CHAPTER 23

CITRUS FRUIT, BANANAS, AND SUBTROPICAL FRUIT

THIS chapter covers the harvesting, handling, processing, storage requirements, and possible disorders of fresh market citrus fruit grown in Florida, California, Texas, and Arizona; of bananas; and of subtropical fruit grown in California, Florida, Hawaii, and Puerto Rico.

CITRUS FRUIT

MATURITY AND QUALITY

The degree of citrus fruit ripeness at the time of harvest is the most important factor determining eating quality. Oranges and grapefruit do not improve in palatability after harvest. They contain practically no starch and do not undergo marked composition changes after they are picked (as do apples, pears, and bananas), and their sweetness comes from the natural sugars they contain when picked.

Citrus fruit ripeness increases slowly and is closely correlated with increases in diameter and weight. Citrus fruit must be of high quality when harvested to ensure quality during storage and shelf life.

Quality is often associated with the fruit rind's appearance, firmness, thickness, texture, freedom from blemishes, and color. However, quality determination should be based on flesh texture, juiciness, soluble solids (principally sugars), total acid, aromatic constituents, and vitamin and mineral content. Age is also important. Immature fruit is usually coarse and very acid or tart and has an internal texture that is ricey or coarse. Overripe fruit held on the tree too long may become insipid, develop off-flavors, and possess short transit, storage, and shelf life. The importance of having good-quality fruit at harvest cannot be overemphasized. The main objective thereafter is to maintain quality and freshness.

HARVESTING AND PACKING

Picking

Citrus fruit is harvested in the United States throughout the year, depending on the growing area and kind of fruit. Figure 1 shows the approximate commercial shipping seasons for Florida, California/Arizona, and Texas citrus. Trained crews from independent packing houses or large associations do the picking, which is scheduled to meet market demands. Fruit that is not handled through cooperatives is normally sold on the tree to shippers or processors and is picked at the latter's discretion.

Pickers carefully remove fruit from the trees, either by hand or with special clippers, and then place the fruit in picking bags that are emptied into field boxes. An increasing amount of fruit is handled in bulk, so pickers put fruit into pallet boxes or wheeled carts. In some

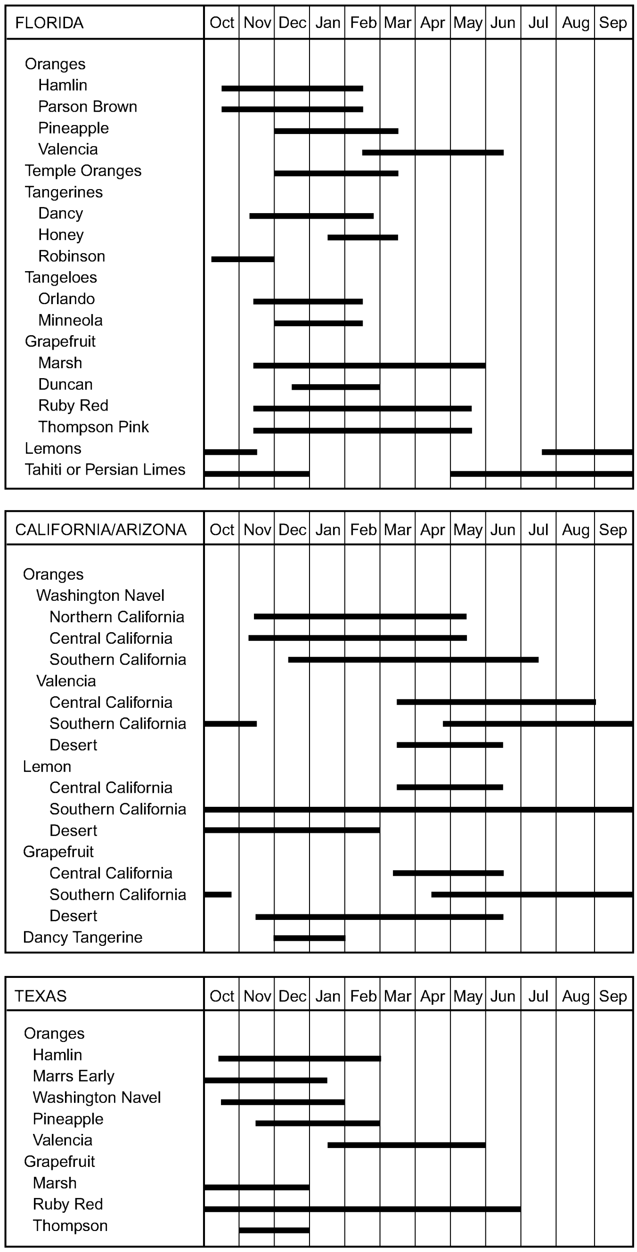

Fig. 1 Approximate Commercial Shipping Season for U.S. Citrus

The preparation of this chapter is assigned to TC 10.9, Refrigeration Application for Foods and Beverages.

cases, especially when fruit is picked for processing, it is loaded loose into open truck trailers. In Florida, over 90% of the oranges and slightly more than 50% of the grapefruit and specialty fruit are processed, while in California and Arizona less than 35% of all citrus fruit is processed.

At the beginning of the season, fruit is often spot-picked; only the riper, larger, or outside fruit is harvested. Later, the trees are picked clean. In California, lemons usually are picked for size with the aid of sizing rings.

Various labor-saving devices have been tested, including mechanical platforms and positioners, tree shakers with catch frames, and air blasts for fruit removal. Mechanical harvesting, however, is limited to a very small percentage of the total crop. Because of damage incurred, fruit intended only for processing is mechanically harvested. Preharvest sprays have also been developed to improve color and to loosen fruit to facilitate harvest.

Handling

After fruit is received at the packinghouse, it is removed from the boxes or bulk containers carefully to prevent damage to the fruit. It is then presized to remove oversized or undersized fruit. Before washing, fruit may be floated through a soak tank, which usually contains a detergent for cleaning and an antiseptic for decay control.

