fruit.

WATER CORE

The watersoaking symptoms of this disorder result from flooding of the intercellular spaces by a fruit solution high in sorbitol. Water core is often associated with low calcium levels in the fruit and is most severe in fruit from young, vigorous, lightly cropped trees. Red Delicious, Fuji, and Granny Smith are sensitive varieties. Fruit of advanced maturity are generally more severely affected. Fruit grown at high temperatures, especially if exposed to afternoon sun and cold nights, appear most prone to water core. Mild water core may disappear during short-term cold storage, but if severe, tissue may turn brown during storage. If harvested fruit is found to contain water core, fruit should be marketed as soon as possible, and fruit should not be stored for long periods. Cooling delays of 1 to 2 days may reduce the severity of water core symptoms and allow fruit to be stored in regular storage. Under no circumstances should water cored fruit be placed in controlled atmosphere storage. In California, water core has not been a significant problem in Fuji apples; however, in Washington, water core can be severe in Fuji.

BITTER PIT

Bitter pit symptoms are expressed by the development of dark, dry, pithy spots or pits near or below the fruit surface, especially at the calyx end (fig. 27.4). Bitter pit is another common cause of losses in apples. Lenticel blotch pit is a similar disorder with very shallow pits on Granny Smith apple. Tree

Figure 27.3

Apple fruit in bins being drenched with diphenylamine (DPA) just after harvest for control of storage scald.

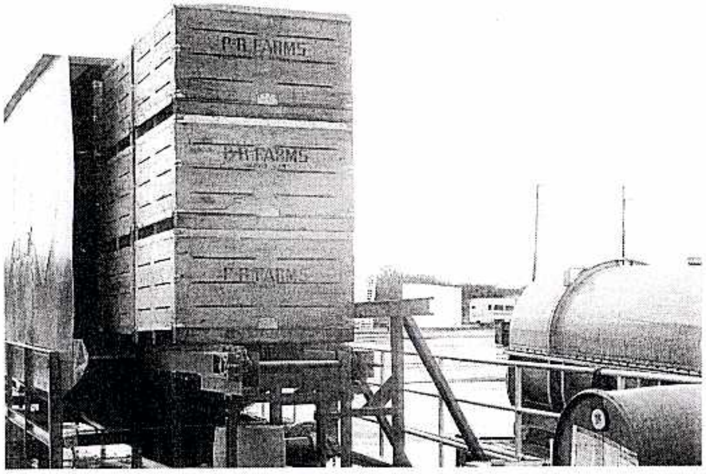
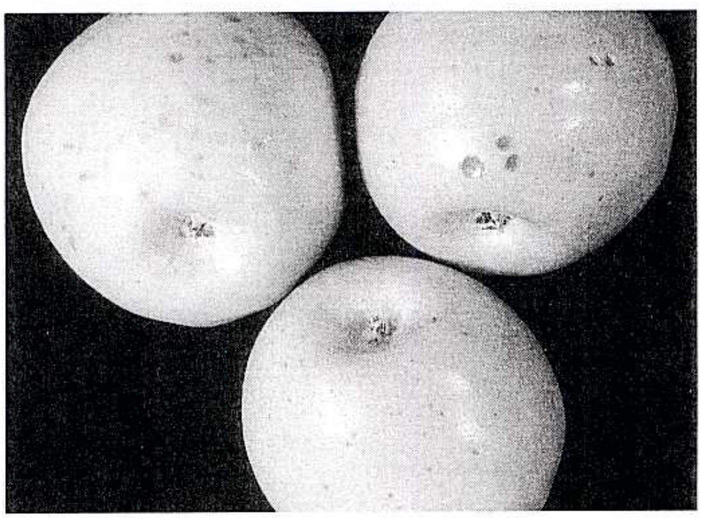


Figure 27.4

Symptoms of bitter pit on Granny Smith apples. Pits can be of various sizes on the surface of the apple or just under the skin of the apple.



conditions that are associated with bitter pit include extreme vigor, light crop, and low fruit calcium content. Early-harvested, early-maturity fruit are most susceptible. The symptoms are sometimes visible at harvest but commonly develop during the first month of storage. Rapid cooling and high RH can reduce the development of symptoms during storage. Multiple calcium sprays on fruit before harvest, following label instructions, are the most effective treatment for bitter pit. Calcium application and rapid cooling following harvest may further reduce the problem. Application of pressure or vacuum, while dipping in calcium solution, has increased penetration into the flesh and reduced bitter pit incidence in susceptible cultivars, but there may be an added risk of internal browning from waterlogged tissues, and decay.

