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STORAGE OF AVOCADOS

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Storage of any perishable commodity is critical to successful marketing and includes the time the fruits are held by the grower, the packer and shipper, the time in transit and the time held by the receiver and distributor. Storage of avocados will be considered on the tree, in a conventional refrigerated system, in controlled atmosphere (CA) and modified atmosphere (MA) systems and in a low pressure (hypobaric) system.

Storage on the Tree

Avocados are unusual in that, depending on cultivar, the grower does not have to pick them as soon as the fruits are mature. Mature avocados of some cultivars, notably 'Fuerte' and 'Hass', can be "stored" on the tree and harvested to suit marketing needs. Fruits of the most desirable cultivars will store on the tree past palatable maturity, but the fruit ripens (with concomitant softening) only after it is picked (2). 'Hass' avocados can remain palatable for 6 months or longer on the tree after maturity is reached. Florida-grown avocados, depending on the cultivar, remain attached to the tree for as short as 3 weeks to as long as 3 months after maturity before excessive abscission occurs. Generally, fruit of the summer cultivars (West Indian race) remain attached to the tree for shorter periods after maturity than later cultivars. Hybrids often have long tree-storage life, although 'Bacon' is an example of a hybrid with a short life on the tree (2).

Harvesting and shipping of fruits which have reached the fullest degree of maturity on the tree are not recommended. The seed may sprout while the fruit is on the tree or the fruits may ripen so rapidly after harvest that they cannot be shipped satisfactorily (13).

Conventional Refrigerated Storage

Once the grower decides to pick, the best storage conditions cannot improve the basic quality of the avocados. The fruits must be picked at the mature stage to develop proper flavor. Immature fruits often shrivel during storage and ripening and do not develop the most desirable flavor. Avocados must be handled as gently as possible during and after harvest to avoid wounds. For storage, fruits should be selected that are free from wounds and decay which could adversely affect storage life and marketability.

Ripening and decay proceed at rates that are directly related to the temperature of the avocados. In southern Florida the temperature at harvest may be 32°C or higher, which would foster ripening and decay during storage. Storage life can be prolonged and ripening delayed by removing this field heat by holding fruits in a refrigerated room (8)

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or by rapid cooling with low temperature air or water (6). This marked delay in the softening of precooled avocados is illustrated in Table 1. In the absence of continuous refrigeration, the heat evolved from respiring fruits can be reduced by storage at low temperatures which decreases the respiration rate of the avocados as shown in Table 2 (3, 11). Respiration rates are an index of the speed at which vital processes are being carried on within the avocados. The faster the rate of respiration, the sooner the nutrients within the fruit will be consumed and the shorter its storage life.

Table 1. Softening rate of precooled 'Lula' avocados.

Cooling conditions (°C and time)	% Soft-ripe on various days after harvest					
	4	5	6	7	8	9
°C						
21° — no cooling	10	53	30	5	0	0
10° for 1 day	0	35	45	10	10	0
10° for 3 days	0	0	0	10	70	20
2° for 1 day	0	0	26	58	16	0
2° for 3 days	0	0	0	0	50	50

[z] Source: Hatton et al. (8).
[y] Values presented are not cumulative. Fruits ripened (softened) at 21°C

Table 2. Rate of respiration and evolution of heat by avocados at various temperatures. [z]

Temperature (°C)	Rate of respiration (mg CO_2/kg/hr)	Rate of heat evolution[y] (g cal/kg/hr)
4-5°	20-30	51-77
15-16°	62-157	158-400
20-21°	74-347	189-885
25-27°	118-428	301-1091

[z] Source: Biale (3).
[y] Heat evolution was computed by multiplying the respiration values by 2.55, the amount of heat in gram calories generated for each mg of CO_2 produced by the combustion of a hexose sugar.

The use of low temperature storage not only reduces the rate of respiration of the avocados but also retards the development of decay. The type and amount of decay that develop depend to some degree on the disease resistance of the avocado cultivar (13). Because no post harvest fungicide treatment is available to control decay, proper temperature and humidity in the storage chamber are important. A relative humidity of 80-90% is recommended (11). Free water on the fruits generally stimulates fungal spore germination, infection of fruit tissue and decay. The temperature of storage should be low enough to retard decay but not so low as to cause chilling injury (CI) to the avocados.