The washer is generally equipped with transverse brushes that revolve up to 120 rpm. If not applied at the soak tank, soap or antiseptic may be dribbled or foamed on the first series of brushes. A fresh water spray then rinses the fruit.

Fruit then passes under fans that circulate warm air through the moving pieces. When dried, fruit is polished and waxed (typically with a water wax), and then passes through a second drying. It then passes over roller conveyor grading tables. After grading, it is conveyed to sizing equipment that separates the pieces into the standard packing sizes; the pieces are then dropped at stations for hand packing or conveyed to automatic or semiautomatic box-filling or bagging machines. Electronic sizing, based on machine vision, is used extensively.

Packinghouse handling of California lemons for fresh market is interrupted by an extended storage period. After washing, fruit is conveyed to a sorting table for color separation by electronic means or by human eye. Usually, separation is into four colors: dark green, light green, silver, and yellow. The dark green is a full green; the light green is a partially colored green (a green with color well broken); the silver is fully colored with a green tip (stylar end); and the yellow is fully colored and mature with no green showing. The normal storage life for dark green fruit is 4 to 6 months; for yellow fruit, it is 3 to 4 weeks. These periods are approximate, because storage (or keeping) quality of fruit varies considerably with season and grove. A light concentration of water/wax emulsion is usually applied to lemons before they are put into storage. The section on Storage has more information on storing the different varieties of citrus fruit.

After storage, lemons are waxed, then sized and packed. Poststorage washing to remove mold is desirable but requires a washer with very soft roller brushes.

Shipping and storage containers vary considerably for the different types of citrus fruit. In California and Florida, 0.8 bushel fiberboard cartons are the standard. In addition, over 15% of Florida fresh fruit is consumer-packed in mesh and polyethylene bags that are normally shipped in 40 lb master cartons. After the packages are filled and closed, they are conveyed either to precooling rooms to await shipment or directly to standard refrigerator cars or trucks. Containers are stacked so that air distribution is uniform throughout the load. Either slipsheets or wooden pallets are commonly used for palletized handling.

Accelerated Coloring or Sweating

All varieties of citrus fruit must be mature before they are picked. Maturity standards are based on internal attributes of soluble solids, acid percentage, and juice percentage. Color is not always a criterion of maturity. The natural change of color in oranges from dark green to deep orange is a gradual process while the fruit remains on the tree. The fruit remains dark green from its formation until it is nearly full size and approaching maturity; then the color may change very rapidly. Color change is influenced greatly by temperature variations. A few cold nights followed by warm days may turn very green oranges to deep orange. Color changes in lemons and grapefruit similarly turn the fruit yellow. Unfavorable weather conditions may delay coloring even after maturity.

Up to a certain point, the natural color changes in Valencia oranges follow the trend described, but complete or nearly complete orange color generally develops some time before the fruit is mature. Some regreening of Valencias may occur after the fruit has reached its prime. Navel oranges in California, as well as the Florida varieties of Hamlin, Parson Brown, and Pineapple harvested in late fall and early winter, may be mature and of good eating quality even if the rind is green. Grapefruit, lemons, tangerines, tangelos, and other specialty fruit may also be mature enough for eating before they are fully colored. Because the consumer is accustomed to fruit of characteristic color, poorly colored fruit is put through a coloring or **degreening** process in special rooms, bulk bins, or trailer degreening equipment.

These units are equipped to maintain temperature and humidity at desired levels. Approximately 5 ppm ethylene is maintained in the air. The concentration of ethylene and duration of degreening depends on the variety of fruit and the amount of chlorophyll to be removed. During degreening, fresh air is introduced into the room, and a relative humidity of 90 to 96% is maintained. In Florida, temperatures of 82 to 85°F are recommended, whereas in California temperatures of 65 to 70°F are used. Lemons are usually degreened at 60°F. In California, the process is called **sweating** instead of coloring or degreening.

Oranges, grapefruit, and specialty citrus fruit requiring ethylene treatment are frequently degreened upon delivery to the packinghouse, but they may receive a fungicide drench before degreening. Lemons are washed and graded or color-separated before being degreened.

Color-Added Treatment

A high percentage of Florida’s early and midseason varieties of oranges and tangelos receive color-added treatment with a certified food dye that causes the rind of pale fruit to take on a brighter and more uniform orange color. This is usually in addition to degreening with ethylene gas. In color-added treatment, the fruit is subjected for 2 to 3 min to the dye solution, which is maintained at 120°F. Treatment can be in an immersion tank filled with vegetable dye solution, or the dye can be flooded on the fruit as it passes on a roller conveyor. The immersion tank is between the washer and the wax applicator. Oranges with the desired color at harvest, as well as tangerines and grapefruit, bypass the dye tank; alternatively, the flow of dye may be cut off as the fruit passes over the equipment. Standards for maturity are slightly higher in Florida for oranges given color-added treatment. California oranges are not artificially colored.

Cooling

After the fruit is packed, it is cooled. Cooling room efficiency depends on

- Cooling air rate per railcar load (at least 3000 cfm)
- Relative humidity of supply air (95% or above)
- Temperature of supply air entering room (no more than 2°F below the selected cooling temperature)

The fruit may also be cooled in a refrigerated truck trailer or container after it has been loaded.

In California, air is used to cool oranges but not lemons or grapefruit. In Florida, specialty fruit such as Temple oranges, tangerines, and tangelos may be cooled. Chapter 15 discusses cooling practices and equipment used for various commodities in more detail.

TRANSPORTATION

Fruit packed in piggybacks, trucks, ship vans, or rail cars should be stowed in appropriate modifications of the spaced bonded block to ensure good air circulation, uniform temperature, and stable load. No dunnage is required. Such stowing provides continuous air channels through the interior of the load and improves the likelihood of sound arrival. Trailers and containers that circulate air from the bottom provide uniform temperatures throughout the load with a regular bonded-block stow.

In Florida, the present quarantine treatment for the Caribbean fruit fly, *Anastrepha suspensa*, is to subject an export load of citrus to specified temperatures for up to 24 days (Ismail et al. 1986). This treatment may be implemented in containers or in a ship's hold.