INTERNAL BROWNING

Development of internal browning as a result of CO_2 injury has been reported in Fuji, Cox's Orange Pippin, Braeburn, and Jonathan apples. Brown discoloration occurs in the flesh, usually originating in or near the core, and the discoloration is firm, but moist. The brown areas have well-defined margins and may include dry cavities resulting from desiccation. Symptoms can range from a small spot of brown flesh up to nearly the entire apple's flesh being affected in severe cases. Symptoms develop during the first month of CA storage. This disorder is associated with later harvested, large fruit stored with high CO_2 concentrations; however, the incidence varies season to season and orchard to orchard. Because internal browning is not visible externally, the disorder may be detected by buyers and consumers. Nondestructive means of detection are currently under development.

BRUISING

Apples can be damaged by bruising. Roller bruising affects the surface of the fruit, resulting in brown areas or bands where rolling, rubbing, or vibration occurred, and damage is usually not apparent below the surface. Impact bruising affects the flesh, resulting in brown spots under the skin that may or may not be visible from the surface. The browning results from oxidation of phenols in the presence of an oxidizing enzyme, primarily polyphenoloxidase. Climatic differences in severity are apparently related to the level of phenols or the relative activity of the browning enzyme. Any mechanical injury can stimulate ethylene production, and thus speed fruit ripening and deterioration. Any surface damage can result in inoculation by fruit rot organisms and more rapid water loss from the fruit.

PATHOLOGICAL DISORDERS

GRAY MOLD AND BLUE MOLD

Gray mold (*Botrytis cinerea*) and blue mold (*Penicillium expansum*) can develop in wounds or at the stem or calyx end on apple fruit. Gray mold can be quite common after long-term storage. Sanitation in the field and packinghouse (especially water systems) and careful handling of fruit to avoid wounding are the best means of control. Temperature management will slow the growth of fungi that might be present. Fungicides added to the drench water can provide some protection; however some fungi have developed resistance to commonly used thiabendizole-type fungicides.

MUCOR ROT

Mucor rot has become a serious problem in Granny Smith and Fuji apples grown in California. The fungus, *Mucor piriformis*, lives in the orchard soil. Fruit collected from the orchard floor and soil attached to field bins transport the fungus into drench systems and dump tanks where healthy fruit can become infected. *Mucor* causes a very soft rot that can liquify fruit tissue, resulting in dripping of spores onto healthy fruit in the bin and thereby spreading of the disease in storage. While low temperatures greatly reduce its growth, this fungus continues to grow slowly at 0°C (32°F). Chlorine and most fungicides are not very effective against this organism. The best means of control are orchard sanitation and preventing orchard soil from entering the drench or dump tank water. Leave ground fruit in the orchard, place field bins on trailers in the field, and use a fresh water prerinse of loaded bins and trailer prior to the drench system.

CORE ROT

Core rot is a disease in which one or more of a series of fungi attack the core area of the apple fruit. The disease may begin in the field or during storage. Inoculation of the core area can occur during petal fall in the orchard or during drenching of the fruit. The disease may be restricted to the seed cavity or may involve the apple flesh and eventually the entire apple. Core rots present a marketing challenge because they are not visible externally, unless very severe. Efforts are under way to develop nondestructive methods for sorting out defective fruit during packing.

