Table 13. Respiration rates of certain fruit (Adapted from Weight et al., 1968 and Grierson, 1976).

Fruit	Temperature (°F) (°C)	BTU/ton/day	Kg-cal/m.ton/day
Oranges	32	900	250
	40	1400	390
	50		
	60	5000	1400
	70	6200	1735
	80	8000	2240
	90	9900	2770
Grapefruit	32	500	140
	40	1100	290
	50	1500	420
	60	2800	785
	70	3500	980
	80	4200	1175
	90	6000	1680
Lemons	32	580	160
	40	800	225
	50	2300	645
	60	3000	840
	70	4100	1150
	80	6200	1735
	90	8000	2240
Bananas			
(green)	60	4850	1360
	70	7400	2070
(ripening)	60	11250	3150
	70	19200	5375
	80	32500	9100
Mangos	40	3500	980
	70	25000	7000
	80	26400	7390
Avocados	40	5500	1540
	60	24500	6860
	70	46300	12965
	80	60000	16800

Table 14. The percentage of oranges unmarketable because of stem end rind breakdown increases drastically when fruit are held under low humidity conditions (Grierson, 1965).

Treatment	% Unmarketable Fruit		% Sound Fruit Remaining
	Peel injury	Decay	
Moist	5.0	4.0	91.0
Dry	46.25	4.25	49.5

Table 15. Some thermodynamic data for citrus fruit (From Grierson, 1976).

Value	Oranges	Grapefruit	Lemons
Specific gravity	0.96	0.88	0.85
Specific heat	0.86	0.88	0.89
Thermal diffusivity	0.0049	0.0047	0.0049
Thermal conductivity, as:			
BTU/hr/sq.ft./°F/in	2.95	3.00	2.85
Kg cal/sec/sq.cm/°C/cm	1.1	0.78	1.05

Table 16. Transit and storage conditions for citrus fruit (From Grierson, 1976).

Type of Fruit	Temperature [°F]	[C°]	Humidity [% RH]	Potential storage life [weeks] z	Chilling injury symptoms if held too cold x	Typical Storage Diseases y
Oranges						
Calif.-Arizona	40-44	4.4-6.7	85-90	6	Rind staining and pitting	Stem-end rot, Penicillium molds,
Florida-Texas	32-34	0-1	85-90	8	Light surface pitting	stem-end rind breakdown.
Grapefruit						
Early	60	15.5	90-95	5	Severe peel pitting	Stem-end rot
Mid-season	55	12.8	90-95	7	Oil gland darkening	Penicillium molds
Latex	50x	10.0	90-95	8		Stem-end rot and Penicillium molds
Tangerines						
Temples, tangelos	38-40	3.3-4.4	85-90	2	Off flavors, rind staining	Stem-end rot, Penicillium molds, sour rot, anthracnose rot.
Limes	50	10.0	90-95	4	Severe peel pitting	Yellowing, peel collapse
Lemons						
Green	58-60	14.4-15.5	85-90	20	Peel pitting (peteca), membranous staining albedo browning	Penicillium molds, stem-end rot (Florida only), sour rot.
Yellow	38-40	3.3- 4.4	85-90	4		

z Any estimate of storage life is very approximate and varies greatly with variety, district, care in harvesting, use of fungicides, etc. These estimates are conservative.

y For illustrations of these disorders see (14).

x Very late grapefruit picked after the next bloom can become susceptible to chilling as early fruit.

Table 17. Calculation of heat load for a truck shipment of oranges From Florida.[a]

Specifications

A. Truck and Contents

1. Semitrailer (40 ft.): weight 4,000 lb., steel construction, with 3 ton refrigeration unit.
2. Fruit: 800 4/5 bu. cartons; weight 45 lb. for fruit, 2 lb. for carton.

B. Temperatures

Ambient (in transit): Average 75°F (day=90°, night=60°).

2. Trailer thermostat setting: 32°F.
3. Fruit: 85° not precooled, 50° precooled, 35° final temperature.

Equations and Factors

1. Total heat load (H_T) = Heat of respiration (H_R) + field heat (H_S) + heat leakage from trailer (H_L) and fan heat (H_F).
2. Average H_R = 4000 BTU per ton per day (not precooled; 1500 BTU per ton per day (precooled).
3. H_S =([(no. cartons x fruit wt. x heat capacity) + (no. cartonx x carton wt. x heat capacity)] x temperature difference) + [(truck wt. x heat capacity) x temperature difference].
4. H_L = 100 BTU per hour per °F temperature difference through trailer wall, etc.
5. H_F = 3000 BTU per hour.
6. Factors:
   a. Heat capacity (specific heat): 0.86 oranges, 0.2 cartons, 0.15 trailer.
   b. Temperature differences:
      1) Trailer: (Ambient - trailer thermostat) = (75-32) = 43° for H_L; (Ambient day - trailer thermostat) = (90-32) = 58° for H_S.
      2) Fruit: Not precooled (85-35°) = 50°; precooled (50-35°) 15° for H_S.
7. Refrigeration: (3 tons x BTU per ton per hour) = (3 x 12,000) = 36,000 BTU per hour.