A uniform sample of 1500 fruit is withdrawn from a shipment before ship or container loading and is held at 80°F or higher. These fruit are then examined after a 10 day incubation period. If an infestation of *A. suspensa* is found, the entire load must undergo the long treatment process. Table 1 details temperature and time schedules.

STORAGE

Performance of any citrus storage facility depends on three conditions: (1) provision of sufficient capacity for peak loads; (2) an evaporator and secondary refrigerating surface sufficient to permit operation at high back pressures, which prevents low humidity and lowers operating costs; and (3) efficient air distribution, which ensures velocities high enough to effect rapid initial cooling and volumetric flows great enough to permit operation during storage with only a small temperature rise between delivery and return air. Chapters 11, 13, and 14 have further information on storage design.

Oranges

Valencia oranges grown Florida and Texas can be stored successfully for 8 to 12 weeks at 32 to 34°F with a relative humidity of 85 to 90%. The same requirements apply to Pope's Summer orange, a late-maturing Valencia-type orange. A temperature range of 40 to 44°F for 4 to 6 weeks is suggested for California oranges. Arizona Valencias harvested in March store best at 48°F, but fruit harvested in June store best at 38°F.

Oranges lose moisture rapidly, so high humidity should be maintained in the storage rooms. For storage longer than the usual transit and distribution periods, 85 to 90% relative humidity is recommended.

Table 1 Quarantine Treatment of Citrus Fruit for Caribbean Fruit Fly

	Temperature,[a] °F	Days
Short Treatment[b]	33	10
	34	12
	35	14
	36	17
Long Treatment[b]	33	14
	33.5	16
	34	17
	34.5	19
	35	20
	35.5	22
	36	24

[a]Required center pulp temperatures.
[b]To avoid chilling injury, a conditioning period of 7 days at 59°F is recommended before cold treatment.

Florida and Texas oranges are particularly susceptible to stem end rots. Citrus fruit from all producing areas are subject to blue and green mold rot. These decays develop in the packinghouse, in transit, in storage, and in the market, but they can be greatly reduced if fruit is properly treated. Proper temperature is effective in reducing decay. However, once storage fruit is removed to room temperature, decay develops rapidly.

Prolonged holding at relatively low temperatures may cause the development of physiological rind disorders (mainly aging, pitting, and watery breakdown) not ordinarily encountered at room temperature. This possibility often complicates orange storage. California and Arizona oranges are generally more susceptible to low-temperature rind disorders than Florida oranges.

Successful long storage of oranges requires harvest at proper maturity, careful handling, good packinghouse methods, fungicidal treatments, and prompt storage after harvest.

The rate of respiration of citrus fruit is usually much lower than that of most stone fruit and green vegetables and somewhat lower than that of apples. Navel oranges have the highest respiration rate, followed by Valencia oranges, grapefruit, and lemons. Heat from respiration is a relatively small part of the heat load. Table 2 shows heat generated through respiration.

Grapefruit

Florida and Texas grapefruit is frequently placed in storage for 4 to 6 weeks without serious loss from decay and rind breakdown. The recommended temperature is 50°F. A temperature range of 58 to 60°F is recommended for storing California and Arizona grapefruit.

A relative humidity of 85 to 90% is usually recommended for storage rooms containing grapefruit. Weight and water loss occur rapidly and can be avoided by maintaining the correct humidity and taking the additional precaution of a wax coating.

Long storage of grapefruit may cause decay and rind breakdown during or after storage. Proper prestorage treatments with fungicides greatly reduce these problems. Also, stored fruit should be inspected periodically for the least symptom of rind pitting or excessive decay so that storage can be terminated if necessary.

Export may require 10 days to 4 weeks of storage in a refrigerated hold and may present problems similar to those encountered in refrigerated storage. Marsh Seedless and Ruby Red grapefruit picked before January retain appearance best when stored at 60°F. With riper fruit, 50 to 55°F is better for export shipments. Very ripe fruit harvested in April and May, however, develops excessive decay following after at 50 to 60°F.

Lemons

Most of the lemon crop is picked during the period of least consumption and stored until consumer demand justifies shipment. Lemons are generally stored near producing areas rather than consuming areas.

Table 2 Heat of Respiration of Citrus Fruit

	Heat of Respiration, Btu per Ton of Fruit per Day					
	Oranges			Grapefruit		Lemons
Temp., °F	Florida	Calif. Navels	Calif. Valencias	Florida	Calif. Marsh	Calif. Eureka
32	700	900	400	500	500	700
40	1400	1400	1000	1100	800	1100
50	2700	3000	2600	1500	2000	2500
60	4600	5000	2800	2800	2600	3500
70	6600	6000	3900	3500	3900	5000
80	7800	8000	4600	4200	4800	5700

Source: Haller et al. (1945)

All lemons, except the relatively small percentage that are ripe when harvested, must be conditioned or cured and degreened before shipping. When lemons are stored prior to shipment, the curing and degreening processes occur during storage. These lemons are usually stored at 52 to 55°F and 86 to 88% rh. Local conditions may suggest slight modifications of these values.

Lemons picked green but intended for immediate marketing, (e.g., most lemons grown in the desert portions of Arizona and California) are degreened and cured for 6 to 10 days at 72 to 78°F and 88 to 90% rh. The thin-skinned Pryor strain of Lisbon lemons degreens in about 6 days, whereas the thick-skinned old-line Lisbon requires as long as 10 days.

Lemon storage rooms must have accurately controlled temperature and relative humidity; the air should be clean and uniformly circulated to all parts of the room. Ventilation should be sufficient to remove harmful metabolic products. Air-conditioning equipment is necessary to provide satisfactory storage conditions, because natural atmospheric conditions are not suitable for the necessary length of time.

A uniform storage temperature between 50 and 55°F is important. Fluctuating or low temperatures cause lemons to develop an undesirable color or bronzing of the rind. Temperatures 50°F and lower can stain or darken the membranes dividing the pulp segments and may affect flavor. Temperatures above 55°F shorten storage life and promote the growth of decay-producing organisms.

