33

Postharvest Handling Systems: Fruit Vegetables

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The fruit vegetables comprise two important groups that can be distinguished by the stage of maturity at harvest:

Immature fruit vegetables:

- Legumes: snap, lima, and other beans; snow pea, sugar snap and garden peas
- Cucurbits: cucumber, soft-rind or summer squashes, chayote, bitter melon, luffa
- Solanaceous vegetables: eggplant, tomatillo
- Others such as okra and sweet corn

Mature fruit vegetables:

- Cucurbits: cantaloupe, honeydew, and other muskmelons; watermelon, pumpkin, hard-rind or winter squashes
- Solanaceous vegetables: mature-green and vine-ripe tomatoes, mature-green and ripe peppers

With the exceptions of peas and broad beans, fruit vegetables are warm-season crops. All the fruit vegetables, with the exception of sweet corn and peas, are subject to chilling injury. Fruit vegetables are not generally adaptable to long-term storage. Exceptions are the hard-rind (winter) squashes and pumpkin. This chapter discusses the general postharvest requirements and handling systems for this group of commodities. The immature fruit vegetables and the mature fruit vegetables are discussed separately.

IMMATURE FRUIT VEGETABLES

MATURITY INDICES

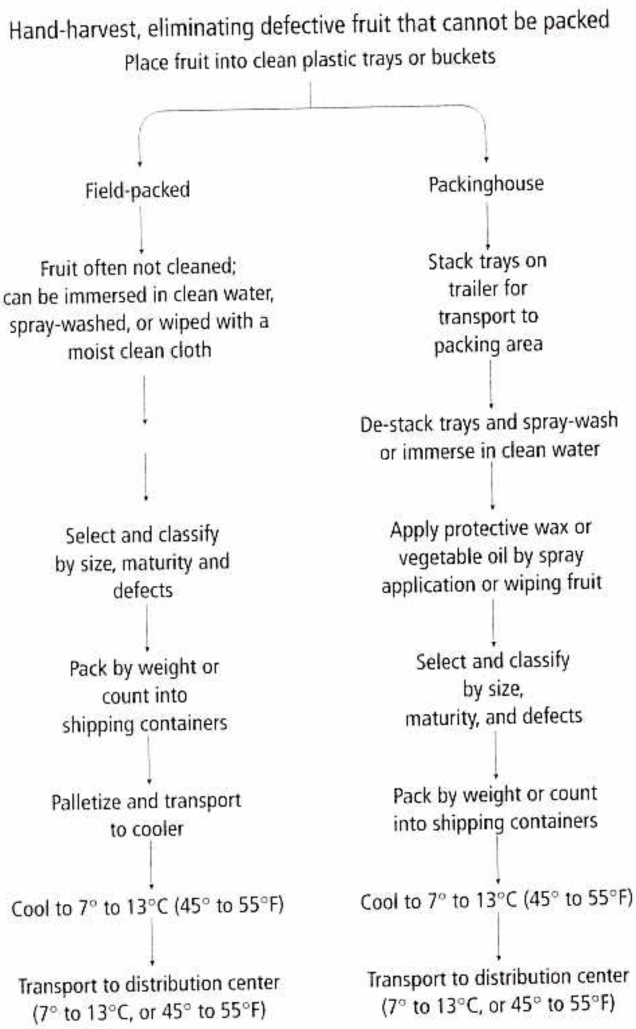
The harvest index for most immature fruit vegetables is based principally on size and color. Immature soft-rind squashes, for example, may be harvested at several sizes or stages of development, depending upon market needs. Fruit that are too developed when harvested are of inferior quality and show undesirable seed development and color changes after harvest. Because these vegetables are growing very rapidly during the harvest period, frequent harvests are necessary to ensure harvesting at the desired stage of maturity. These vegetables are subject to very rapid compositional changes (e.g., conversion of sugars to starch in peas and sweet corn, fiber development in okra, increases in sugars and acids in tomatillo), high rates of water loss and loss of firmness (beans and summer squash), and rapid color changes (cucumbers, bitter melon). It is, therefore, extremely important to cool them as soon as possible after harvest to minimize undesirable postharvest changes.

HARVEST

Most of the immature fruit vegetables are harvested by hand, with pickling cucumbers, snap beans, peas, and sweet corn being the major exceptions. Mechanically harvested peas and sweet corn may be harvested at night when product temperatures are the coolest. Most of these vegetables have very tender skins that are easily damaged during harvest and handling. Special care must be taken in all handling operations to prevent product damage and the associated loss of visual appearance, increased water loss, and increased decay. Minimizing handling transfers of the vegetables is key to reducing physical damage.

Figure 33.1

Postharvest handling of immature fruit vegetables such as summer squash, eggplant, and cucumbers.



FIELD-PACKING

Field-pack operations, in which grading, sorting, sizing, packing, and palletizing are carried out in the field, minimize product handling (fig. 33.1). Mobile packing facilities are commonly towed through the fields for eggplant, cucumber, and summer squashes. An alternative is to have small shaded packing tables at the ends of rows. The vegetable is harvested into buckets or plastic containers and then packed directly from the harvest container. This reduces product damage and, therefore, increases pack-out yields. Handling costs are also reduced in field-pack operations. One difficulty with field packing is the need for increased supervision to maintain consistent quality in the packed product. Proper product sanitation and cleaning is difficult with field-packing. A further consideration with field-pack operations is that small lots of packed product need to be frequently transported to a cooling facility to minimize water loss and other undesirable postharvest changes.

PACKINGHOUSE OPERATIONS

A centralized packinghouse can result in packed product of a more consistent quality (fig. 33.1). However, the product is usually harvested and dumped into a larger container or bin, which in turn is dumped onto the packing line. If a water dump is used, and the water recycled, chlorine or another sanitizing agent needs to be used to avoid microbial contamination. In small operations, product may be packed directly from the harvest container, as is done with field packing. If plastic crates are used, the product can be batch-washed or dipped to remove surface dust on the product. Although using a packinghouse may permit a more uniform pack-out, it also usually causes more damage. In addition to dumping injuries, dirt on conveyors or tables can easily scratch and damage the skin of the tender immature vegetables. However, a packinghouse operation permits use of fungicides and waxes or other treatments that are not easily accomplished in the field.

After an initial sorting or selection for removing cull and other defective fruit, food-grade waxes, but more commonly vegetable oils, may be applied to cucumber, eggplant, and summer squash. Postharvest fungicides are seldom applied to these vegetables. Application of wax and postharvest fungicides must be indicated on each shipping container. European cucumbers are frequently shrink-wrapped rather than waxed.

Fruit may be classified by quality into two or more grades according to U.S. standards, California grade standards, or a shipper's own more rigorous grade standards. The immature fruit vegetables are often sized manually, although weight and diverging roller sizers are sometimes used for cucumbers. Okra, cucumber, and legumes are commonly weight- or volume-filled into shipping containers. They and the other immature fruit vegetables may be place-packed into shipping containers by count. Those that are place-packed are often sized during the same operation.