Table 17. (cont.)

Calculations

A. Not Precooled

1. H_R = [(4000/24) x (36,000/2000) = 3000 BTU per hour.

2. H_S = ([(800 x 45 x 0.86) + (800 x 2 x 0.2)] x 50) + [(4000 x 0.15) x 58] = [(30,960 + 320) x 50] + (600) x 58 = 1,564,000 + 34,800 = 1,598,800 BTU's.

3. H_L = 100 x 43 = 430 BTU per hour

$$\text{Cooling time (hours)} = \frac{H_S}{R - (H_R + H_L + H_F)}$$

$$\frac{1,598,800}{36,000 - (3000 + 430 + 3000)} = 54.6$$

B. Precooled

1. H_R = (1500/24) x 18] = 1124 BTU per hour.

2. H_S = (30960 + 320)15] + (600) x 58 = 504,000 BTU's.

$$\text{Cooling Time (hours)} = \frac{504,000}{36,000 = (1125 + 430 + 3000)} = 16.0.$$

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[a]Basic references: Lutz and Hardenburg, 1968; Ashby, 1970

Table 17A

Storage of citrus fruits

(Talk by W. Grierson to

Société Agricole de Services au Maroc,

Casablanca, Morocco

June 1981).

CRITERIA FOR STORAGE

Identifying the Major Hazard

In storage of any type of fruits or vegetables (except possibly dates) we start with a living product which will eventually die. It helps to know the most likely manner of death.

Climacteric and non-climacteric fruits. Fruits tend to fall into one or other of two physiological groups. Most are "climacteric." That is to say they are picked at a low point in their on-tree metabolism and thereafter ripen, their respiration rate going into a very considerable rise, after which respiration rate drops and the fruit's tissues become disorganized. Apples, pears, peaches and avocados are typical climacteric fruits. Even if protected against fungal invasion they will die physiologically after the peak of the climacteric, becoming overripe and ultimately inedible. For such types of fruits it has become common to use "controlled atmosphere storage" (sometimes called "gas storage") in which the climacteric rise in respiration is suppressed by lowering the oxygen (O_2) level, raising the level of carbon dioxide (CO_2), or both. The effect is to delay the physiological death of the fruit

In contrast, "non-climacteric" fruits, of which citrus and grapes are typical, do not have a climacteric rise in respiration, do not ripen after harvest and the end of postharvest life almost invariably comes from attack by a fungus. An additional difference between citrus and most other fruits is that citrus can have a very long period of "tree storage" during which it can be picked at any time. If postharvest life is to be extended by use of refrigeration, citrus fruits must be picked considerably before the end of the tree storage period. Not only must there be some storage potential, but also susceptibility to decay increases with increasing maturity.

Success in storing citrus fruits lies in minimizing the inevitable losses from fungal decay, not in prolonging physiological life.

Harvesting

The single most critical factor in fruit storage is careful harvesting. Fruit that has been abused during harvesting will have very poor storage potential.

The structure of a citrus fruit is admirably suited to resist gentle pressure that would cause bruises in apples or pears. But this same structure makes the citrus fruit very susceptible to decay. The peel consists of the flavedo (colored part) and the albedo (white part). Embedded in the flavedo are oil cells. If an oil cell is broken, the extruded oil is toxic to the surrounding flavedo cells, killing them causing oleocellosis. The albedo consists of very thin-walled cells with a large amount of inter-cellular atmosphere at 100% relative humidity. No matter how small, any break in the flavedo admits spores to the albedo which then provides a perfect culture medium. The juice vesicles that make up the "flesh" of the fruit are within carpellary sections and attached by fine threads of tissue that make perfect channels for fungal hyphae to penetrate to the center of the fruit. Once infected, a citrus fruit is never salvageable.