A relative humidity of 86 to 88% is generally considered satisfactory for lemon storage, although a slightly lower humidity may be desirable in some locations. Higher humidities prevent proper curing, encourage mold growth on walls and containers, and hasten decay; much lower humidities cause excessive shrinkage.

Stacking fruit containers properly in storage rooms is important to ensure uniform air circulation and temperature control. Stacks should be at least 2 in. apart, and rows should be 4 in. apart; trucking aisles at least 12 ft wide should be provided at intervals.

Specialty Citrus Fruit

In Florida, small amounts of various specialty citrus fruit are grown commercially. These types of fruit, which are usually channeled to fresh market, include tangerines, tangerine hybrids (Murcott Honey oranges, Temple oranges, tangelos), King oranges, and other mandarin-type fruit.

Careful handling during picking and packing is especially necessary for these types of fruit. Because of their perishable nature and limited shelf life, specialty citrus fruit should not be stored longer than required for orderly marketing (2 to 4 weeks). A temperature of 38 to 40°F at 90 to 95% rh is recommended. Adequate precooling and continuous refrigeration during transit are required.

Tahiti or Persian limes are also grown in southern Florida. This is the only citrus fruit marketed while it is green in color. The fully ripe (yellow) fruit lacks consumer appeal and is undesirable for fresh market. Limes should be picked while still green, but after the fruit has lost the dimpled appearance around the blossom end. Good-quality fruit may be stored satisfactorily for 6 to 8 weeks at 48 to 50°F. However, mature fruit gradually turns yellow at this temperature. Preventing desiccation is very important, as is a relative humidity above 85%. Pitting occurs below 45°F, and temperatures above those recommended allow stem end rot to develop.

Controlled-Atmosphere Storage

Tests of modified- or controlled-atmosphere (CA) storage for oranges, grapefruit, lemons, and limes have found minor benefits but have not shown that CA storage extends storage or market life. For this reason, CA storage is not generally recommended for citrus fruit. Atmospheres used for storage of apples and other deciduous fruit are unsatisfactory for citrus fruit and lead to rind injuries, off-flavors, and decay.

STORAGE DISORDERS AND CONTROL

Postharvest Diseases

Citrus fruit often carries incipient fungus infections when harvested. Decay organisms may also enter minor injuries caused during harvesting and handling. Major postharvest diseases (with symptoms) encountered in storage include the following:

Alternaria Rot. Usually a black, dry, deeply penetrating decay at stylar end of navel oranges; a slimy, leaden-brown storage decay of core starting at stem end in other citrus fruit. *Control*: Provide optimum growing conditions. Harvest oranges before they are overripe. Do not store tree-ripe lemons. Restrict storage period for other lots known to be weak. Green buttons indicate strong fruit.

Anthracnose (*Colletotrichum*). Leathery, dark brown, sunken spots or irregular areas. Internal affected tissues dark gray, fading through pink to normal color. Most serious with degreened early-season tangerines, tangerine hybrids, and long-stored oranges, and long-stored grapefruit. *Control*: Use recommended postharvest fungicide. Avoid long storage and move promptly.

Blue (and Green) Mold Rot (*Penicillium*). Soft, watery, decolorized lesions that, under moist conditions, become quickly covered with blue or olive-green powdery spores. *Control*: Prevent skin breaks. Use recommended fungicides in washes. Cool fruit to as near to 32°F as practicable.

Brown Rot (*Phytophthora*). Extensive firm, brown decay with a penetrating rancid odor. Chiefly on fruit from California and Arizona. *Control*: Orchard spraying and good sanitation. Submerge fruit at packing for 2 min in 114°F water.

Sour Rot (*Geotrichum*). Soft, watery rot with sour smell after peel injuries. Similar to early stages of mold rot, except that no powdery spores are formed. Most serious on lemons and mandarin-type fruit. *Control*: Avoid peel injuries at harvest; refrigerate at lowest practical temperature. Approved fungicides are of little or no value.

Stem End Rot (*Diplodia*; *Phomopsis*). Pliable, fairly firm, extensive brown decay starting at stem. Sour, pungent odor. Prevalent in Florida and found occasionally in Arizona and California fruit. *Control*: Treat harvested fruit promptly in recommended fungicides and cool promptly below 50°F.

The U.S. Environmental Protection Agency (EPA) approves several chemical fungicides for postharvest use on citrus fruit. These include thiabendazole (TBZ), orthophenylphenol (OPP or SOPP), and imazalil. These materials are applied after washing and before waxing or are incorporated in the wax coating. Under certain conditions, it is beneficial to use a combination of these materials because all are not equally effective against the same organism. Strains of the blue and green molds (*Penicillium*) that are resistant to certain fungicides have developed in citrus storage houses, so care must be taken in selecting the fungicide and the time of application.

Physiological Disturbances

Various physiological conditions can also cause defects. Using fruit at prime maturity and proper handling after harvest can eliminate these defects. Proper temperature and humidity levels are required during handling, storage, and transit. The following are the physiological disorders and symptoms:

Stem End Rind Breakdown. Small to large sunken, drying, discolored, firm areas in skin around stem button or on the upper part of fruit. *Control*: Pick before overmature. Avoid overheating in packinghouse treatments. Wax fruit. Store for limited period only in fairly high relative humidity (85 to 90%). Follow storage temperatures recommended for variety and growing area.

Freezing Injury. Field freezing is found scattered through boxes. Transit and storage freezing are worse in exposed fruit in bottom-layer boxes or those nearest cooling coils. Affected fruit may show water-soaked areas in rind. The internal tissue is disorganized, water-soaked, and milky and has rind flavor. Frozen fruit loses moisture, causing drying, separation of juice vesicles, and buckling of segment walls. The freezing point of citrus fruit is about 28.5°F.

Internal Decline. In lemons, core tissues near the stylar end break down and dry, becoming pink. *Control*: Maintain optimum moisture conditions in grove.