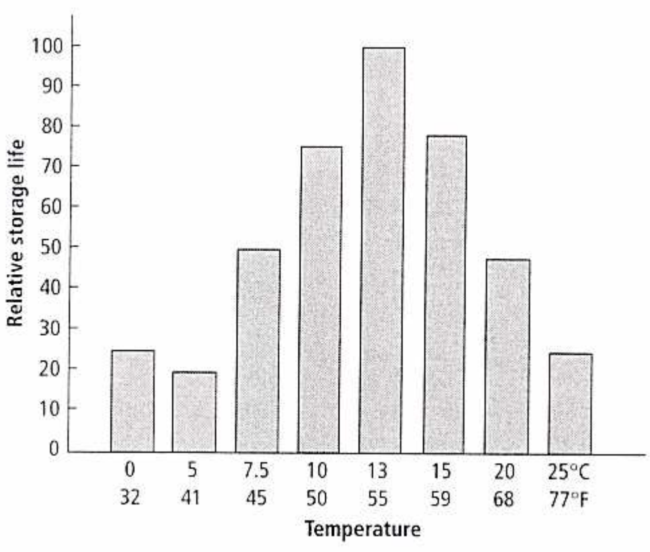
Table 33.1. Typical chilling injury symptoms on fruit vegetables

Immature fruit vegetables	Product Symptoms
Beans (snap, lima, and long)	Darkening or dullness if stored below 5°C (41°F); rusty brown lesions if stored at 5°–7.5°C (41°–46°F); discoloration of seeds; increased susceptibility to decay; surface pitting
Cucurbits (bittermelon, luffa, fuzzy melon, cucumber, summer squash)	Surface pitting followed by brown or black lesions; water-soaked areas; increased susceptibility to decay
Eggplant	Brown, discolored areas; surface pitting leading to large sunken areas; calyx discoloration; seed and flesh browning; off-odors
Okra	Darkening and discoloration; pitting, water-soaked areas; increased susceptibility to decay
Mature fruit vegetables	
Cantaloupe	Only slightly sensitive to chilling injury; if stored below 2°C (36°F) for extended periods, fruit can show surface browning and increased decay after removal from storage.
Honeydew and other melons	Failure to ripen normally; water-soaked areas, increased susceptibility to decay; dull or bronzed surface
Peppers	Surface pitting leading to large sunken areas; seed browning; calyx discoloration; water-soaked tissue; increased susceptibility to decay, especially Alternaria
Tomatoes	Short exposures (4–6 days) to <10°C (50°F) results in poor flavor; longer exposures cause failure to ripen normally, pitting, shriveling, softening, and increased susceptibility to decay, with Alternaria rot a diagnostic symptom
Watermelon	Surface pitting and sunken areas that dehydrate upon removal from storage; off-flavors; internal brown discolored areas on the rind
Winter squash and pumpkins	Weakening of tissue, especially on the stem end with increased susceptibility to decay, particularly Alternaria rot.

Source: Adapted from Hardenburg et al. 1986; Kader 1996; Zong et al. 1992.

Figure 33.2

Shelf life of cucumber in relation to storage temperature.



Except for sweet corn, the immature fruit vegetables are often handled in low-volume operations, where palletizing is not common because of lack of forklifts. In these cases, the products are palletized at a centralized cooling facility or as they are loaded for transport. Palletizing is usually done after hydrocooling or package-ice cooling, but before forced-air cooling. In field-pack operations, palletizing is generally done in the field.

COOLING

Various methods are used for cooling the immature fruit vegetables. Forced-air cooling can be used for virtually all these vegetables, but it is most commonly used for beans, cucumbers, peas, and soft-rind squashes. Evaporative cooling is used to a limited extent on green beans, squashes, and eggplant, all particularly sensitive to water loss. Beans, sweet corn, and okra are hydrocooled before or after packing, depending on whether they are packed in a waxed or other water-resistant container. Sweet corn is routinely liquid-iced; less commonly, package ice is used as a supplement to hydrocooling. After cooling, the packed product is then temporarily stored in a cold room or transported to a centralized short-term storage facility at a distributor.

STORAGE AND TRANSPORT TEMPERATURES

Peas and sweet corn are the only immature

Figure 33.3

External (left) and internal (right) quality of bitter melon in relation to storage temperature.

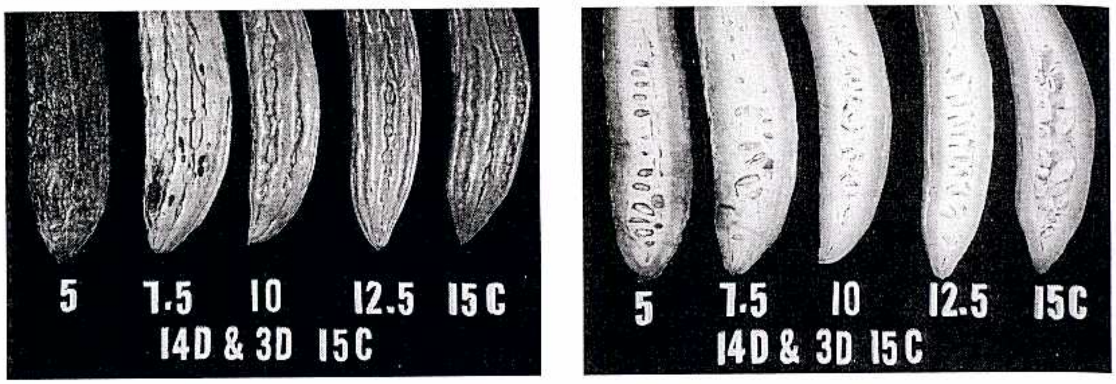


Figure 33.4

Rusty brown lesions as symptoms of chilling injury on green beans. About 7 days at 5°C (41°F) are required to obtain these symptoms.

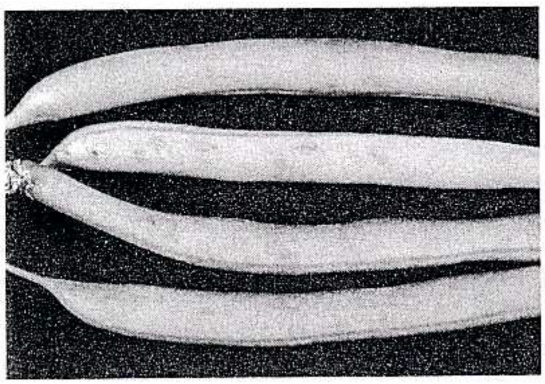
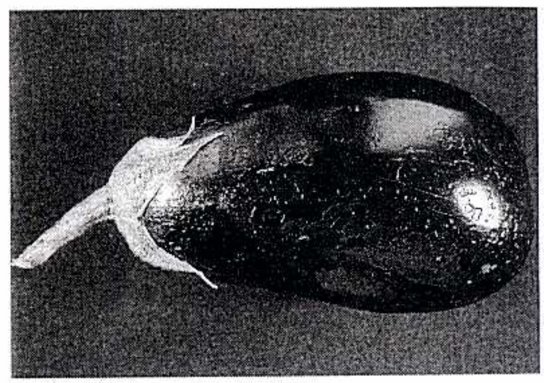


Figure 33.5

Typical external symptoms of chilling injury on eggplants include discoloration of the calyx, pitting, and discoloration of the fruit surface.

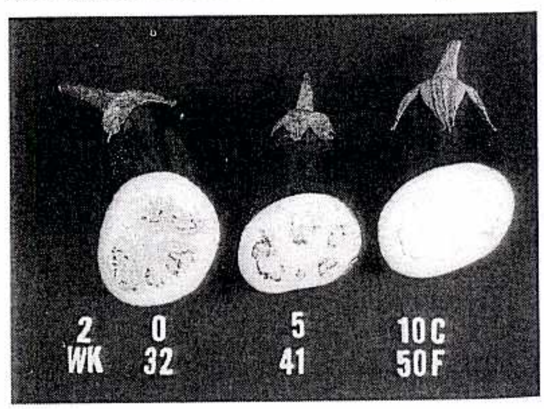


fruit vegetables that should be stored at 0°C (32°F) and 95% RH. A temperature of 5°C (41°F) results in a more rapid loss of sugar than storage at 0°C (32°F), even in supersweet corn varieties (see fig 33.7). All the other immature fruit vegetables are chilling sensitive (table 33.1). Chilling injury occurs when they are stored below the recommended temperature; chilling injury is cumulative, and its severity depends on the temperature and the duration of exposure (figs. 33.2, 33.3, 33.4, 33.5, 33.6). The chilling susceptibility of cucumbers, summer squash, eggplants, and green beans may vary greatly depending on the variety. For example, table 33.2 shows that Chinese eggplants are more tolerant to storage at chilling temperatures than are globe or Japanese-type eggplants.