The principal post harvest decays of Florida avocados are anthracnose, caused by *Colletotrichum gloeosporioides* Penz. and stem-end rot, caused by *Diplodia natalensis* P. Evans (13). Dothiorella rot is the most troublesome decay of avocados in California but is a problem only on 'Fuerte' and thin-skinned cultivars grown in moist coastal areas (10). Different avocado-growing areas of the world have different decays depending on the climate, fungal population and avocado cultivar. In Israel, control of fungi causing anthracnose decay and diplodia stem-end rot of avocados has resulted in increased populations of an *Alternaria* sp. which now causes serious losses through development of flesh and stem-end rots (21). Although it is important to select for storage fruits that are free of decay and injuries, most fungal infections at harvest are hidden in a dormant stare in the skin, as in anthracnose decay (4, 20); in the tissue of the stem, as in stem-end rot (22); or in the stomata, as in dothiorella rot (10). Such infections develop rapidly as the fruit ripens. Development of stem-end rot reportedly is retarded in avocados picked with long stems (22), but that procedure is not practical since the stems can cause puncture wounds in other fruits during handling. The importance of storage conditions that favor the fruits and not the fungi cannot be overemphasized.

Avocados may develop CI if held too long at a chilling temperature. Chilling injury in avocados is commonly seen as a grayish-brown discoloration of the vascular tissue. The discoloration may be inconspicuous or be so severe as to discolor all the flesh. Severe CI is accompanied by a sickly brown discoloration of the rind. Uneven ripening and undesirable flavors and odors are often associated with CI. In some cases, fruits may appear satisfactory while in storage, but subsequently develop CI when allowed to soften (8).

Avocados stored at 13°C generally do not develop CI, but since injury depends on both time and temperature and varies with cultivar, maturity and season, fruits of cultivars of the cold-sensitive West Indian race of avocados ('Fuchs', 'Pollock' and 'Waldin', for example) sometimes develop CI even at this temperature (8). Fruits of the major hybrid cultivars (Guatemalan x West Indian) grown in Florida, such as 'Booth 7'', 'Booth 8' and 'Lula', are cold tolerant and can be stored at 4°C. Even fruits of these cultivars, however, can develop CI if stored too long. The 3 horticultural races of avocado vary in their cold tolerance—the Mexican race is most tolerant, the Guatemalan race is intermediately tolerant and the West Indian race is least tolerant (2). The leading California cultivars, 'Fuerte' and 'Hass', are hybrids of Mexican—Guatemalan parentage and 'Hass' is largely of Guatemalan parentage. These cultivars would thus be more tolerant to low temperature (4-7°C) storage than the hybrid Florida cultivars mentioned above.

The optimum storage temperature and expected storage lives of some of the important cultivars of Florida avocados are shown in Table 3. In commercial practice, avocados are sometimes stored up to a week at the packinghouses prior to transit and then again at the terminal markets and retail outlets. When avocados are stored near the grove source, the shipper must plan carefully to move the fruits to the terminal market while they are still firm to avoid damage or overripeness on arrival. Time spent in transit must be considered as storage time when the orderly handling of the fruits is planned.

Table 3. Optimum temperatures and expected safe storage periods of some Florida avocados. [z]

Cultivar	Temperature (°C)	Storage time (days)
Fuchs[y]	13	3
Pollock[y]	13	6
Waldin[y]	13	10
Booth 7	4-7	14
Booth 8	4	14
Lula	4	21

[z] Source: Hatton *et al.* (8).
[y] Softening of the fruits often occurred before storage time was completed.

Controlled and Modified Atmosphere Storage

In CA storage, the normal composition of air is changed, usually by decreasing the oxygen (O_2) concentration and increasing the carbon dioxide (CO_2) concentration. Air normally contains 20.95% O_2 and 0.03% CO_2, inert nitrogen composes most of the remaining gases. The purpose of controlling the atmosphere is to extend storage life and maintain the quality of the commodity more satisfactorily than conventional refrigerated storage in air.

In MA storage, the ambient atmosphere is altered by use of wraps, films, cartons, or other means which allow CO_2 evolved by respiration of the commodity to increase in concentration while the O_2 concentration decreases as it is utilized in respiration. In this type of MA, the concentration of O_2 and CO_2 cannot be controlled precisely. Approximate O_2 and CO_2 concentrations can be estimated by calculations based on the volume of the commodity, its respiration rate at the storage temperature and on the specifications and gas permeability characteristics of the packaging material (7).