Pitting. Depressed areas of 0.1 to 0.8 in. diameter in the peel of citrus fruit. Affected tissues collapse and may appear bleached or brown. Pits occur anywhere on the fruit and may coalesce to form large irregular areas. The cause is not fully understood. In general, pitting is a low-temperature disorder. However, lack of immediate cold storage for Florida grapefruit has accentuated pitting. *Control*: Follow storage temperatures recommended for cultivar and growing area.

BANANAS

HARVESTING AND TRANSPORTATION

Bananas do not ripen satisfactorily on the plant; even if they did, deterioration of ripe fruit is too rapid to allow shipping from tropical growing areas to distant markets. Bananas are harvested when the fruit is mature but unripe, with dark green peels and hard, starchy, inedible pulps. Each banana plant produces a single stem of bananas that contains from 50 to 150 individual pieces of fruit (or fingers). The stem is cut from the plant as a unit with fingers attached and transported to nearby boxing stations.

Bananas are removed from the stem, washed, and cut into consumer-sized cluster units of four or more fingers. The clusters are packed in protective fiberboard cartons that contain 40 lb of fruit. The cartons move by rail from the tropical boxing stations to port and then are loaded into the holds of refrigerated ships. On the ship, fruit is cooled to the optimum carrying temperature, usually 56 to 58°F, depending on variety.

Bananas are unloaded still green and unripe at seaboard and transported under refrigeration at a holding temperature of 58°F to interior wholesale distribution centers by both truck and railcar. The objective is to maintain the product in an optimal environment and move it to its destination as quickly as possible to minimize postharvest deterioration.

DISEASES AND DETERIORATION

Bananas are subject to various diseases and physiological disorders. Proper temperature and moisture during storage and careful handling slow aging and development of decay.

Anthracnose (Ripe Rot) (*Gloeosporium*). Shallow black spots on stems of ripening fruit. Under moist conditions, pink spore masses cover center of spots. Dark discoloration of skin may extend from stem end over entire fruit. *Control*: Protect fruit from mechanical injury; damage is reduced if fruit is transported in corrugated boxes. Schedule ripening so that fruit can be marketed and consumed before appearance of defect.

Black Rot (*Ceratocystis*). Transmitted from wounds via fibrovascular system of plant; progresses into crowns and stem ends of fingers, and produces brownish-black areas in peel at fruit ends. As fruit ripens, skin becomes grayish-black and water-soaked. Pulp is rarely affected. *Control*: In the tropics, dip or spray freshly cut tips and bunches with fungicides before boxing. Avoid mechanical injury and maintain sanitation program from tropics to ripening room.

Chilling Injury. Dull gray skin color with increased tendency to darken on slight bruising. Latex in green fruit does not bleed freely and will be clear rather than cloudy. Subsurface peel tissue streaked with brown. Turning or ripe bananas are more susceptible to injury than green fruit. *Control*: Avoid temperatures below 55°F. Moving air accelerates chilling.

Fungus Rots (Several Fungi). Extensive soft rot of scarred, split, or broken fruit. Affected skin and flesh are moist and brown to black. Under high humidity, the surface is often covered with mold. *Control*: Handle fruit carefully to avoid bruising and mechanical injury. Cool stored fruit rapidly to 56°F.

EXPOSURE TO EXCESSIVE TEMPERATURES

Fruit pulp temperatures only a few degrees below optimum holding temperatures, although considerably above the actual freezing point of bananas, can cause chilling injury. Severity varies directly with the duration of exposure and indirectly with temperature. It is primarily a peel injury in which some surface cells of the banana peel are killed. The contents of the dead cells eventually darken because of oxidation and give the fruit a dull appearance. Both green and ripe bananas are susceptible to chilling injury; severely chilled green bananas never ripen properly. Fruit pulp temperatures only a few degrees above the optimum holding temperatures can cause fruit to ripen prematurely in transit.

Once bananas arrive at wholesale distribution centers, they are unloaded and placed in specially equipped processing rooms for controlled ripening. As soon as the bananas have ripened to an edible state, they are rushed to retail because ripening cannot be stopped. Even under ideal refrigeration, ripe bananas eventually progress to the point where they are too ripe to sell.

WHOLESALE PROCESSING FACILITIES

Wholesale banana processing facilities are distinguished from general wholesale produce storage facilities by special banana ripening rooms. The ripening room controls initiation and completion of fruit ripening; Figure 2 shows a typical banana room. The ability to ripen bananas properly is so critically linked to the design of the ripening rooms that major banana importers maintain technical staffs that specialize in banana room design. These technical staffs provide free, nonobligatory consultation to wholesalers, architects, engineers, contractors, and others involved in banana ripening facility design, construction, and operation.

A typical banana processing facility consists of a bank of five or more individual ripening rooms. For design purposes, one complete turnover per week is assumed; therefore, the combined capacity of all rooms should approximately equal total weekly volume, allowing for seasonal variations.

Each load is scheduled for optimum ripeness on a particular day. Fruit shipped from this load a day ahead of schedule will be underripe; fruit shipped a day late will be overripe. Therefore, shipping for several days out of one room is not practical. There should be at least as many rooms as there are retail shipping days per week.

Because bananas cannot be processed on a continuous flow basis, individual room capacities are multiples of carlots, usually one-half or one carlot. As the capacity of transportation equipment has increased in recent years, the design capacity of processing rooms has also increased. It is generally cheaper to build one or two

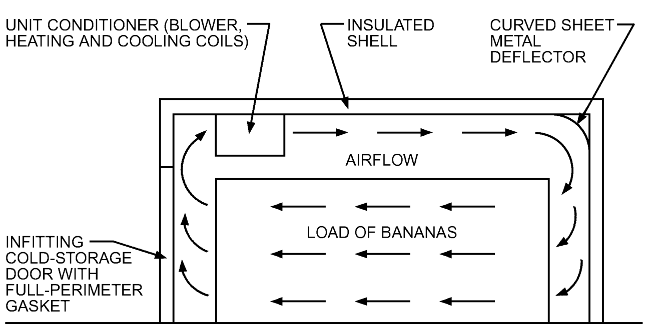

Fig. 2 Banana Room (Side View)

large rooms than several small rooms with equivalent total capacity. However, minimizing construction cost is not the pertinent consideration; having all bananas in each particular processing room reach optimum ripeness for shipment to retail at the same time is more important.