The optimal product temperatures with 90 to 95% RH for short-term storage and transport of the chilling-sensitive immature fruit vegetables are

Figure 33.6

External and internal symptoms of chilling injury on globe eggplant stored 2 weeks at different temperatures.



- Eggplant, cucumber, soft-rind squashes, okra: 10° to 12.5°C (50° to 55°F).
- Lima beans, snap beans: 5°to 8°C (41° to 46°F)

Table 33.2. Time required for development of visible chilling injury symptoms in three types of eggplant

Temperature		Days required for any chilling symptom to appear		
°C	°F	Globe type cv. Black Bell	Japanese type cv. Millionaire	Chinese type cv. unknown
0	32	1–2	—	2–3
2.5	36	4–5	5–6	5–6
5	41	6–7	8–9	10–12
7.5	45	12	12–14	15–16
10	50	No symptoms	No symptoms	No symptoms

Note: The calyx is more sensitive than the fruit surface to chilling injury.

Table 33.3. CA and MA requirements and recommendations for fruit vegetables

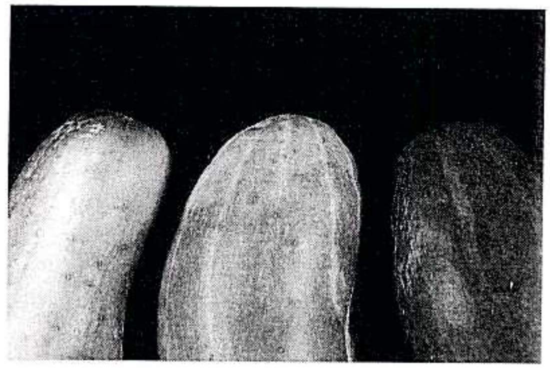
	Temperature		Atmosphere	
Product	Optimum °C (°F)	Range °C (°F)	% O_2	% CO_2
Immature fruit vegetables				
Beans, green, snap	8 (46)	5–10 (41–50)	2–3	4–7
Beans, processing	8 (46)	5–10 (41–50)	8–10	20–30
Cucumber, fresh	12 (54)	8–12 (46–54)	1–4	0
Cucumber, pickling	4 (40)	1–4 (33–40)	3–5	3–5
Okra	10 (50)	7–12 (45–54)	Air	4–10
Peas, sugar	0 (32)	0–5 (32–41)	2–3	2–3
Sweet corn	0 (32)	0–5 (32–41)	2–4	5–10
Mature fruit vegetables				
Cantaloupe	3 (38)	2–7 (36–46)	3–5	10–20
Pepper, bell	8 (46)	5–12 (41–54)	2–5	2–5
Pepper, chili	8 (46)	5–12 (41–54)	3–5	0–5
Pepper, processing	5 (41)	5–10 (41–50)	3–5	10–20
Tomato, mature-green	12 (54)	12–20 (54–68)	3–5	2–3
Tomato, partially ripe	10 (50)	10–15 (50–59)	3–5	3–5

Source: Adapted from Saltveit 1997.

Chilling injury is a serious practical problem for these products, compounded by the fact that they are frequently shipped in small volumes as part of mixed loads. One option to reduce exposure may be the use of pallet blankets to maintain a slightly warmer temperature around the product. Another practical option is minimizing the period of exposure. In many cases, as illustrated in table 33.2, short periods at chilling temperatures are not sufficient to cause permanent physiological damage that leads to chilling symptoms.

Figure 33.7

Yellowing of cucumbers due to ethylene exposure. The fruit were exposed to air (fruit on right) or 10 ppm ethylene (2 fruit on left) for 2 days and then stored an additional 5 days at 12.5°C (55°F).



ETHYLENE EXPOSURE

Because the immature fruit vegetables are often produced in small volumes, most are transported in trucks as part of mixed-load shipments. Often these vegetables are shipped with commodities that produce ethylene, and many of them, such as cucumber, bitter melon, and eggplant are very sensitive to ethylene exposure. Ethylene exposure can favor decay development, cause discoloration and abscission of the calyx in eggplant, and de-greening of cucumbers (fig. 33.7).

MODIFIED ATMOSPHERES

Modified atmospheres (MA) are seldom used commercially for immature fruit vegetables, although extension of shelf life can be demonstrated for some (see table 33.3). Short-term holding of green beans under high-CO_2 atmospheres is beneficial to reduce brown discoloration before processing, and MA help retain green color in immature fruit vegetables such as cucumber and bitter melon. Figure 33.8 shows changes in the visual quality of sweet corn and sugar content of the kernels in relation to air or CA storage.

MATURE FRUIT VEGETABLES

MATURITY INDICES

The harvest index for mature fruit vegetables depends on several characteristics, and proper harvest maturity is the key to adequate shelf life and good quality of the ripened fruit. The principal harvest indices for cantaloupe

Figure 33.8

Quality changes in hybrid sweet corn stored at 0°C (32°F) or 5°C (41°F) in air or at 5°C in a controlled atmosphere of 3% O_2 and 10% CO_2.

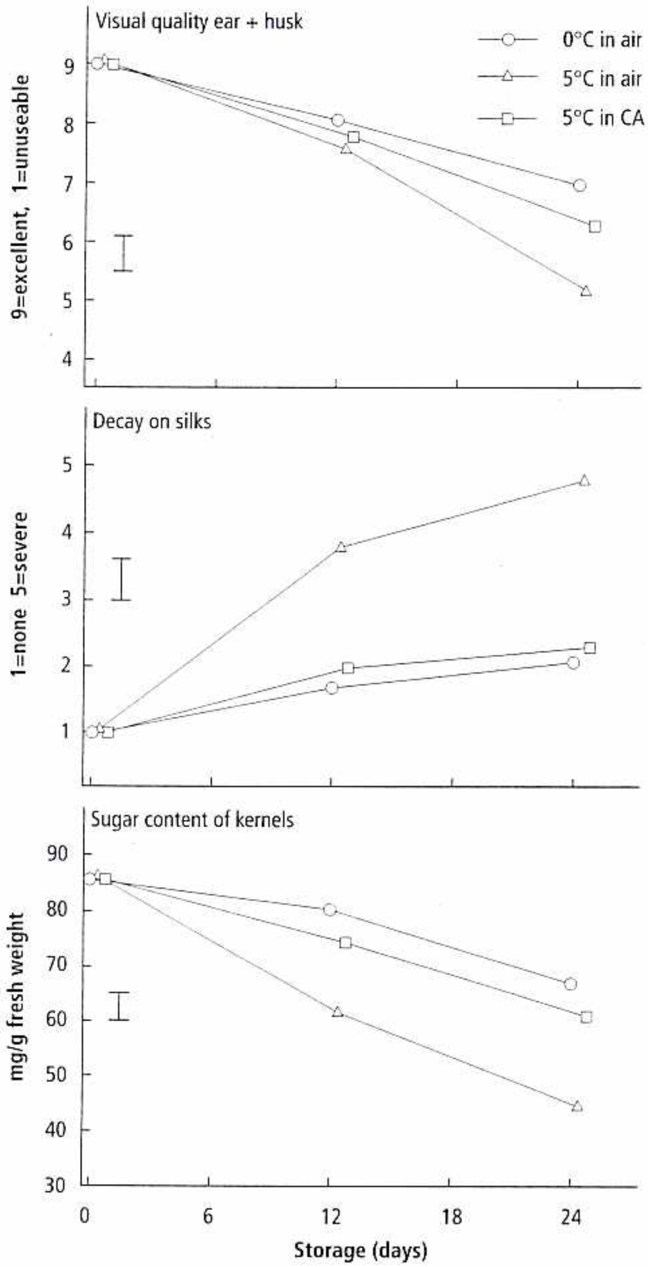
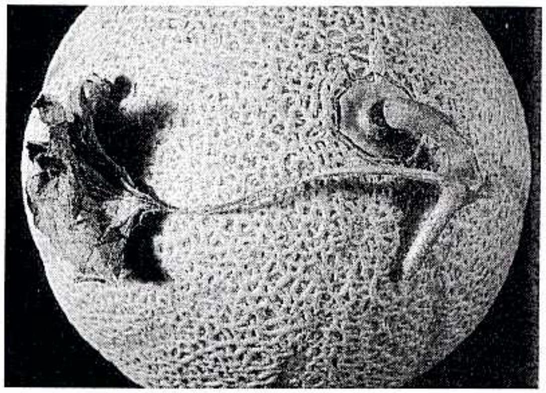