Effective use of CA and MA is based on an optimum combination of temperatures and proportions of O_2 and CO_2. The optimum combinations must be determined for each cultivar. If CA and MA storages are to be commercially feasible, their economic advantages must outweigh those of conventional air storage.

The storage life of some cultivars of Florida avocados has been doubled with the use of CA storage (9, 12, 15). Percentage acceptability of stored avocados is also increased by absorption of the ripening hormone (ethylene) during CA storage (9). 'Lula' avocados stored in a CA of 2% O_2 with 10% CO_2 at 4-7°C and 98-100% relative humidity were still 100% acceptable after 60 days, as shown in Table 4 (15). 'Waldin' avocados have been stored successfully for 6 weeks at 7°C in CA (17). The combination of 2% O_2 and 10% CO_2 inhibits ripening, decay and CI development (17). 'Waldin' avocados, for example, normally develop CI at 7°C, but CI development is inhibited under CA. the increased storage life of avocados under CA can be used to extend the marketing season into periods (February and March in Florida, for example) when market supplies are low and prices are high. Use of CA storage would also be useful to hold excess supplies during times of market over-supply.

Table 4. Characteristics of 'Lula' avocados after storage for 20, 40 and 60 days in a controlled atmosphere of 2% O_2 with 10% CO_2 or in air at various temperatures followed by softening at 21 C. [zy]

Storage time and temperature (°C)	Acceptable fruit (%) [x]		Softening time (days) [w]		External chilling injury (rating) [v]		Decay (rating) [v]	
	Air	*CA*	*Air*	*CA*	*Air*	*CA*	*Air*	*CA*
20 days								
4	80 ab	100 a	3.3	6.0	1.5	0.4	0.1	0.1
7	73 b	100 a	3.4	5.6	1.3	0.4	0.0	0.0
10	47 c	100 a	3.1	6.0	2.1	0.3	0.3	0.5
40 days								
4	0 d	100 a	- [u]	5.1	4.0	0.9	0.8	0.2
7	0 d	93 ab	- [u]	5.5	3.7	1.1	1.5	0.3
10	0 d	100 a	- [u]	5.4	- [u]	0.9	4.0	0.3
60 days								
4	0 d	100 a	- [u]	5.0	4.0	1.1	- [u]	0.1
7	0 d	100 a	- [u]	5.3	- [u]	1.7	- [u]	0.1
10	0 d	87 ab	- [u]	5.0	- [u]	0.7	- [u]	0.7

[z]Source: Spalding and Reeder (15).
[y]Each figure represents the average of data using 20 fruits per treatment.
[x]Mean separation by Duncan's multiple range test, 5% level.
[w]Softening time of unstored fruits was 6.4 days.
[v]Ratings based on percentage of total surface area affected: (0) None; (1) Trace; (2) Slight; (3) Moderate and (.4) Severe.
[u] Readings not made because of severe decay.

The Florida avocado industry constructed the first CA facility for the storage of avocados and used it successfully to store 'Lula' avocados during the 1972-73 season (16). To obtain the desired atmosphere, air from a sealed CA room is passed through a catalytic burner containing a platinum-palladium catalyst to oxidize propane. The O_2 of the air is consumed in the process, but incomplete oxidation of propane releases both CO_2 and ethylene. Ethylene is eliminated by venting the atmosphere from the catalytic burner outside the building until the temperature of the burner is approximately 593°C at which temperature ethylene is destroyed. When tests, with an ethylene analyzer, indicate that the air contains less than 0.5 ppm of ethylene, the air is cooled and admitted to the CA room. The atmospheric gases were also scrubbed with water to reduce ethylene concentrations in large-scale avocado CA storage tests in Israel (14). Air from the CA room is recycled through the catalytic burner until the desired O_2 concentration is obtained. The CO_2 concentration can, if necessary, be reduced by adding bags of lime to absorb CO_2. The concentration of CO_2 must be kept below 15% to prevent fruit injury.

Use of an MA involving packaging of avocados in polyethylene bags has been proposed by workers in Trinidad (19) as a means to delay ripening and extend storage life so the fruits can be shipped to distant markets. Data in Table 5 show that the system permits an extra 2 days for marketing. Additional time would increase safe storage time so that fruit could be transported by sea to northern industrial countries. Decay was not a problem in the polyethylene bags, probably because exceptionally sound fruits were selected. However, other researchers (1) have reported problems with decay of avocados packaged in polyethylene bags. Possibly an effective fungicide treatment is needed to prevent decay of avocados in packages.