Airtightness

Exposing fruit to ethylene gas, introduced into the room from cylinders, initiates ripening. The dose is 1 ft^3 of ethylene gas per 1000 ft^3 of room air space. Ethylene is explosive in air at concentrations between 2.75 and 28.6%. Many ethylene systems gas the fruit automatically over a 24 h period.

To be effective, the gas must be confined to the ripening room for 24 h, so banana rooms must be airtight. Floor drains must be individually trapped to prevent gas leakage. Special care should be taken to seal all penetrations in room walls where refrigerant piping, plumbing lines, and the like enter rooms. Doors should have single-seal gaskets all around and sweep gaskets at the floor line.

Refrigeration

A direct-expansion halocarbon system is recommended. Because of ammonia's harmful effect on bananas, direct-expansion ammonia systems should not be used. Malfunctioning refrigeration equipment during processing could cause heavy product losses, so each ripening room should have a completely separate system despite high initial installation costs.

For maintenance-free operation in the high-humidity environment of processing rooms, evaporator coils should have a fin spacing of 4 fins/in. Coils should be amply sized and capacity-rated at a design temperature difference of 15°F with a refrigerant temperature of 40°F. Air temperatures used during processing range from 45 to 65°F. Because of the danger of banana chilling, refrigerant temperatures below 40°F are not recommended. With programmers, suction pressure control devices or hot-gas bypass systems must be installed.

Refrigeration Load Calculations

These calculations are based on the same methods used for other fresh fruit. A typical half-carlot-capacity banana room holds approximately 432 boxes of fruit. Approximate outside dimensions for a three-tier forklift-type room, shown in Figure 3, are 30 ft long by 6 ft wide by 22 ft high. Pallets are 48 by 40 in. and are stacked 6 pallets deep in each of 3 tiers, totaling 18 pallets per room. Boxes for use in banana rooms are approximately 10 in. high by 16 in. wide by 22 in. long and are stacked 4 boxes per each of 6 layers, totaling 24 boxes per pallet. With 18 pallets per room, 432 boxes of bananas can be stored (18 pallets by 24 boxes). Each box has a net weight of 42 lb and a gross weight of 47 lb.

Transmission load is calculated in the normal manner; the air change load is negligible. The electrical load is based on continuous operation of multikilowatt fan motor(s). The peak heat of respiration is 0.5 Btu/h per pound multiplied by the total net weight of bananas in the ripening room. For product cooling, the specific heat of bananas is 0.8 Btu/lb·°F multiplied by the total net weight of the bananas, plus the total tare weight of the cartons multiplied by 0.4 Btu/lb·°F, the specific heat of fiberboard. The total calculated load is thus approximately 60 Btu/h per box. A pulldown rate of 1°F/h is assumed. Total system design capacity is calculated by assuming simultaneous peak respiration and pulldown load.

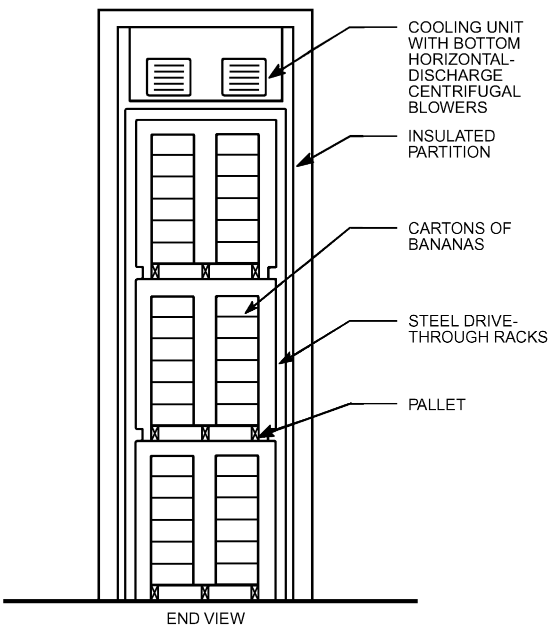

Fig. 3 Three-Tier Forklift Banana Room (End View)

Heating

Heat is not required during most ripening cycles. However, occasional loads may come in at temperatures below desired levels for treatment with ethylene gas, making heating necessary. Many banana room refrigeration units come with integrated electrical heating elements. If electrical heating strips are used, they should be enclosed in a corrosion-resistant sheath and have a surface temperature of not more than 800°F in dead still air; this temperature limitation is necessary because of the proximity of the heating strips to refrigerant coils and the inherent danger should leakage occur. Portable plug-in electric heaters are also used. Heating system capacity should be sufficient to raise load temperature at a rate of 1°F/h. Open-flame gas heaters should never be used in banana rooms for two reasons: (1) ethylene gas used during ripening is explosive at certain concentrations; and (2) the necessary room airtightness could easily result in the open-flame heaters' consuming the available oxygen within the space, thereby extinguishing the flame and permitting raw gas to enter the room.

Air Circulation

Table 3 shows the fruit pulp temperature schedules for 4 to 8 day ripening cycles. A temperature variation of only a few degrees considerably alters the rate of fruit ripening. For even ripening, fruit temperatures must be uniform throughout the room, so the volumetric airflow circulated throughout the entire load must be comparatively large. Centrifugal fans are necessary. They are installed for bottom horizontal discharge, so that the top boxes are not chilled immediately in front of the unit. Fan air output should be rated at 0.62 in. of water external static pressure. Because of heat of respiration, heat must be continually withdrawn from the product even when it is held at a constant temperature. Temperature variation in the load is therefore inevitable, with warmer fruit downstream relative to the circulated air. Unit conditioners at the front of the room over the door discharge toward the rear of the room. This arrangement leaves riper fruit near the door to be shipped first.