Figure 33.9

Cantaloupe exhibiting harvest indices: well-developed abscission zone, well-developed net, ground color change from green to green-yellow, and death of the subtending leaf.



are green-yellow surface color, a well-developed net, and the formation of the abscission zone (fig. 33.9). Maturity and ripeness classes for honeydew melon are described in table 33.4 and those for tomato are shown in table 33.5.

HARVEST

The mature fruit vegetables are harvested by hand. Some harvest aids may be used, including pickup machines and conveyors for melons. Cantaloupes are sometimes harvested with "sack" crews, who empty the melons into bulk trailers, but most cantaloupes are field-packed, and physical handling is minimized. Mixed melons, which are very susceptible to mechanical injury, may also be field-packed but are often harvested and placed in lined low-volume trailers for transport to a packing facility. Mature-green tomatoes are usually hand-harvested into buckets that are emptied into field bins or gondolas. Almost all fresh-market tomatoes grown in California are bush-type, and the plants are typically harvested once, sometimes twice. At the time of harvest, 5 to 10% of the tomatoes should have external pink or yellow color fruit, which are harvested and packed as vine-ripes. Harvesting the field at this time maximizes the proportion of mature-green fruit that can ripen into acceptable eating quality and minimizes immature fruit. Immature fruit respond to ethylene during ripening but have poor eating quality because of low levels of sugars and acids. Some varieties of cluster tomatoes may lack uniform quality at the ripe stage due to differences in maturity of fruit on the raceme. The least mature fruit on the raceme should have some external red color (breaker stage at minimum) at time of harvest.

Many of the mature fruit vegetables are hauled to packinghouses, storage, or loading facilities in bulk bins (hard-rind squashes, peppers, pink tomatoes), gondolas (mature-green tomatoes and peppers), or bulk field trailers or trucks (muskmelons, hard-rind squashes).

Table 33.4. Maturity and ripeness classes for honeydew melons*

Class	Characteristics	Internal ethylene (ppm)	Pulp firmness† (kgf)	Soluble solids (%)
0 = Immature	Greenish external color; peel fuzzy/hairy; no aroma; may be harvested by mistake	—	—	—
1 = Mature, unripe	External color white with greenish aspect; peel slightly fuzzy/hairy; no aroma; melon splits when cut, pulp is crisp; minimum commercial harvest maturity; minimum 10% soluble solids	0.8	3.1	10
2 = Mature, ripening	External color white with trace of green; peel not fuzzy, slightly waxy; slight to noticeable aroma; melon splits when cut, flesh crisp; harvest for long-distance markets	5.2	2.1	11–12
3 = Ripe	External color creamy white to pale yellow; peel waxy; noticeable aroma; stem may begin to separate from fruit; flesh firm, when sliced does not split; ideal eating; harvest for local markets	27.1	1.5	12–14
4 = Overripe	External color yellow; soft at blossom end; very aromatic; fruit is separated from stem; flesh soft, somewhat water soaked in appearance	29.4	1.1	14–15

Source: Adapted from Pratt 1971.

Notes: * Values averaged from 5 honeydew varieties. † Firmness measured using a 1.1-cm diameter probe on a 5-kgf penetrometer.

Table 33.5. Maturity and ripeness classes for fresh-market tomatoes

Class	USDA classification	Description
Immature	—	Seed cut by a sharp knife on slicing the fruit; no jellylike material in any of the locules; fruit is more than 10 days from breaker stage
Mature-green A	1	Seed fully developed and not cut on slicing fruit; jellylike material in at least one locule; fruit is 6 to 10 days from breaker stage; minimum harvest maturity
Mature-green B	1	Jellylike material well developed in locules but fruit still completely green; fruit is 2 to 5 days from breaker stage
Mature-green C	1	Internal red coloration at the blossom end, but no external color change; fruit is 1 to 2 days from breaker stage
Breaker	2	First external pink or yellow color at the blossom end
Turning	3	More than 10% but not more than 30% of the surface, in the aggregate, shows a definite change in color from green to tannish-yellow, pink, red, or a combination thereof
Pink	4	More than 30% but not more than 60% of the surface, in the aggregate, shows pink or red color
Light red	5	More than 60% of the surface, in the aggregate, shows pinkish-red or red, but less than 90% of the surface shows red color
Red	6	More than 90% of the surface, in the aggregate, shows red color
Full red	—	Fruit has developed full final red color; fruit is more aromatic and softer than at red stage

Harvesting at night or near daybreak, when products are the coolest, is sometimes used for cantaloupes. Night harvest may reduce the time and costs of cooling products, may result in better and more uniform cooling and helps maintain product quality. Fluorescent lights attached to mobile packing units have permitted successful night harvesting of cantaloupe in California, although this is not done frequently due to difficulties in scheduling harvest crews.

FIELD VERSUS SHED PACKING

For many of the mature fruit vegetables, grading, sorting, sizing, packing, and palletizing are carried out in the field (figs. 33.10 and 33.11). The products are then transported to a central cooling facility.

Figure 33.10

Mobile packing unit for field-packing of cantaloupe.

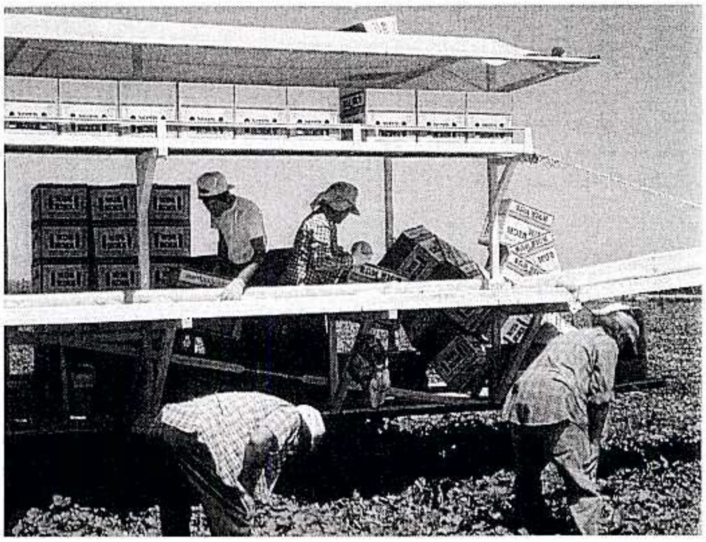


Figure 33.11

Postharvest handling of melons.