II. European Pears

MATURITY

In California, Bartlett pear standards utilize an index combining firmness and soluble solids content that is modified by fruit diameter and color (table 27.2). Most legal standards define minimum maturity; California also imposes a maximum maturity standard (minimum flesh firmness level) for Bartlett pears destined for processing. Many other pear varieties are picked on the basis of flesh firmness (table 27.3).

MATURITY VERSUS RIPENING

European pears that are allowed to ripen on the tree typically develop poor texture and lack juiciness and the characteristic flavor of the cultivar. Thus, they are harvested when physiologically mature but still quite firm, then ripened before processing or consumption. Freshly harvested Bartlett pears, especially those harvested early in the season, ripen slowly and unevenly and with poor eating quality if placed immediately into a ripening environment (13° to 24°C [55 to 75°F]) without prior time in cold storage. d'Anjou pears can remain hard and unripe for 50 to 60 days under the same conditions. However, the same fruit ripen quickly and uniformly if first stored at low temperature (–1° to 5°C [30° to 41°F]) for 2 to 8 weeks, depending upon the cultivar and harvest maturity. During cold storage, ethylene precursors form within the pear tissue so that when fruit are placed at ripening temperature they increase their ethylene production and ripen uniformly. Most European pears can be ripened without cold storage by applying ethylene to the freshly harvested fruit.

A conditioning treatment is often used for Bartlett and d'Anjou pears that are transported to market without sufficient cold storage to allow for uniform ripening. For Bartletts, warm, freshly harvested fruit are packed, exposed to 100 ppm ethylene at 20° to 25°C (68° to 77°F) for 24 hours, then forced-air cooled and transported to market. The fruit lose little flesh firmness during the treatment and do not become more subject to handling damage, but they ripen quickly and uniformly when warmed during marketing. d'Anjou pears are treated with ethylene for 2 to 3 days at near 20°C (68°F), with a goal of softening the pears to 11 to 12 lbf firmness prior to recooling and shipping, and these pears are not intended for long storage.

Table 27.2. California minimal maturity standards for Bartlett pears,

	Fruit firmness (lbf)	
Minimum soluble solids	Diameter 2⅜ to 2½ in (60.3 to 63.5 mm)	Diameter 2½ in (63.5 mm) and larger
< 10%	19.0 (84.5)	20.0 (89.0)
10%	20.0 (89.0)	21.0 (93.4)
11%	20.5 (91.2)	21.5 (95.6)
12%	21.0 (93.4)	22.0 (97.9)
13%	No maximum	No maximum

Source: California Pear Advisory Board, 1999

Table 27.3. Pear harvest firmness recommendations

	Flesh firmness (lbf)*		
Cultivar	Maximum	Optimum	Minimum
Anjou	15	13	11
Bartlett	19	17	15
Bosc	16	13	11
Comice	13	11	9
Hardy	11	10	9
Kiefer	15	13–14	12
Seckel	18	16	14
Winter Nelis	15	12.5	11

Note: *Measurements with penetrometer using an 8-mm (5⁄16-in) tip. Conversions: lbf × 2.2 = kgf; lbf × 4.448 = Newtons.

HANDLING

European pears are harvested by hand into large field bins. Most California Bartlett pears are packed within 2 days of harvest. However, in other growing areas, pears are frequently stored for weeks to many months in regular cold storage or CA storage prior to packing. Upon packing, fruit are dumped from bins using either dry, wet, or water immersion dumps. A presizer is used to remove undersized fruit to processing outlets. Most sorting is by hand, particularly for defects. Fruit are segregated into fresh and processing grades based on shape and surface defects. Frequently, over 50% of California Bartlett pears are diverted from a fresh-market sorting line to processing. (Some Bartlett pears are grown strictly for processing.) Sizing is accomplished with weight sizers or optical sizers.