For improved air distribution, a sheet metal (or other suitable material) air deflector curved to a 90° arc is mounted full width on the back room wall. This deflector reduces turbulence and directs the air downward for return through the load.

Airflow Requirements

Air volumetric flow requirements are calculated on the basis of conditions required at the end of the pulldown period. Assume a maximum allowable fruit temperature variation of 2°F, an air temperature drop through the cooling unit of 2°F, and product temperature reduction proceeding at a rate of 0.2°F/h. During initial pulldown, the air quantity so calculated will give about a 5.5°F drop through the cooling unit. The general equations are

Table 3 Fruit Temperatures for Banana Ripening

Ripening Schedule	Temperature, °F							
	1st Day	2nd Day	3rd Day	4th Day	5th Day	6th Day	7th Day	8th Day
Four days	64	64	62	60				
Five days	62	62	62	62	60			
Six days	62	62	60	60	60	58		
Seven days	60	60	60	60	60	58	58	
Eight days	58	58	58	58	58	58	58	58

$$q_t = q_r + q_p \quad (1)$$

$$q_t = \dot{m}c_p\Delta t \quad (2)$$

where

q_t = total heat removed, Btu/h
q_r = heat of respiration, Btu/h
q_p = pulldown load, Btu/h
$\dot{m}$ = mass flow rate of air, lb/h
c_p = specific heat of air = 0.24 Btu/lb·°F
Δt = temperature change of air, °F

The values of q_r and q_p can be determined using the heat of respiration and specific heat values given in the section on Refrigeration Load Calculations. For calculation of q_p, assume a temperature reduction rate of 0.2°F/h is occurring at the end of the pulldown period.

$$q_r = 0.5 \text{ Btu/h·lb} \times 42 \text{ lb/box} = 21 \text{ Btu/h per box}$$

$$q_p = 0.2\text{°F/h}[(0.8 \text{ Btu/lb·°F} \times 42 \text{ lb/box}) + (0.4 \text{ Btu/lb·°F} \times 0.5 \text{ lb/box})] = 6.76 \text{ Btu/h per box}$$

$$q_t = 21 + 6.76 = 27.76 \text{ Btu/h per box}$$

At equilibrium, the air temperature Δt equals the fruit temperature Δt, and

$$m = q_t/c_p\Delta t = (27.76 \text{ Btu/h·box})/(0.24 \text{ Btu/lb·°F} \times 2\text{°F}) = 57.83 \text{ lb}_{air}\text{/h per box}$$

$$\text{Volumetric flow rate} = (57.83 \text{ lb/h·box})/(0.075 \text{ lb/ft}^3 \times 60 \text{ min/h}) = 12.85 \text{ cfm per box}$$

For a room with 432 boxes, the airflow should be 432 × 13.02 = 5600 cfm at 0.62 in. of water external static pressure.

Humidity

A high relative humidity around the fruit is important during banana ripening. Bananas ripened under low-humidity conditions are more susceptible to handling damage. When bananas were ripened on the stem, naked fruit was directly exposed to the moving airstream, and automatic room humidifiers were used to prevent excessive fruit dehydration. However, banana room humidifiers are not required with tropical boxing. The fiberboard carton shields the fruit from the moving airstream. In addition, ample sizing of evaporator coils keeps the temperature difference across the coil to 10 to 15°F, thereby limiting dehumidification. Both natural transpiration of the fruit and airtight room design also contribute to high room humidity.

Controls

Ripening room air temperatures are varied frequently during banana processing. Temperatures should be controlled by remote bulb-type thermostats, with bulbs for heating and cooling mounted in the return airstream within the ripening room to prevent short-cycling of equipment. Thermostats should be mounted on the exterior of the ripening room and have a range of 45 to 70°F, calibrated in 1°F increments, with no more than 2°F differential. The thermostats are best mounted on a control panel having a selector switch providing heating and cooling with continuous fan operation.

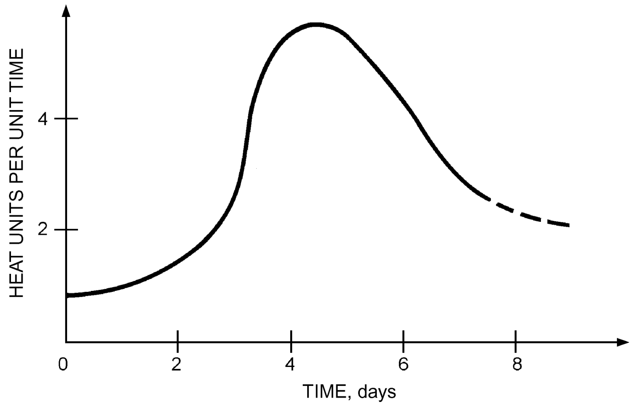

Fig. 4 Heat of Respiration During Banana Ripening

Automatic temperature controllers or programmers are installed in new facilities. Bananas produce heat continuously, but the rate of heat production varies considerably during the ripening cycle. Figure 4 shows a generalized heat-of-respiration curve. Although more complex, the removal of heat of respiration from the load can be viewed, for the purpose of analysis, as a simple conduction process. Applying the general conduction equation,

$$q = \frac{kA\Delta t}{L} \quad (3)$$

$$\frac{k}{L} = \frac{1}{R}$$

where

q = heat of respiration, Btu/h
k = thermal conductivity of packaging material, Btu·in/h·ft²·°F
A = surface area of packaging material, ft^2
Δt = banana temperature minus air temperature, °F
L = thickness of packaging material, in.
R = thermal resistance of packaging material, $\text{ft}^2\text{·°F·h/Btu}$

If kA/L is a constant, Δt must vary as q. Assuming the banana temperature is also constant, room air temperature must be lowered as q increases during ripening. However, the exact value of q at any particular point in the ripening cycle is unknown.

With the conventional, manually adjustable air-sensing thermostat-control system, fruit temperatures are taken manually with a pulp thermometer, and thermostat settings are continually adjusted to followed ripening schedules. This is essentially a trial-and-error procedure.

