Avocado

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Scientific Name and Introduction

The avocado originated in Central America and southern Mexico. The Aztecs considered the avocado an aphrodisiac and called it "huacatl." In Chile, Peru, and Ecuador, it is called "palta," an Incan name. Spanish-speaking people also call it "aguacate," "cura," or "cupandra." The avocado is known as "abogado" in Spain. Historically, the avocado has also been referred to as "alligator pear," "vegetable butter," "butter pear," and "midshipman's butter."

The avocado is botanically classified into three races: (1) West Indian (WI), *Persea americana* Mill. var. *americana* (*P. gratissima* Gaertn.), tropical with large variably shaped fruit and lower oil content; (2) Mexican (MX), *P. americana* Mill. var. *drymifolia* Blake (*P. drymifolia* Schlecht. & Cham.), semitropical with smaller elongated, thin-skinned fruit and higher oil content; and (3) Guatemalan (G), *P. nubigena* var. *guatemalensis* L. Wms., subtropical with mostly round, thick-skinned fruit and intermediate oil content (Bergh and Lahav 1996). Many of the commercial cultivars are hybrids of these three races. There is great variability in fruit traits not only between races but between cultivars within a race. One of the most distinct differences between cultivars is the peel color when ripe. The peel of some cultivars changes from green to black or purple with increasing maturity or ripening.

Avocados are available year-round in the United States and are supplied by two major producing areas: California (90%) and Florida (10%). Fruit (mainly 'Hass') are also imported from (in approximate order by volume) Chile, Mexico, the Dominican Republic, New Zealand, Bahamas, and Jamaica.

There are many cultivars of avocados grown commercially in the United States, and they come in assorted sizes and shapes. The primary California cultivar is Hass, a G-MX hybrid that accounts for approximately 95% of the planted acreage. Other cultivars include 'Bacon,' 'Fuerte,' 'Gwen,' 'Lamb Hass,' 'Pinkerton,' 'Reed,' and 'Zutano.' With the exception of 'Reed,' which is believed to be entirely of the G race, the other cultivars are considered to be primarily G-MX hybrids. 'Hass' accounts for 80% of avocado consumption in the United States and is the main focus of research and development. The main Florida cultivars (West Indian and Guatemalan races and hybrids) are 'Simmonds,' 'Nadir,' 'Booth 8,' 'Choquette,' and 'Lula.'

Quality Characteristics and Criteria

For avocado, the major quality criteria used during grading are size and skin color, as well as freedom from wounds, blemishes, insect damage (particularly from caterpillar and thrip scarring), spray residues (most commonly copper), and other contaminants on the skin. When ripe, the key issues are

absence of disease (body rot and stem end rots), physiological disorders (flesh graying), and physical damage (bruising). Many of these quality factors depend on the cultivar, and consumer preference for size, shape, and color can vary from region to region.

While avocados from both Florida and California are high-quality fruit, there are significant differences in size, texture, and flavor. Florida avocados are usually at least twice as large as those from California and often sell at a lower price. The smaller California avocados have a desirable nutlike flavor and a richer, creamier texture than the less oily Florida fruit, which are sometimes marketed as "lite avocados." These differences are mainly due to the fact that different horticultural races of the avocado are produced in California and Florida.

Avocados are one of the few fruit that contain significant quantities of oil; sometimes more than 30% of fresh weight, depending on cultivar and maturity. Oil content is a key part of the sensory quality. Oil quality is very similar to that of olive oil, with approximately 75% monounsaturated, 15% saturated, and 10% polyunsaturated fatty acids (omega-6). However, there is variation with race, cultivar, growing region, and season. The high-monounsaturated, high-polyunsaturated, and low-saturated fatty acid content makes this a "healthy" oil in terms of effect on heart disease. In addition, avocado oil contains a range of other health-promoting compounds such as chlorophyll, carotenoids, α-tocopherol, and β-sitosterol. These health factors, along with the absence of cholesterol, should be emphasized with consumers since avocados are perceived by some as an unhealthy or "fat" fruit. Extraction of oil from reject avocados is carried out in some countries for use in cosmetic products and for culinary purposes.

Traditionally, fruit produced in the United States have been "clip" harvested (peduncle cut to leave a "button" at the top of the fruit). However other producing countries (Australia, Israel, Spain, and South Africa) are now "snap"-harvesting 'Hass' fruit. The ultimate success of snap harvesting depends on fruit maturity, growing conditions (rain), and cultivar (Arpaia and Hofshi 1998).