Pears may be wrap-packed, tight-fill packed, tray-packed, or bagged. A large percentage of fresh-market California Bartlett pears are tight-fill packed into corrugated cartons. The remaining California Bartletts and most other pear varieties are either wrap-packed or tray-packed into corrugated cartons, although some wood cartons are still in use, especially internationally. A number of single or double layer cartons, some corrugated and others of reusable plastic, are gaining popularity. The corrugated cartons used in California are well ventilated to allow for efficient forced-air cooling; however, pear boxes from many other growing areas are not vented and may include a plastic liner. Bagging of pears is also increasing in popularity, particularly for marketing at consumer warehouse stores. A flow diagram for the handling of Bartlett pears (see fig. 27.1) shows the steps involved in fresh-market handling and processing of this commodity.

STORAGE

TEMPERATURE MANAGEMENT

Because pears are so sensitive to temperature effects, immediately following packing, California Bartlett pears are forced-air cooled prior to shipment or storage. For Bartlett pears, the recommended storage temperature is 0° to 0.5°C (32° to 33°F) for up to 1 month of storage and −1°C (30°F) if fruit is to be stored more than one month. The lowest safe storage temperature is related to the extent of temperature fluctuation in the room and the soluble solids content of the fruit. Freezing injury usually occurs first in the smallest pears with the lowest soluble solids content. Therefore, knowledge of the soluble solids content of the core tissue is necessary to predict the lowest safe storage temperature. Bartlett pears in California should be cooled to near storage temperature within 24 hours of harvest. The estimated maximum storage life for European pear cultivars stored in air at −1°C (30°F) is shown in table 27.4.

REDUCING WATER LOSS

Maintaining 95% RH in the storage room will prevent loss of moisture from the fruit during storage. In many commercial cold storages, this level of humidity is difficult to maintain. Humidity should be considered in the design and sizing of the refrigeration system. Even with the best system design, supplemental humidity may need to be added. During bin storage, wetting of wooden bins prior to loading, use of plastic bins, and use of plastic bin liners can help to reduce water loss from fruit during storage.

Using perforated polyethylene bags or liners within the packed box to maintain humidity, once a common practice, is now seldom done in California because it interferes with temperature management; but it is still used in many other growing areas. Wax or plastic coatings on corrugated containers are extensively used, when polyethylene liners are not used, to provide a moisture barrier for pear fruit.

CONTROLLED ATMOSPHERE STORAGE

Pears are second only to apples in the volume stored under controlled atmospheres (CA). Although CA storage of pears is used to a limited extent in California for pears, it is very common in other growing areas. Maintenance of the proper concentrations of O_2 and CO_2 are critical to successful CA storage, as is storage of fruit at the proper stage of maturity. Overmature fruit harvested toward the end of the harvest season is more subject to low O_2 or high CO_2 damage. Fruit harvested early in the harvest season is the best candidate for long-term CA storage. Recommended atmospheres for pear varieties are shown in table 27.4.

PHYSIOLOGICAL DISORDERS

SUPERFICIAL SCALD

D'Anjou, Packham, and Bartlett pears are susceptible to superficial scald, a disorder similar to storage scald in apples. Superficial scald develops during cold storage, but it may not become visible until after fruit are transferred to warm temperatures for ripening. It is a surface disorder that results in browning of the skin. Unlike storage scald in apples, pear susceptibility to superficial scald appears to be less dependent on fruit maturity. Treatment of freshly harvested fruit with an antioxidant such as Ethoxyquin can greatly reduce the incidence of superficial scald. Ethoxyquin is not registered (neither is DPA) for use on pears in California, but it is used in other growing

Table 27.4. Storage conditions and estimated maximum postharvest life of European and Asian pears stored in air or CA at −1° to 0°C (30° to 32°F)

Cultivar	Months in air	% O_2	% CO_2	Months in CA
		European Pears		
Anjou	6–7	1–2.5	0–0.5	7–8
Bartlett	2–3	1–2	0–3	3–5
Bosc	3–4	1–2.5	0.5–1.5	4–8
Comice	4	1.5–4	0.5–4	5–6
Forelle	4–5	1.5	0–1.5	6–7
Hardy	2–4	2–3	3–5	4–6
Packham	5–6	1.5–1.8	1.5–2.5	7–9
		Asian Pears		
Chojuro	2–3	2	1–2	3–4
Kosui	2–3	1–2	0–2	3–4
Tsu Li	2–4	1–2	0–3	3–5
20th Century	3–4	1–3	0–1	5
Ya Li*	2–3	4–5	0–3	3–4

Source: Adapted from Hardenburg et al. 1986; Richardson and Kupferman 1997.