Turgidity is of critical importance in susceptibility of tender varieties to damage in harvesting, which is why they are most liable to damage when picked early in the morning. Fruit for storage should not be picked until some time after the dew has gone. The rind oil rupture pressure can be measured with a pressure tester such as is used to measure flesh firmness of apples and pears. Damage to oil cells can be detected with colorimetric papers and minute injuries to the flavedo can be detected with a "vital stain," triphenyl-tetrazolium chloride

A preharvest spray of the systematic fungicide benomyl ("Benlate") one to four weeks prior to picking, can give remarkable resistance to postharvest decay.

Picking equipment. Provide light ladders, picking bags with rigid framing and rigid containers into which to put the fruit. Baskets should never be used.

Above all, fruit should never touch the ground which is a source for infection by fungicide-resistant fungi that cause such storage rots as "sour rot" and "brown rot."

Prestorage Treatments

Except for possible application of a fungicide, the less done to citrus fruit prior to storage the better. One increasingly common technique is to bring the fruit in from the field in large "pallet boxes (bins) holding about 350 to 400 kilograms of fruit. On arrival at the packinghouse, the pallet boxes go through a "drencher" in which the fruit is thoroughly flooded with a fungicide (thiabendazole (TBZ), benomyl or 2-aminobutane, NOT sodium o-phenylphenate). Sometimes fruit are trans-erred from one container to another (as when harvesting into 20 KG boxes and transferring to pallet boxes for storage). When this is the the fungicide can be applied as a spray over a roller conveyor. In any case, care should be taken to prevent contamination of the main supply of fungicide solution (or emulsion) by fungicide resistant organisms such as "sour rot" (Geotrichum candidum) or "brown rot" (Phytophthora spp.).

A special case occurs when lemons crop in cool weather and are to be held for many months until the hot weather market, as in the coastal areas of California. Such lemons are picked with adequate size as the criterion. At harvest they are hard and green. They are then washed treated with a fungicide and with about 500 parts per million (ppm) of 2,4-D and waxed with a half-strength water emulsion wax. These treatments greatly delay the green to yellow color change. As they color in storage, the yield of extractable juice increases markedly

Another special case is storage of grapefruit whose susceptibility to chilling injury is greatly decreased by several days "curing" prior to storage. A pre-storage weight loss of 2 to 3% makes grapefruit considerably more resistant to low temperature than if stored immediately.

The situation is very different for oranges (C. sinensis (L.) Osbeck) and mandarins (C. reticulata Blanco). These should be handled as quickly as possible and held in humid, or at least shaded, conditions until packed or stored. Particularly in some growing districts, oranges and mandarins that have been allowed to dry during the harvesting period sometimes later develop dark withered areas at the stem end ("stem end rind breakdown"

Conditions of Storage

Containers

Containers must be rigid (wood or metal) with the weight of boxes within a stack carried by the container and not by the fruit. Containers should have openings for ventilation; openings in the top and bottom are much more effective than in the sides. (Openings in the bottom of the box amounting to about 5% of the total area are adequate). If pallet es are used they can be stacked tightly within the rows so that the pallets form continuous ducts

Humidity

Humidity should be high. If cartons are used (which is not advisable humidity should be as high as the cartons can stand, which is seldom over 85% relative humidity (% RH). With wood, metal, or plastic containers humidity should be as high as possible without risking precipitation. Without instrumental control of humidity, this is seldom higher than 90% RH. With humidity controlled by a "humidistat," 95% RH is practical. The first move in getting such consistently high humidities is to have the cooling coils large enough that the temperature change as the air crosses them is minimal. If the coil is too small, it has to be run at so low a temperature that it becomes very hard to maintain high humidity even when instrumentally controlled humidifiers are used

Ventilation

Some ventilation is necessary, but excessive ventilation is very expensive, particularly in hot climates. It is usually stated that ventilation is to remove carbon dioxide (CO_2) but this is really incidental. It is ethylene (C_2H_4) that must be removed. Unlike the climacteric fruits, sound citrus fruits give off very little ethylene. But any fruits infected by fungus gives off great amounts of ethylene as they decay. simple portable ethylene analyzer is available and can be used to detect as low a concentration of ethylene as 1 ppm. As soon as ethylene s detectable at this level, ventilation should be increased.