Horticultural Maturity Indices

The percentage of dry matter in avocado fruit is highly correlated to oil content and is the key maturity index used in California and worldwide (Lee et al. 1983). Minimum dry matter percentage ranges from 17 to 25%, depending on cultivar. In California, the minimum percentage of dry matter at harvest for the major cultivars are 'Bacon' (17.7%), 'Fuerte' (19.0%), 'Gwen' (24.2%), 'Hass' (20.8%), 'Pinkerton' (21.6%), 'Reed' (18.7%), and 'Zutano' (18.7%). In California, fruit are also released into the market at predetermined dates based on dry matter and size for each cultivar. For example, the size and release dates for 'Hass' are size 40 and greater on November 28; Size 48, December 12; Size 60, January 2; and Size 70 or smaller, January 16. Florida avocados have lower oil content (3 to 15%) and are generally harvested at a specific date and weight or size.

Avocados can be held on the tree for many months after they are physiologically mature because they do not ripen until they are harvested. However, time to ripen does decrease with increasing time on the tree. Freshly harvested avocados tend to have "green" skins, though 'Hass' fruit that are harvested late in the season may have some skin darkening at harvest. The peel of ripe 'Hass' and 'Lamb Hass' avocados should have a dark, purple-black or black skin, while green-skinned cultivars remain green when ripe. Avocados are ripe when the fruit yields slightly to light finger pressure. Pulp color, texture, and flavor when ripe are cultivar specific.

Grades, Sizes, and Packaging

California avocados are packed in single-layer 12.5 lb (5.67 kg) flats or trays, 2-layer 25 lb (11.34 kg) lugs, and 25 lb (11.34 kg) volume-fill boxes. RPCs (returnable plastic containers) are used increasingly. There is also increased usage of prepacked units such as polyethylene containers ("clam shells") or mesh bags. For Florida avocados, the common packages used are single-layer, 13 lb (6.12 kg) flats; two-layer, 27 lb (12.47 kg) lugs; 35 lb (15.88 kg) cartons; and 10 lb (4.54 kg) natural packs.

California avocados are graded as No. 1 or No. 2. Florida avocados are graded as U.S. No. 1, U.S. No. 2, and U.S. Combination. However, only some Florida varieties are graded, while the others are marketed as unclassified. In California, fruit are weight-sized into the following categories: 20 (18.75 to 22.0 oz, 532 to 624 g), 24 (15.75 to 18.75 oz, 447 to 532 g), 28 (13.75 to 15.75 oz, 390 to 447 g), 32 (11.75 to 14.0 oz, 333 to 397 g), 36 (10.5 to 12.5 oz, 298 to 354 g), 40 (9.50 to 11.50 oz, 269 to 326 g), 48 (7.50 to 9.50 oz, 213 to 269 g), 60 (6.25 to 7.50 oz, 177 to 213 g), 70 (4.75 to 6.25 oz, 135 to 177 g), and 84 (3.75 to 4.75 oz, 106 to 135 g) count for 25 lb packs, and half these values for flats (or single-layer trays). Florida fruit are packed by count. Regulations specify that the pack shall be at least fairly tight and that the weight of the smallest fruit in any container shall not be less than 75% that of the largest fruit in the same container. Commonly used sizes for Florida packages are 6, 7, 8, 9, 10, 12, 14, 16, 18, 20, and 24 count.

Precooling Conditions

Ripening and associated softening of avocados can be delayed by cooling soon after harvest. This is critical where long storage periods are required or where field temperatures are above 25 °C (77 °F). Forced or passive air-cooling is generally carried out as rapidly after harvest as possible; within 24 to 48 h or sooner is recommended. Hydrocooling of 'Hass' is also used commercially. Recommendations as to the target temperature (prior to packing) vary between 5 and 15 °C (41 and 59 °F) and may be influenced by the emphasis on whether fruit should be graded with condensation or not.

Optimum Storage Conditions

Optimum storage conditions vary by cultivar, growing conditions, time in the season (maturity), and length of storage required. However, in general, unripe avocados should be stored at 5 to 12 ºC (41 to 54 ºF) with RH of 85 to 95%. Optimum storage temperatures for 'Hass' are 5 to 7 °C (41 to 45 °F) for early-season fruit and 4 to 5.5 °C (40 to 42 °F) for late-season fruit. After 3 to 4 weeks storage, 'Hass' fruit quality is reduced, and storing fruit for longer than 6 weeks remains a challenge.