*Ya Li may show chilling injury at temperatures less than 5°C (41°F).

areas. CA storage can reduce the incidence of storage scald, especially when low O_2 is used (1%), but with low O_2, care should be taken to keep CO_2 below 0.5%. More research is needed to address fruit tolerance issues as well as the effectiveness of low-O_2 CA for scald control.

SENESCENT SCALD

Senescent scald develops in pears that have been stored beyond their potential postharvest life. The background color of scalded fruit changes from green to yellow during storage, and the fruit lose their capacity to ripen. Fruit from very early or late harvest, fruit suffering delayed cooling, and fruit held at too high a storage temperature are all more susceptible to senescent scald. Symptoms begin on the fruit surface but can progress into the flesh during ripening. Proper harvest maturity, good temperature management, and avoiding storing for too long are all important in minimizing senescent scald of pears. CA storage can delay fruit senescence and thus delay development of senescent scald.

CORK SPOT

Similar to bitter pit in apples, cork spot occurs in tissue low in calcium or with a high potassium to calcium ratio. Patches of corky brown tissue, usually near the calyx end, occur either just beneath the skin or deep in the flesh. Affected pears become partly yellow and exhibit premature ripening. d'Anjou and Packham's Triumph pears are highly susceptible. Preharvest calcium sprays are beneficial, especially late in the season, but there is a risk of phytotoxicity.

CARBON DIOXIDE OR LOW OXYGEN INJURY

Pears are much less tolerant of CO_2 than apples. CO_2 injury is evident as browning in the core area. Cavities may develop in the browned tissues. The susceptibility of pears to CO_2 injury increases with advanced maturity, delayed storage, and low O_2 levels in the atmosphere. Fruit grown in a cool season have a greater susceptibility to CO_2 injury. Low-O_2 injury can occur at less than 1% O_2 and is manifested as a browning in the core area that may be tinged with pink. Fruit with advanced maturity are more susceptible.

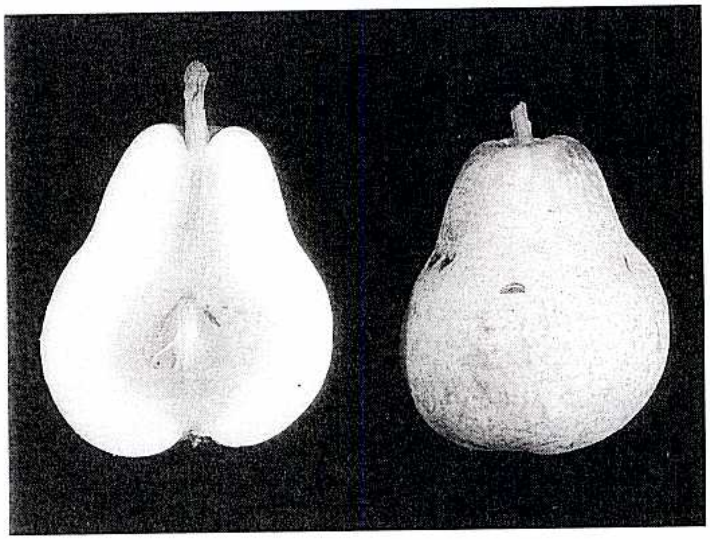
CORE BREAKDOWN

Pears can suffer losses due to various core breakdown problems (sometimes called internal breakdown or brown core). Symptoms are browning and softening of the tissue in and around the fruit core (fig. 27.5). Late-harvested fruit are most susceptible to these disorders. Symptoms may develop in storage or during subsequent ripening. A range of similar symptoms associated with specific cultivars or handling and storage treatments have been described by various researchers.