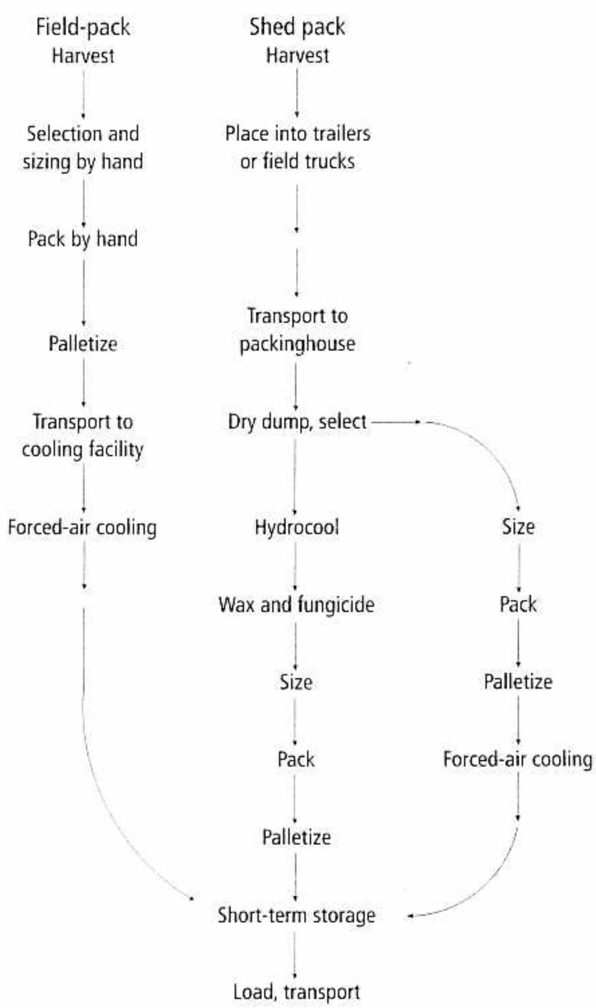
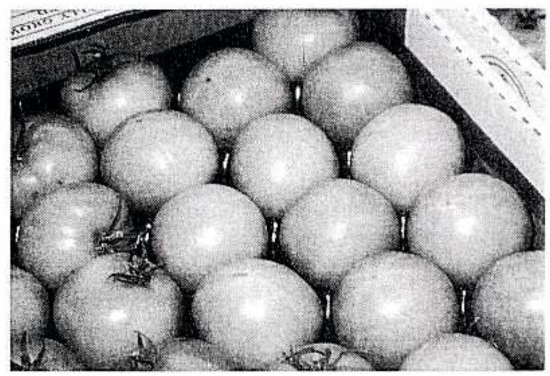


Figure 33.12

Harvest of greenhouse vine-ripe tomatoes into plastic crates on a railed cart.

Figure 33.13

Hand-packed single-layer carton of vine-ripe tomatoes. Some fruit were turned to show undesirable variation in ripeness within a single tray.



Mobile packing facilities are commonly towed through the fields for cantaloupe, honeydew melon, peppers, and vine-ripe tomatoes. Handling costs are reduced in field-pack operations, and there is much less handling of products than in packinghouses. In melons, for example, field packing means less rolling, dumping, and dropping and thus helps reduce the "shaker" problem, in which the seed cavity loosens from the pericarp wall. It also reduces scuffing of the net, which reduces water loss, a major cause of firmness loss in cantaloupes. One difficulty with field packing, however, is the need for increased supervision to maintain consistent quality in the packed product. Field packing is not generally used for commodities that require classification for both color and size, such as tomato. For greenhouse tomatoes or

Figure 33.14

Postharvest handling of vine-ripe tomatoes.

Hand-harvest
Eliminating defective fruit that cannot be packed

↓

Place fruit into clean vented plastic trays
Stack trays for transport to packing area

↓

De-stack trays and wash tomatoes
Submerge briefly into a clean water followed by a chlorinated water bath or shower wash or use a moist clean cloth to remove dust

↓

Drain tray and allow tomatoes to air-dry before further handling

↓

Packer selects fruit from tray and classifies individual fruits (3 sizes, 2 or 3 color stages)
Places fruit into shipping container (single- or double-layer carton box; paper or foam pad between layers)

↓

Open containers move by gravity conveyer and are palletized after inspection for final quality and closing of carton

↓

Pallets are strapped vertically to reduce vibration injury during transport

↓

Palletized fruit are cooled to 10° to 13°C (50° to 55°F) as soon as possible (at packing site) and transported (trailer or air)

field-grown vine-ripes, a simplified handling system is used that minimizes handling steps much as is done in field packing operations (figs. 33.12, 33.13, 33.14). To keep cluster tomatoes on their stems, handling should be minimal. The racemes are cut carefully and placed in crates, from which they are subsequently sorted and packed.

PACKINGHOUSE OPERATIONS

Loaded field vehicles should be parked in shade to prevent product warming and sunburn damage. Products may be unloaded by hand (some muskmelons, watermelon), dry-dumped onto sloping, padded ramps (cantaloupe, honeydew melon, sweet peppers,) or onto moving conveyor belts (mature-green tomatoes), or wet-dumped into tanks of moving water to reduce physical injury (melons, tomatoes, peppers) (figs. 33.15, 33.16). Considerable mechanical damage occurs in dry-dumping operations; bruising, scratching, abrading, and splitting are common examples. The water temperature in wet-dump tanks for tomatoes should be slightly warmer (5°C, or 10°F) than the product temperature to prevent uptake of water and decay-causing organisms into the fruits. The dump tank water needs to be chlorinated (see chapter 17). An operation may have two tanks separated by a clean water spray to improve overall handling sanitation.

PRESIZING, SORTING, AND SELECTION

For many commodities, fruit below a certain size are eliminated manually or mechanically by a presizing belt or chain. Undersize fruit are diverted to a cull conveyor or used for processing. The purpose of the sorting step is to eliminate cull, overripe, misshapen, and otherwise defective fruit and separate products by color, maturity, and ripeness classes (e.g., tomato and muskmelons) (see fig. 33.15). Electronic color sorters are used in some tomato operations to separate mature-green and vine-ripe tomatoes or to classify fruit at different ripening stages. Fruit are sorted by quality into two or more grades according to U.S. standards, California grade standards, or a shipper's own grade standards.

WAXING

Food-grade waxes may be applied to cantaloupes and tomato, although their use is decreasing. Waxing replaces some of the natural waxes removed in the washing and cleaning operations, reduces water loss, and may improve appearance. Fungicides (e.g., SOPP and potassium sorbate) may be added to the wax. Application of wax and postharvest fungicides must be indicated on each shipping container.