Increased physiological disorders—for example, chilling disorders and uneven ripening—and rots result from suboptimal storage temperatures. Therefore, it is important to maintain the appropriate temperature for unripe fruit and stack containers to allow for proper air circulation and temperature control.

Controlled Atmosphere (CA) Considerations

CA storage is commonly used for transporting fruit to distant markets in refrigerated shipping containers. The atmosphere used and technology for controlling the atmosphere vary between shipping

companies. Generally, O_2 levels of 2 to 5% (or possibly as high as 10%) + 3 to 10% CO_2 are used. The primary benefit of low O_2 is that of delayed softening and reduction of respiration and ethylene production from standard storage temperatures. Elevated CO_2 may delay softening and reduce sensitivity to external chilling injury and allow lower storage temperatures (Faubion et al. 1992). Low-O_2 injury may appear as irregular brown to dark brown patches on the skin and may additionally cause diffuse browning of flesh beneath affected skin. CO_2 atmospheres above 10% can be detrimental by leading to discoloration of the skin and development of off flavor, particularly when the O_2 concentration is less than 1%. Reducing ethylene levels to below 1 µL L^{-1} using ethylene scrubbers during CA storage may provide added benefits for retarding ripening and decrease development of chilling injury (Faubion et al. 1992).

Alternative Technologies for Long-Term Storage

1-MCP Treatments. Use of 1-MCP (1-methylcyclopropene) is in the experimental stage and should be used with caution. Application of 1-MCP to avocados delays ripening and thus reduces internal chilling injury (flesh graying, vascular browning), which is associated with ripening during storage if storage times are long or temperature management is poor (Pesis et al. 2002). The optimum treatment conditions are likely to be in the area of 50 to 100 nL L^{-1} (ppb) at about 6 °C (43 °F) for 18 to 24 h. For 'Hass,' 1-MCP treatments will have benefit if fruit are stored for longer than 4 weeks. However, for other cultivars that exhibit higher levels of internal chilling injury at even short storage times, 1-MCP may be of more benefit. Care should be taken because applying higher concentrations may result in excessive delays to softening and ripening, which in turn are likely to increase disease incidence. 1-MCP does not reduce external chilling injury (skin blackening) of 'Hass' avocados.

Step-Down Temperatures. The other key technology for maintaining fruit quality (particularly preventing internal chilling injury), proven over many years by the South African industry, is the use of "step-down" temperatures (Vorster et al. 1987). Temperatures are typically decreased 1 to 2 °C each week during shipping, with the final temperature not to drop below 3.5 °C (38 °F), and with progressively lower initial temperatures as fruit maturity increases. These temperature regimes have been developed and refined over many years and have resulted in a protocol for each cultivar for differing times in the season and growing region.

Retail Outlet Display Considerations

Avocados are best ripened at 15 to 20 ºC (59 to 68 ºF) (Hopkirk et al. 1994). The ripening rate at temperatures below 15 ºC (59 ºF) is relatively slow, and ripening at temperatures above 25 ºC (77 ºF) may result in increased decay, uneven ripening of the flesh, and off flavors. As for bananas, ethylene treatment can be used to "precondition" or "preripen" fruit. Avocados are very susceptible to bruising during softening (Arpaia et al. 1987) and thus should be handled carefully during transport and display. Any means of minimizing "squeezing" by customers will also improve quality. Since quality can decrease rapidly during softening, it is best to check avocado ripeness every day and to display or use the ripest fruit first. If possible, ripe or near-ripe fruit should be held at lower temperatures (1 to 6 °C, 34 to 43 °F) (Young and Kosiyachinda 1976) to reduce the proportion of fruit that become overripe, with concomitant increase in rots and other disorders. Avocados should not receive a water sprinkle or top ice.