Flesh breakdown that develops during storage and ripening can be reduced by good postharvest temperature management. This should include rapid movement from tree to cooler, rapid cooling, and maintenance of the proper low storage temperature. When climatic, cultural, or maturity factors predispose the fruit to breakdown, the problem may be unavoidable; however, storage life may be lengthened and intensity of the disorder can be reduced by good temperature management. In some tests with watery breakdown of Bartlett pears in California, late-season, high-maturity pears developed no breakdown if fruit was cooled within 1

Figure 27.5

Core breakdown in senescent Bartlett pear.



day of harvest, as compared with 5% breakdown with 2-day cooling, and over 10% breakdown with 3-day cooling. In other tests with similar pears that were cooled within 1 day of harvest, stored for 5 weeks, and then ripened, breakdown incidence was 0% after –1°C (30°F) storage, almost 2% after 0.5°C (33°F) storage, and about 3.5% after 2°C (36°F) storage.

PREMATURE RIPENING

Reports from cool-climate production areas describe a fruit breakdown in Bartlett pears caused by premature ripening. In Oregon, this problem can develop when daytime high temperatures do not exceed 21°C (70°F) and night temperatures are no higher than 7°C (45°F) for 2 days, 10°C (50°F) for 9 days, or 13°C (55°F) for 21 days. Affected fruit develop a pink color around the calyx (blossom) end. Night temperatures above 13°C (55°F) or day temperatures above 32°C (90°F) prevent premature ripening. Bartlett pears grown in cool climates also tend to soften faster and be more susceptible to core breakdown. By contrast, d'Anjou pears grown in warm climates have a higher incidence of mealy breakdown of the flesh.

WATERY BREAKDOWN

A problem associated especially with Bartlett pear, watery breakdown involves soft, watery breakdown in portions of the fruit, usually without brown discoloration during its early stages. This enzymatic softening can affect any part of the fruit and probably results from severe physiological stress on the fruit. In some seasons in California, this disorder is responsible for loss of as much as 10% of fruit destined for processing. Fast cooling and low storage temperatures (avoiding freezing) are effective in minimizing the problem.

ROLLER BRUISING (BRUSH BURN, FRICTION DISCOLORATION)

This can occur whenever fruit have freedom to move, rub, or vibrate against a hard surface such as bins or package surfaces, packing belts, or other fruit. Pears are generally more susceptible to roller bruising damage than are apples. As Bartlett and d'Anjou pears remain in storage, they normally become more susceptible to roller bruising injury, and if packaging does not occur within 1 to 2 weeks of harvest, special care must be taken to avoid fruit injury. Data on other cultivars are unavailable. Avoidance of roller bruising involves prevention of fruit rubbing or vibrating at all stages of handling from harvest to market.

IMPACT BRUISING

Injuries can follow any impact of the fruit, and incidence and severity of bruises increase with increasing height of drop of the fruit. Impact bruising is important because of its effect on fruit appearance, and because the injury induces higher respiratory activity of the tissue, thus reducing storage life. Some reports suggest that symptoms are less apparent in fruits that are impacted after CA storage.

III. Asian Pears

Asian pears comprise a large group of pears (*Pyrus serotina*) that are crisp in texture and ready to eat at harvest. Asian pears do not markedly change texture after harvest or storage, as do European pears. Hundreds of varieties are grown in Asia, and more than 25 varieties are known in California. Asian pears are also called apple pears, salad pears, Nashi (Japanese for "pear"), and Oriental, Chinese, or Japanese pear.

In the United States, most Asian pears are grown in California, Oregon, and Washington. There are three basic types: round or flat fruit with green to yellow skin (20th Century), round or flat fruit with bronze-colored skin and a light bronze russet (Shinko, Hosui), and pear-shaped fruit with green or russet skin (Ya Li).