SIZING

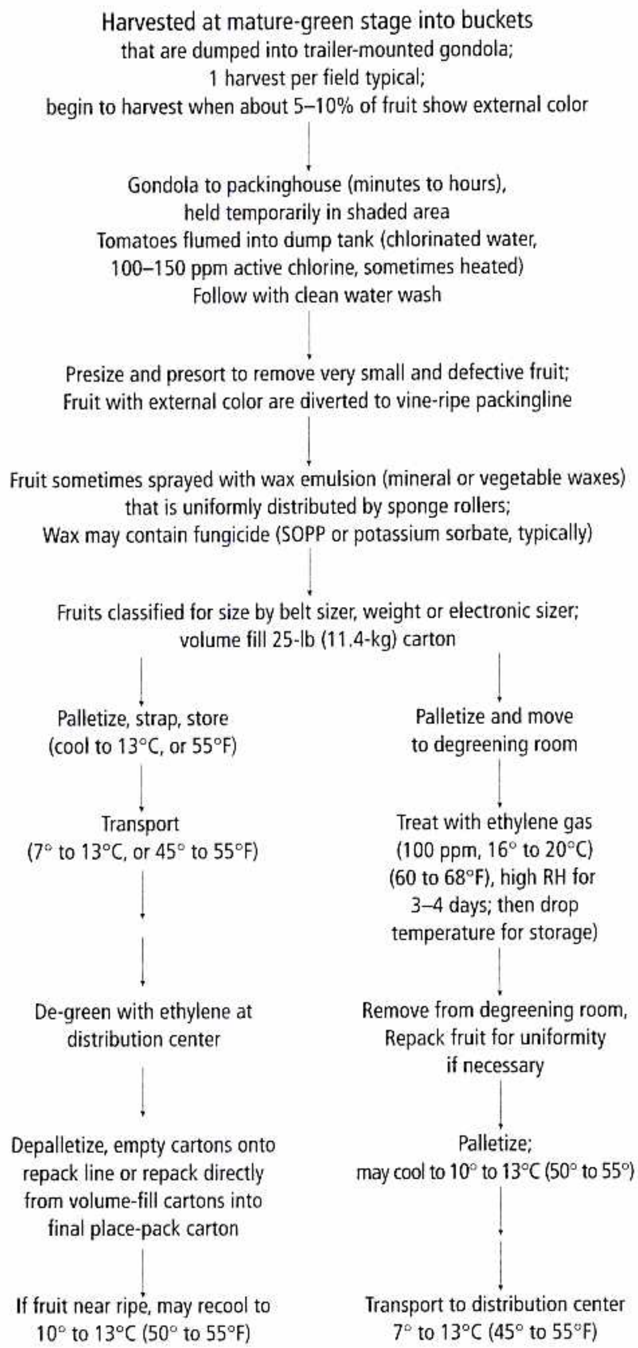
After sorting for defects and color differences, the fruit vegetables are segregated into several size categories. Sizing may be done manually (hard-rind squashes, watermelon), by diverging bar sizers (peppers, melons), volumetric sizers (cantaloupe melons), or by belt or weight sizers (tomatoes) (fig. 33.17).

PACKING AND PALLETIZING

Mature-green and pink tomatoes, and bell and chili peppers, are commonly weight- or volume-filled into shipping containers. All other fruit-type vegetables (and many tomatoes and peppers) are place-packed into shipping containers by count, bulk bins

Figure 33.15

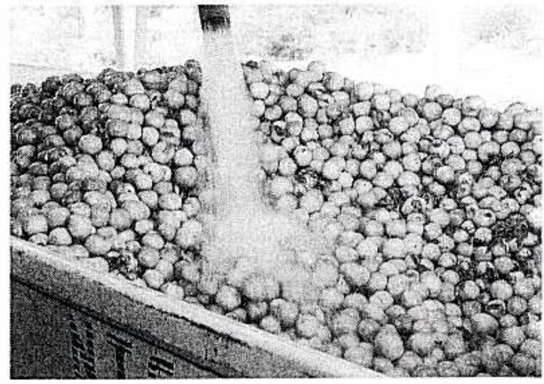
Postharvest handling of mature-green tomatoes.



(hard-rind squashes, pumpkin, muskmelons, watermelon) or bulk trucks (watermelon). Fruit-type vegetables that are place-packed (greenhouse tomatoes and peppers) are often sized during the same operation. Packed shipping containers of most fruit vegetables in large-volume operations are palletized for shipment.

Figure 33.16

Mature-green tomatoes being flumed from a gondola.



COOLING

Various methods are used for cooling the mature fruit vegetables. Forced-air cooling is used for melons, peppers, and tomatoes. Delays from harvest to forced-air cooling can result in excessive water loss. Forced-air evaporative cooling is sometimes used in small-volume operations (e.g., cherry tomato), but it could also be used for any of the chilling-sensitive mature fruit vegetables. Hydrocooling is sometimes used before grading, sizing, and packing of cantaloupe and other melons that are not field packed. Hydrocooling cycles are rarely long enough during hot weather, when product temperatures are the highest. This can be remedied if, after packing and palletizing, enough time is allowed in the cold room to cool the product to recommended temperatures before loading for transport to markets. Package icing and liquid-icing are still used to a limited extent for cooling cantaloupes.

STORAGE AND TRANSPORT CONDITIONS

Good temperature management can effectively control the rate of ripening of mature fruit vegetables, as illustrated for tomato in table 33.6 and fig. 33.18. Most mature fruit vegetables are sensitive to chilling injury when held below the recommended storage temperature (fig. 33.19; see table 33.2). Chilling injury is cumulative, and its severity depends on the temperature and the duration of exposure. In the case of tomato, exposure to chilling temperatures below 10°C (50°F) results in lack of color development, decreased flavor, and increased decay

Figure 33.17

Belt sizing of mature-green tomatoes.

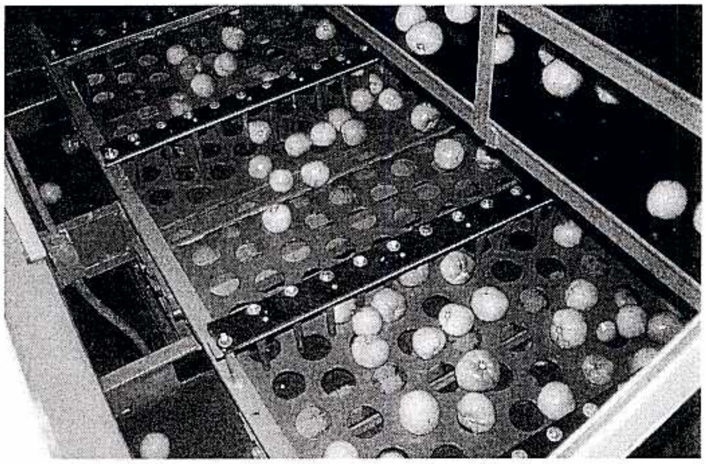
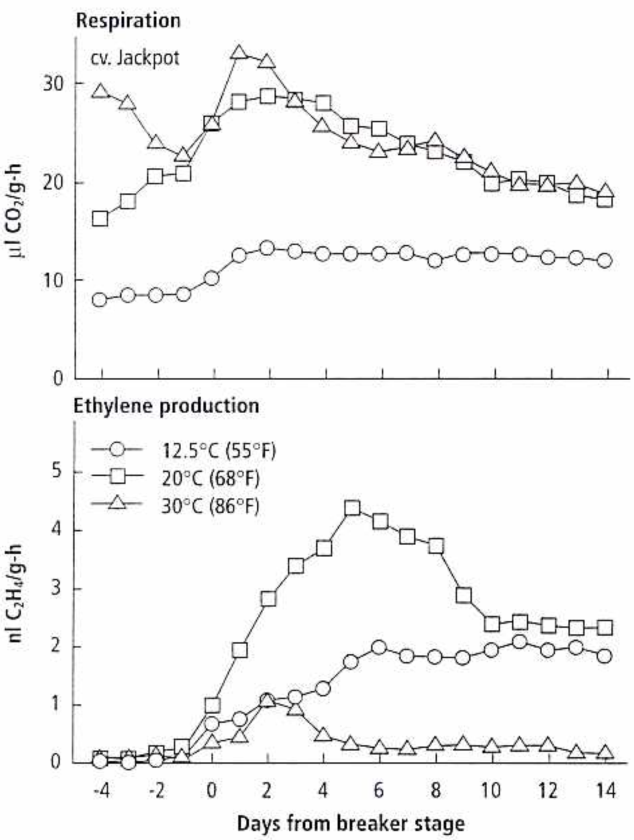


Figure 33.18

Effect of temperature on ripening physiology of tomatoes.