Chilling Sensitivity

Avocados exhibit two forms of chilling injury, internal and external, which are generally induced by quite different storage conditions. Internal chilling injury manifests as a grayish-brown discoloration of the flesh, particularly at the base of the fruit around the seed. This can be associated with vascular browning, which starts at the base of the fruit (rather than at the stem end, which is often associated with stem end rots). In 'Hass,' internal chilling injury tends to occur after about 4 or more weeks in storage at about 6 °C (43 °F), but will be influenced by maturity and growing conditions. Cultivars differ in their susceptibility to this disorder, with some being very sensitive. Calcium levels are a possible explanation for differences in internal chilling injury (Chaplin and Scott 1980). Another low-temperature disorder, "pulp spot," may be observed in 'Fuerte' fruit in which small dark spots can be observed in the flesh. Internal chilling injury is generally associated with softening of fruit during storage and thus is increased by the presence of ethylene (Chaplin et al. 1983). Internal chilling injury is the key limiting factor for long-term storage of avocados.

External chilling injury occurs as irregular patches of blackening on the skin (similar to apple scald) that can be observed during storage but that generally increase slightly in intensity after removal from cold storage. The damage is first seen in inner cell layers of the exocarp and then the outer layers of the skin (Woolf 1997). In cultivars that naturally darken during ripening, such as 'Hass,' the damage will be less apparent after ripening but may be distinguished as brown, corky skin tissue in ripe fruit. External chilling injury is generally induced by temperatures below 3 °C (38 °F). However, fruit become less sensitive with increasing maturity, and ripe fruit are less affected. Fruit exposed to low temperatures may be of poor internal quality when ripe, with a high incidence of rots and softening disorders (Woolf et al. 1995), but will have lower incidence of internal chilling injury (graying). For 'Hass' fruit stored for long periods at standard storage temperatures (for example, 6 to 7 weeks at about 6 °C [43 °F]), a form of external chilling injury is expressed that is of a very similar appearance to that observed at low temperatures. This form of external chilling injury will tend to be seen in fruit that are quite soft (nearly ripe) at the point of removal from storage.

Ethylene Production and Sensitivity

Rates of ethylene production are generally low for unripe avocados, less than 0.1 $\mu L\ kg^{-1}\ h^{-1}$ at 20 °C (68 °F), but increase rapidly after harvest up to levels greater than 100 $\mu L\ kg^{-1}\ h^{-1}$ at 20 °C (68 °F) when fully ripe. Therefore, ripe avocados should not be stored with fruits and vegetables that are sensitive to ethylene damage. Unripe avocados are very sensitive to ethylene. They should not be stored near ripe fruit or other fresh produce that produces more than trace ethylene. Ethylene exposure during storage accelerates ripening and softening and can increase incidence and severity of internal chilling injury and decay.

Ethylene Treatment ("Preconditioning" or "Preripening")

There is an increasing move at the retail level toward "ripe for tonight" programs that generally result in significant increases in sales. This is achieved by treating avocados with 10 to 100 $\mu L\ L^{-1}$ ethylene at 17 to 20 °C (63 to 68 °F) for approximately 48 to 72 h (early season), 24 to 48 h (mid season), or 12 to 24 h (late season). This significantly reduces both the time to ripen (to 3 to 6 days, depending on cultivar and maturity) and fruit-to-fruit variability in ripening. If fruit are stored prior to ethylene treatment, the duration of treatment required to achieve maximum rate of ripening is reduced. For 'Hass,' after 3 to 4 weeks of storage, there may be relatively little benefit to ethylene treatment

(particularly for later-season fruit), since the time to ripen decreases during storage. Because heat production of avocados is much greater than that of many other fruit crops, careful attention should be paid to air flow and temperature management during ethylene treatment and subsequent ripening. Palletized fruit may reach temperatures of more than 30 °C (86 °F), with negative effects on ripe fruit quality. For this reason, ethylene treatment of palletized fruit should be carried out under forced-air conditions. During ethylene treatment, CO_2 levels should be maintained at less than 1 to 2% by either continual venting of the atmosphere or full venting and ethylene reinjection if "shot" systems are used. Following ripening, fruit should be precooled to 5 °C (41 °F).

Respiration Rates

Respiration rate of avocados is relatively high compared with many other fruit crops.

Temperature	mg CO_2 kg^{-1} h^{-1}
5 ºC	20 to 50
10 ºC	50 to 160
20 ºC	80 to 300

Data from Kader and Arpaia (2001).

To get mL CO_2 kg^{-1} h^{-1}, divide the mg kg^{-1} h^{-1} rate by 2.0 at 0 °C (32 °F), 1.9 at 10 °C (50 °F), and 1.8 at 20 °C (68 °F). To calculate heat production, multiply mg kg^{-1} h^{-1} by 220 to get BTU per ton per day or by 61 to get kcal per tonne per day.