HARVEST

Asian pears are harvested in California from mid-July through September, depending on the variety. Harvest maturity is usually assessed by background color and soluble solids content. Studies have shown that background color is best related to the storage potential of the fruit. Other studies have indicated that a combination of starch index, firmness, and soluble solids would provide a good index. Immature fruit usually have poor flavor quality, while overmature fruit are more susceptible to surface marking and storage disorders.

Asian pears appear highly susceptible to surface damage from abrasions to the skin. Careful handling from harvest to consumption is necessary to avoid unsightly fruit damage manifested as brown or black markings on the fruit surface. Pickers may need to wear rubber or soft cotton gloves to avoid fruit injury. Padded, clean picking buckets are essential, and efforts must be made to avoid stem punctures. Often, stems are clipped close to the stem bowl. It is recommended that Asian pears be handled similarly to tree-ripened soft fruit. Handling steps should be minimized. Often, fruit are sized by eye and packed by hand. Many Asian pears are wrapped, using paper or plastic materials, and some are packed into plastic trays or foam punnets. Fruit are often packed one or two layers deep, and padding is added to the box to secure the fruit and prevent movement during transit which would result in roller bruising.

STORAGE

Some varieties can be stored 1 to 3 months at 0°C (32°F) without problems. Hosui and Shinko became spongy and developed storage rots after 2½ months of storage at 0°C (32°F). After 4 months of storage, core browning developed.

Based on limited studies, it appears that the magnitude of CA benefits for Asian pears is cultivar-specific and is generally less than that for European pears and apples. CA may extend the storage life of some Asian pear cultivars by about 25% relative to storage in air. Recommended CA conditions are shown in table 27.4. Care should be taken to avoid low-O_2 or high-CO_2 injury, as described below.

Some cultivars, such as 20th Century, Kosui, and Niitaka, produce very little ethylene and are nonclimacteric. Other cultivars, such as Tsu Li, Ya Li, Chojuro, Shinsui, Kikusui, and Hosui, are climacteric and produce between 1 and 14 µl/kg·hr ethylene. Exposure of climacteric cultivars to greater than 1 ppm ethylene accelerates loss of green color and slightly increases softening at 20°C (68°F). The effects of ethylene at 0°C (32°F) are minimal.

PHYSIOLOGICAL DISORDERS

LOW OXYGEN INJURY

Discolored surface depressions resulting from exposing 20th Century pears to 1% O_2 for 4 months at 0°C (32°F) and from exposing Ya Li and Tsu Li pears to 1% O_2 for 2 months, 2% O_2 for 4 months, or 3% O_2 for 6 months at 0°C (32°F).

HIGH CARBON DIOXIDE INJURY

Exposure to high levels of CO_2 can cause fruit to develop core or medial flesh browning, which may contain cavities in severe cases as a result of tissue death and subsequent desiccation. Ya Li pears may exhibit CO_2 injury after exposure to 5% CO_2 for 6 weeks at 0°C (32°F).

FLESH SPOT DECAY OR INTERNAL BROWNING

Development of brown to dark brown water-soaked areas in the core and flesh occurs either on the tree or during the first 2 to 6 weeks of cold storage. Despite the name often used to describe this disorder, it is physiological in nature and not due to the activity of decay organisms. Harvesting fruit prior to the overmature stage is the best means of controlling this disorder. Studies with Ya Li and Seuri pears indicated that fruit should be harvested before they change color from green to light green-yellow. Fruit harvested yellow developed internal browning within 1 month of cold storage. Results from New Zealand indicate that delaying fruit cooling 36 to 48 hours after harvest reduces the incidence of flesh spot decay.

WATER CORE

A disorder similar to that which occurs in apples, glassy, water-soaked areas develop in the flesh either on the tree or, less commonly, in storage. The affected tissue may be clear and sweet-tasting or brown and bitter-tasting. Avoid harvesting overripe fruit to avoid this disorder.

CORE BROWNING

The core of the fruit turns brown or black and senesces while the flesh remains healthy. Overmature fruit are more prone; therefore harvest maturity is the best means of control. This disorder may be related to flesh spot decay.

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