Temperature

It is not possible to state a single optimum storage temperature for citrus fruits. Not only does optimum storage temperature vary widely between citrus species, but even for a given species optimum storage temperature can vary with variety, maturity, growing district and other factors

Chilling susceptibility. A critical consideration is susceptibility to chilling injury (CI). Certain fruits of tropical origin (of which the banana is the classic example) are subject to severe physiological disorders at storage temperatures well above their freezing point. Limes C. aurantifolia (Christm. Swing.), lemons (C. limon (L.) Burm. .) and grapefruit (C. paradisi Macf. are particularly subject to chilling-induced peel collapse and can seldom be held below 50°F for any considerabl period. In Florida, we have conducted an intensive study of chilling injury of grapefruit. Susceptibility to CI depends to a great extent on the vegetative condition of the tree at time of picking. The more igorous the growth flush, the more susceptible the grapefruit are to CI. Grapefruit picked from dormant, drought-stressed trees in midwinter are particularly resistant to CI. To further complicate the problem, early in the season, grapefruit are very susceptible to chilling injury at 5°C while rather resistant at 1°C. By the end of the grapefruit season susceptibility to CI at both 1° and 5°C is very pronounced. Color appears to be a factor, "cured" yellow lemons being more resistant to CI than when they were green

Oranges (C. sinensis (L.) Osbeck) are much more resistant to CI han are the acid citrus fruits although there are differences amon growing districts. For example Florida- and Texas-grown oranges store well at 0° to 1°C, but California- and Arizona-grown oranges have to be stored at temperatures of 4° to 9°C depending on variety, growing district and maturity at harvest. Every growing district has to be studied indiv-icually to determine the optimum storage temperature for its oranges

Mandarin-type fruits (C. reticulata Blanco) and their numerous hy-brids such as tangelos (C. reticulata x C. paradisi) are usually poorly suited to long term storage and some of them are susceptible to CI at temperatures below 5°C. Until the peculiarities of a given variety are well known, it is not wise to store such varieties at temperatures below 5°C. There are exceptions such as the Japanese satsumas (C. unshiu Marc that store well, but, in general, these "specialty fruits" are not well suited to storage.

Criteria for Storage Life

No two lots of fruit are exactly alike and it is not possible to forecast just how long a given crop can be stored. Therefore, if an extended storage period is contemplated, provision should be made for consistent sampling as the possible end of storage life approaches. Ex-tra fruit should be included that will be sacrificed for these samplings. These extra samples should include some fruit from each size being stored and some from each planting and each day's picking. In general, troubles show up first in the smallest and largest sizes, so these should be represented. As soon as trouble can be reasonably expected, sampling should take place at least once a week.

At each sampling, two lots are withdrawn. The first is placed at room temperature and observed for post-storage breakdown. For most purposes, it is necessary that fruit should have at least one week of post-storage "shelf life." The second sample is examined for

Externally visible decay. In almost any area, losses to green blue molds (Peniccilium digitatum and P. italicum) can be expected and are obvious. In some areas (but probably not Morocco), stem-end rot is common and in its incipient stage is detected by thumb pressure on "button" (calyx)

Internal decay. "Black rot" (Alternaria citri) is ubiquitous but curiously intermittent, being a major factor in some years and almost absent in others. It is purely internal and cannot be detected without cutting the fruit longitudinally. It develops very slowly, seldom being a problem in less than eight weeks at storage temperatures. In the incipient stages, it appears as grayish threads in the center core of the fruit. Fruit infected with Alternaria are often particularly highly colored due to the ethylene evolved by this fungus.

3. Peel injuries. Fruit should be removed when peel injuries (chilling injury, stem-end rind breakdown, etc.) are barely detectable in storage. This is because they are apt to darken and sink during the marketing period if held any longer in storage.

4. Granulation. This takes various forms from a simple drying out of the juice vesicles at the stem end to a "gelling" of the contents of the juice vesicles, typically at the stem-end of Valencia oranges or down the central axis of Navel oranges. When this is detected, storage should be terminated as soon as possible

Post-Storage Handling

Fruit from storage is handled very much as for fruit that has not been stored, but should be treated with particular care.

Rot removal

Some decay is inevitable and molds from storage offer a particu ar hazard in that there is a constant tendency to develop fungicide-resistant strains of molds. This became such a problem for California lemon packers (who store huge amounts of fruit) that they have learned to take special precautions to limit the spread of *Penicillium* mold spores from post-storage fruit. It is common to have a "hood" over the dumper that evacuates air rom the dumping area to the outside. It is also customary to have the workers who pick out the moldy fruit do so with a vacuum attachment that sucks up the fruit and its spores. These are wise precautions

Thereafter the fruit should be washed, fungicide treated, waxed, and packed just as for any other citrus fruit. Particular care should be taken not to pack storage fruit too tightly. After any considerable storage period the fruit has lost much of its resilience and is ver easily deformed.

Citrus Maturity and Packinghouse Procedures
Respiration-Humidity-Degreening-Refrigeration (cont.)

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