(fig. 33.20). For honeydew melons, the riper the fruit, the lower the recommended storage temperature. Class 1 fruits (see table 33.4) can be stored at 10°C (50°F), Class 2 fruits can be stored at 7° to 10°C (45° to 50°F), and Class 3 fruits can be stored at 5° to 7°C (41° to 45°F) without causing chilling injury.

The optimal temperatures for short-term storage and transport are

- Mature-green tomatoes, pumpkin, and hard-rind squashes: 12.5° to 15°C (55° to 60°F).
- Partially to fully ripe tomatoes, muskmelons (except cantaloupe): 10° to 12.5°C (50° to 55°F).
- Honeydew melons that are ripening: 5° to 7.5°C (41° to 45°F).
- Watermelon: 7° to 10°C (45° to 50°F) for short periods; 10° to 15°C (50° to 59°F) for longer than 1 week.
- Bell and chili peppers: 5° to 7.5°C (41° to 45°F). Storage below 7.5°C will cause chilling injury after about 10 days.
- Cantaloupe: 2.5° to 5°C (36° to 41°F).

The optimal RH range is 85 to 90% for tomato and muskmelons (except cantaloupe), 90 to 95% for cantaloupe, and 60 to 70% for pumpkin and hard-rind squashes.

ETHYLENE SENSITIVITY

Among the mature fruit vegetables, watermelon is detrimentally affected by ethylene, resulting in softening of the whole fruit, flesh mealiness, and rind separation. Exposure of winter squash and pumpkin to ethylene may cause abscission of the stem and de-greening, but they are much less sensitive than watermelon. Watermelon should not be shipped with cantaloupe and honeydew melons since they produce large amounts of ethylene gas.

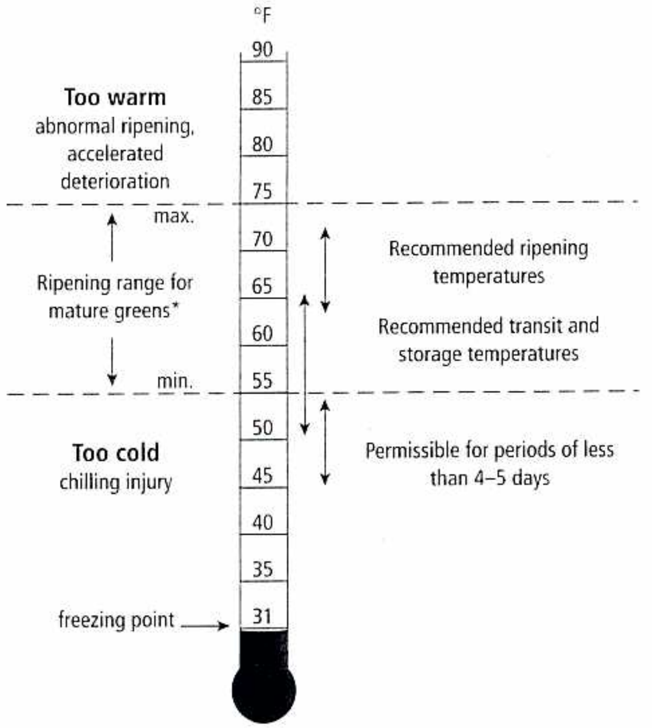
MODIFIED ATMOSPHERES

Modified atmospheres are not frequently used for these commodities, although there are increasing numbers of commercial shipments (marine containers) of cantaloupes under MA for long-distance markets (see table 33.3). The potential for commercial shipments of tomatoes to long-distance markets under MA is also being reevaluated, and consumer packaging of vine-ripe tomatoes may also involve the use of MA. For tomatoes held at recommended temperatures, O_2 levels of 3 to 5% slow ripening, with CO_2 levels held below 5% to avoid injury.

For melons, especially cantaloupes, recommended atmospheres under normal storage conditions are 3 to 5% O_2 and 10 to 15%

Figure 33.19

Effect of temperature on quality and ripening of tomatoes.



*The ripening range is somewhat wider (2° or 3°F) on each side for partially-ripened fruit.

Figure 33.20

Chilling injury (Alternaria decay) on tomatoes held 10 days at 5°C (41°F).

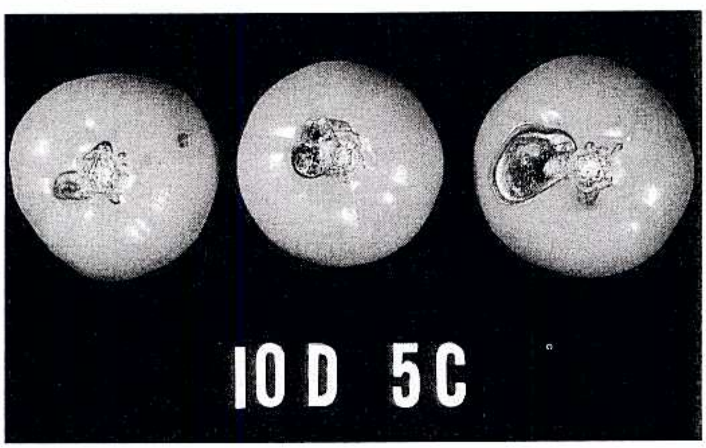


Table 33.6. Effect of temperature on average ripening rate of mature-green, breaker, turning, and pink tomatoes (conventional varieties)

		Days to table-ripe stage at indicated temperature					
	°C	12.5	15	17.5	20	22.5	25
Ripeness stage	°F	55	59	64	68	72	77
Mature-green		18	15	12	10	8	7
Breaker		16	13	10	8	6	5
Turning		13	10	8	6	4	3
Pink		10	8	6	4	3	2

Source: Kader 1986.

CO_2. The main benefit for long-distance shipment of melons is derived from CO_2, which retards decay development (fungista effect) on the stem end and on the rind and also retards color change and softening. Cantaloupes in carton boxes may also be packe in plastic film bags in which the atmospher has been partially evacuated for rapid accumulation of CO_2 from fruit respiration. The plastic film also stops water loss and maintains melon firmness, and it can be maintained through to late stages of marketing. Melons should be thoroughly cooled before using this bagging technique.

RIPENING MATURE FRUIT VEGETABLE

Ripening tomatoes

For uniform and controlled ripening, ethylene is often applied to mature-green tomatoes. Satisfactory ripening occurs at 12.5° to 25°C (55° to 77°F); the higher the temperature, the faster the rate of ripening (see table 33.6). Above 30°C (86°F), red color (lycopene synthesis) development of tomat is inhibited due to inhibition of ethylene production (see fig. 33.18). Fruit ripened above 25°C (68°F) will be less firm than those ripened at 15° to 20°C (59° to 68°F). An ethylene concentration of about 100 pp is commonly used. Tomatoes are usually held at 20°C (68°F) with high humidity an treated for up to 3 days. If tomatoes are at a minimum color stage of "breaker" (table 33.7), ethylene treatment will not further accelerate ripening, since the fruit are producing their own ethylene.

Ethylene treatments may be done at the shipping point or at destination markets, although ripening uniformity and final frui quality are generally considered best if the treatment is applied at the shipping point soon after harvest. Tomatoes may be ethylene-treated before or after packing, but mo are treated after packing. An advantage of treating before packing is that the warmer conditions favor development of any decay on the fruit, so infected fruit can be elimin ed before final pack-out. Packing after ethy ene treatment also permits a more uniform pack-out. Most mature-green tomatoes pro duced in California are packed and then et ylene-treated, and lack of uniformity in col development, or "checkerboarding," often requires a repacking operation.