Table 5. Effects of temperature and polyethylene bagging on the softening of 'Granada' avocado fruits.

	Days to soften in various wrappings			
Storage temperature (°C)	Polyethylene	Perforated polyethylene	Unwrapped	Mean[y]
16-21°	11.2	7.8	7.6	9.4 a
Room temperature	8.5	7.1	6.3	7.5 b
Mean[y]	9.8 a	7.4 b	7.0 b	

[z]Source: Thompson *et al* (19).
[y]Mean separation by Duncan's multiple range test, 5% level.

Low Pressure (Hypobaric) Storage

In low pressure (LP) storage a commodity is placed in a flowing stream of moist, air (80-100% relative humidity) at reduced atmospheric pressure (Generally less than 200 mm Hg) (5). In the LP system, which serves as an aid to refrigeration rather than as a replacement, conventional refrigeration equipment is used. Conflicting results (5, 18) have been reported on the effectiveness of LP for storage of avocados. Results (18) suggest that CO_2 (10%) must be present in the LP atmosphere for successful storage of avocados (Table 6). Regardless of atmospheric pressure, fruits stored in 2% O_2 with 10% CO_2 developed little decay and CA, and most were acceptable; whereas all fruits stored in 2% O_2 without CO_2 developed severe decay and CI and were unacceptable. 'Waldin' avocados lost very little weight and remained firm to hard, regardless of the storage atmosphere. Weight loss during softening was proportional to the softening time.

The CO_2 requirement in the LP system, for acceptable storage of avocados, agrees with the finding that CO_2 is essential in the CA system for avocados (17). However, the addition of CO_2 does not make the LP system superior to the CA system, but simply makes the systems comparable for quality maintenance of avocados. The use of any storage system ultimately depends upon whether it is economically advantageous.

Summary

Four methods of storing avocados *(Persia americana* Mills) are reviewed and discussed. Storage of mature avocados on the tree has generally been more successful with cultivars grown in California ('Fuerte' and 'Hass') than with those grown in Florida. Harvesting and shipping of fruits which have reached the fullest degree of maturity on the tree are not recommended. Conventional refrigeration is effective for storage if the temperature is low enough to retard decay and ripening, but not so low that the avocados will be chilled. Avocados of the West Indian race are sensitive to chilling and should be stored at 13ºC, whereas cold-tolerant avocados can be stored at 4-7ºC, depending on cultivar.

Controlled atmosphere (CA) storage extends storage-life and maintains quality more satisfactorily than conventional refrigerated storage. A CA of 2% O_2 with 10% CO_2 reduces decay and chilling injury, permitting storage of cold-sensitive 'Waldin' avocados at 7ºC. The first commercial CA facility for avocados was built in Florida in 1972. Modified atmosphere (MA) storage extends storage life by-use of wraps, films, cartons or other means to decrease the O_2 and increase the CO_2 concentrations in a container of avocados. The optimum combination of temperature and proportions of O_2, and CO_2 must be determined for each cultivar. Low pressure (LP) or hypobaric storage has not been successful for storage of Florida cultivars unless CO_2 (10%) is present in the LP atmosphere.

Table 6. Quality of 'Waldin' avocados stored at 7ºC for 25 days in various atmospheres under normal (NP) or low atmospheric pressure (LP) and then softened at 21ºC in air under NP.[z]

Storage conditions					Weight loss (%)					
Type NP	(mm Hg)	O_2 (%)	CO_2 (%)	Firmness before and after storage[x]	During storage	During softening	Softening time (days)	Decay (%)	Chilling injury (%)	Acceptable fruit[w] (%)
	Unstored fruits[y]			5.0	-	6.4	5.4	4	0	96
NP	760	21	0	4.0	2.2	1.3	1.2	76	100	0
NP	760	2	0	4.9	1.1	4.9	5.1	100	100	0
NP	760	2	10	5.0	1.1	4.9	5.0	4	4	92
NP	91	2	0	4.6	2.2	2.9	3.2	64	100	0
NP	91	2	10	5.0	3.1	3.8	3.7	0	0	100

[z]Source: Spalding and Reeder (18).
[y] Mean for 25 fruit.
[x] In the rating system for firmness, 5=hard, 4=firm, 3=firm ripe, 2=soft ripe and 1=overripe.
[w] Acceptable fruits had good appearance, were free of moderate or severe decay and chilling injury and had no off-flavors.

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