In contrast, the temperature programmer has a remote bulb, which is placed in a box of bananas in the load. Since the bulb senses fruit temperature directly, heat of respiration is compensated for during ripening. Fruit temperature is automatically adjusted to follow preset cycles.

SUBTROPICAL FRUIT

AVOCADOS

Avocado cultivars grown in California are not grown commercially in Florida, and vice versa. Florida cultivars tend to be larger-fruited than those from California. In California, the Fuerte variety accounts for 75% of the annual crop and is available from October through March. Hass (black skin) is available from April through September. In order of importance, Florida cultivars are Booth 8, Lula, Waldin, and Booth 7. Waldin appears on the market in August, followed by Booth 8 in September, and Booth 7 and Lula from October to February.

The best storage temperature for cold-tolerant Florida avocado cultivars such as Booth 8 and Lula is 40°F. All Florida summer avocado cultivars, such as Waldin, are cold-intolerant and store best at 54 to 55°F. A few cultivars, such as Fuerte, store best at 45°F. Cold-tolerant cultivars can be held in storage a month or longer, but storage of cold-intolerant cultivars is usually limited to 2 weeks because of their susceptibility to softening and chilling injury. The best ripening temperature for avocados is 60°F, but temperatures from 55 to 75°F are usually satisfactory. Temperatures above 79°F frequently cause off-flavor, skin discoloration, uneven ripening, and increased decay.

Storage Disorders

Anthracnose (*Colletotrichum*). Scattered black spots covering firm, decayed tissue that can be removed easily from surrounding flesh. Pink spore masses form on the spots under moist conditions. *Control*: Prevent blemishes and other breaks in the skin.

Chilling Injury. Typified by small to large sunken pits in the skin that turn brown or black and are often accompanied by general browning of the skin and light smoky streaks in the flesh, which develop independently. *Control*: Store at proper temperatures.

MANGOES

The important early cultivars Tommy Atkins and Irwin mature during June and July, followed by such midseason cultivars as the Kent and Palmer, which mature during July and August. The most important cultivar produced in Florida is the large-fruited Keitt, which is late-season and matures during August and September.

Optimum storage temperature for mangoes is 54 to 55°F for 2 to 3 weeks, although 50°F is adequate for some cultivars for shorter periods. Mangoes are subject to chilling injury at temperatures below 50°F. The best ripening temperatures for mangoes are from 70 to 75°F, but temperatures of 60 to 65°F are also satisfactory under certain conditions. At 60 to 65°F, the fruit develops a bright and most attractive skin color, but the flavor is usually tart and requires an additional 2 to 3 days at 70 to 75°F to attain sweetness. Mangoes ripened at 80°F and higher frequently have a strong flavor and mottled skin.

Storage Disorders

Anthracnose (*Colletotrichum*). Large scattered black spots in the skin of ripening fruit. Under moist conditions, pink spore masses develop in spots. *Control*: By regular spraying on the tree and by use of hot water treatment (131°F for 0.12 h) after harvest.

Chilling Injury. Pitting of the skin, which sometimes develops a gray cast. Fruit with chilling injury usually does not ripen uniformly. *Control*: Store at proper temperatures.

PINEAPPLES

Fresh pineapples are available throughout the year, but the supply is much larger from March through June. Only three pineapple cultivars are commercially important in the United States: the Smooth Cayenne from Hawaii and the Red Spanish and Smooth Cayenne from Puerto Rico.

Pineapples harvested at the half-ripe stage can be held for 2 weeks at 45 to 55°F and still have a shelf life of about 1 week. Continuous maintenance of storage temperature is as important as the specific storage temperature. Ripe fruit should be held at 45 to 47°F. Harvesting at the mature green stage is not recommended because some fruit would be too immature to ripen. Mature green fruit is especially susceptible to chilling injury at temperatures below 50°F.

Storage Disorders

Black Rot (*Ceratocystis*). Extensive damage to tissues, which become soft and leaky, ranging from normal to jet black in color. *Control*: Treat freshly cut stem parts with benzoic acid-talc dust, prevent bruising, and cool to 50°F.

Brown Rot (*Penicillium; Fusarium*). Brown, firm decay starting at eyes or cracks; it is common on overripe fruit. *Control*: Provide good growing conditions and market before the fruit is overripe.

Chilling Injury. Fruit takes on a dull hue, the flesh develops water soaking, and the core darkens. *Control*: Hold at recommended temperatures.

REFERENCES

Haller, M.H., D.H. Rose, J.M. Lutz, and P.L. Harding. 1945. Respiration of citrus fruits after harvest. *Journal of Agricultural Resources* 71:327.

Ismail, M.A., T.T. Hatton, D.J. Dezman, and W.R. Miller. 1986. In transit cold treatment of Florida grapefruit shipped to Japan in refrigerated van containers: Problems and recommendations. *Proceedings of the Florida State Horticultural Society* 99:117-121.

BIBLIOGRAPHY

Chace, W.G., Jr., J.J. Smoot, and R.H. Cubbedge. 1979. Storage and transportation of Florida citrus fruits. *Florida Citrus Industry* 51:16.

Chau, K.V., C.D. Baird, P.C. Talasila, and S.A. Sargent. 1992. Development of time-temperature-humidity relations for fresh fruits and vegetables. ASHRAE Research Project RP-678, *Final Report*.

Hardenburg, R.E., A.E. Watada, and C.Y. Wang. 1986. The commercial storage of fruits, vegetables, and florist and nursery stocks. *USDA Handbook* 66. U.S. Department of Agriculture, Washington, D.C.

McCornack, A.A., W.F. Wardowski, and G.E. Brown. 1976. Postharvest decay control recommendations for Florida citrus fruit. *Florida Cooperative Extension Service Circular* 359-A.

Smoot, J.J., L.G. Houck, and H.B. Johnson. 1971. Market diseases of citrus and other subtropical fruits. *USDA Handbook*, p. 398.

Wardowski, W.F., S. Nagy, and W. Grierson. 1986. *Fresh citrus fruits*. AVI Publishing, Westport, CT.