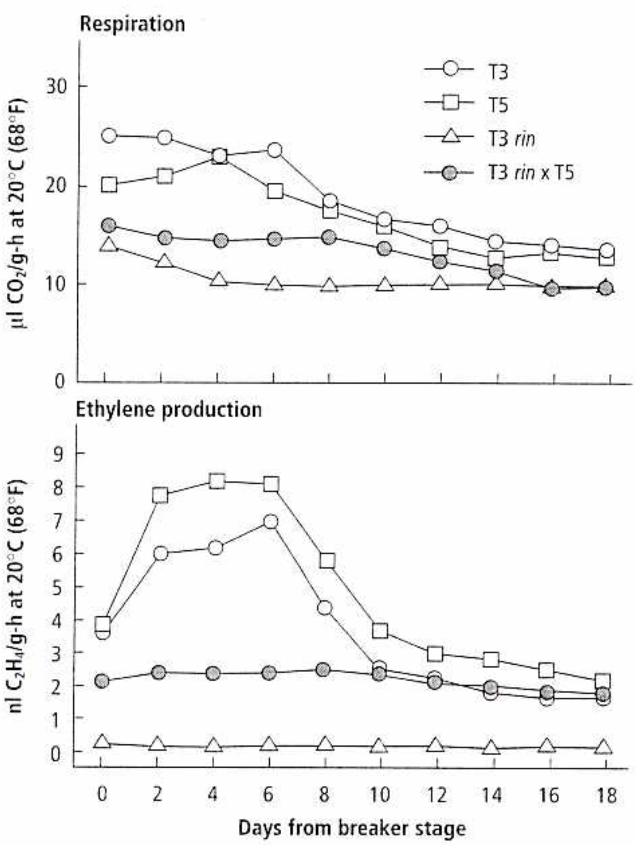
Table 33.7. Typical color changes during the ripening of tomato fruit

Stage of development/color	USDA classification	L*	a*	b*	Chroma	Hue
Mature-green	1	62.7	−16.0	34.4	37.9	115.0
Breaker	2	55.8	−3.5	33.0	33.2	83.9
Pink-orange	4	49.6	16.6	30.9	35.0	61.8
Orange-red	5	46.2	24.3	27.0	36.3	48.0
Red; table-ripe	6	41.8	26.4	23.1	35.1	41.3
Dark red; overripe	—	39.6	27.5	20.7	34.4	37.0

Note: L* indicates lightness (high value) to darkness; a* changes from green (negative value) to red. Chroma and hue are calculated from a* and b* values and indicate intensity and color, respectively. The lower the hue value, the redder the tomato.

Figure 33.21

Ripening physiology of conventional, *rin*, and hybrid tomatoes.



Decay is a common problem during tomato handling. Most of the decay-causing organisms are related to physical injury (*Geotrichum*, *Rhizopus*, etc.), but chill damage increases decay due to *Alternaria*. Prestorage conditioning treatments, heat treatments, intermittent warming, and irradiation have all been tested for effectiveness in reducing chilling injury or decay. Although such treatments may be partly effective, the best option is to avoid prolonged exposure to chilling temperatures.

Ripening mutant genes (*rin*, ripening inhibitor; *nor*, nonripening) have been used for development of long shelf life (LSL) varieties, especially for the vine-ripe greenhouse tomato industry. Figure 33.21 illustrates the effect of the *rin* mutation on tomato ripening physiology. Crosses between a *rin* and a normal ripening line result in intermediate ripening behaviors, and therefore longer shelf life. LSL varieties typically maintain firmness (table 33.8) longer than conventional varieties during storage, but they may have reduced flavor quality. Also, red color development (table 33.7) may be reduced in LSL varieties with reduced ethylene production rates.

Tomatoes have also served as a model crop for the molecular modification of genes associated with ethylene production and cell wall enzyme activity. Resulting transgenic varieties with modified ripening and storage characteristics may provide more options in postharvest handling regimes for fresh-market tomatoes.

Ripening melons

Honeydew melons (usually maturity class 1 or 2) and other melons are sometimes held in ethylene up to 24 hours to improve aroma, induce softening, and for other ripening-associated changes. However, sugar content does not increase with this treatment since melons do not have starch reserves that can be converted into sugars. Since cantaloupes and melons are harvested partially ripe and produce their own ethylene, temperature conditioning (15° to 20°C, or 59° to 68°F) without ethylene treatment will ensure good eating quality. If cantaloupes have been stored for 2 weeks or longer, decay will occur rapidly during ripening, and they will need to be marketed quickly. Melons have also been the subject of molecular studies, with focus on genetic manipulation of ethylene-producing capabilities and cell wall enzyme activities to slow the rate of ripening and pulp softening.

Ripening peppers

Bell peppers are nonclimacteric fruits, and ethylene does not enhance ripening of partially colored peppers (fig. 33.22). Holding bell and chili peppers at warm temperatures

Table 33.8. Typical textural characteristics of tomatoes and their relationship to objective firmness and slice integrity measuremer

Firmness class	Description based on resistance to finger pressure	Firmness* (mm compression)	Description based on slicing characteristics	Slice integrity (% weight los
Very firm	Fruit yields only slightly to considerable pressure	0.5–1.0	No loss of juice or seed when sliced	0–2
Firm	Fruit yields only slightly to moderate pressure	1.0–1.5	A few drops of juice or seed may be lost when sliced	2–5
Moderately firm	Fruit yields to moderate finger pressure	1.5–2.0	Some juice and seed are lost when sliced	5–8
Moderately soft	Fruit yields readily to moderate finger pressure	2.0–2.5	Some juice and seed are lost when sliced	5–8
Soft	Fruit yields to slight finger pressure	2.5–3.0	Considerable juice and seed are lost when sliced	8–10
Very soft	Fruit yields very readily to slight finger pressure	>3.0	Much of the juice and seed is lost when sliced	>10

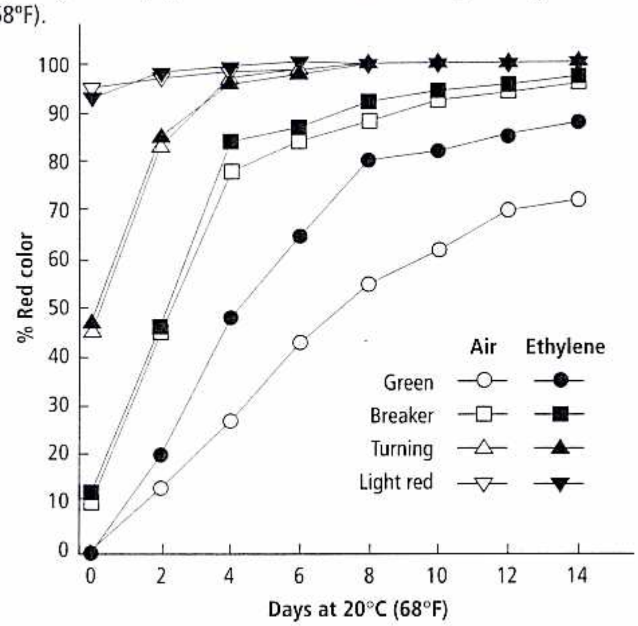
Notes:

*Measured by placing a 500-g (17.6-oz) weight for 10 seconds on the equator of the fruit.

†Measured by weighing fruit before and after slicing into 0.8-cm-wide (0.3-in-wide) slices and draining.

Figure 33.22

Ripening of bell pepper fruit stored in air or 100 ppm ethylene at 20°C (68°F).



of 20° to 25°C (68° to 77°F) with greater than 90% RH is the best way to complete ripening or color changes. Chili peppers are climacteric in their ripening behavior, and they may respond to ethylene treatment, although the response appears to be highly variety dependent.

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