Physiological Disorders

There is a range of physiological disorders of avocados (Arpaia et al. 2009), and most of these occur following long storage periods. The key disorders are flesh graying, vascular browning, and pulp spot, which are all symptoms of internal chilling injury (see *Chilling Sensitivity*). If fruit are stored for excessively long periods, the flesh may also fail to ripen evenly and become increasingly susceptible to pathogens. The timing of expression of internal chilling injury and its severity depend on temperature management, initial ripeness, cultivar, production area, and fruit maturity. External chilling injury may occur if fruit are stored at low temperatures (0 to 3 °C [32 to 38 °F]) or for long periods (more than 6 weeks) at standard storage temperatures.

Postharvest Pathology

Rots of avocados are divided into two categories on the basis of their location (Snowdon 1990). Stem end rots enter the fruit at the stem, or peduncle end of the fruit, and move down the fruit resulting in discolored flesh, often with associated browning of the vascular strands (Johnson and Kotze 1994). Body rots invade through the skin and are generally manifested as circular brown to black spots that may be covered with spore masses in the later stages of infection. Decay penetrates through to the flesh resulting in discrete areas of discolored flesh. In cultivars that darken when ripe ('Hass'), rots may be less obvious externally. Rots are rarely observed at harvest or during storage but can increase rapidly with fruit softening. Where infection pressure is high and physical damage to the skin occurs prior to storage, small, soft-black circles of infection ("measles") can occur during storage. These generally spread rapidly outwards after removal from storage.

The causal organisms can vary with growing environment and country. The following pathogens (in order of frequency) have been isolated from decayed California avocados: *Colletotrichum, Dothiorella, Alternaria,* and *Phomopsis* spp. (Smilanick and Margosan 2001). Differences in the pathogens responsible for decay exist among countries; for example, New Zealand versus Australia (Everett 1996, Arpaia et al. 2009).

Preharvest control methods for postharvest fungal decay include good orchard sanitation (removal of mummified fruit and dead wood) and effective preharvest fungicide application, such as copper, which is widely used in some countries (including the United States, in Florida) where humid growing conditions prevail. Harvesting should not be carried out in the rain or when fruit are wet, and careful handling to minimize skin damage helps reduce rots. Snap picking of fruit can reduce stem end rot incidence in dry periods, but it can result in increased rots in humid growing environments or when fruit are harvested in wet conditions.

Perhaps the most important area for reducing rots is that of maintaining good ripe-fruit quality by optimizing temperatures during handling, storage, transport, and ripening. It is also critical not to store fruit for long periods. Ripening fruit at lower temperatures—for example, 15 to 20 °C (59 to 68 °F)—can lead to significant reduction in rots compared with higher temperatures (Hopkirk et al. 1994). Storing 'Hass' fruit for 1 to 3 weeks can also reduce rot incidence (as compared with nonstored fruit), as can ethylene treatments, which both synchronize and hasten ripening. Postharvest fungicides (prochloraz, benlate [benomyl], and thiabendazole) are used in some countries, but these are not registered for use in the United States (Darvas et al. 1990). Research on biological control agents is being carried out in South Africa, New Zealand, and Australia.

Quarantine Issues

Issues relating to quarantine will vary according to the marketplace and country of origin, and guidance should be sought from the Department of Agriculture. If avocados are grown in fruit-fly-infested areas, significant quarantine issues will arise. Methyl bromide treatment is an APHIS-approved treatment for Mediterranean fruit fly, but it results in a significant reduction in fruit quality. Because avocados do not tolerate standard high-temperature disinfestation treatments, (for example, fruit core temperatures of 47 °C [117 °F] for 20 min), low-temperature disinfestation is the most viable approach. Tolerance to temperatures that can be used for low-temperature disinfestation can be imparted by pretreatments at 38 °C (100 °F) (Sanxter et al. 1994, Woolf et al. 1995), for example, or by low-temperature conditioning (Woolf et al. 2003). However, the only commercial disinfestation treatment in use is for Queensland fruit fly in 'Hass' avocados: 6 to 8 °C (43 to 47 °F) for 3 to 5 days followed by 16 days at temperatures <1 °C (34 °F) (Hofman et al. 2003). However, this low-temperature disinfesting treatment may not be effective for all fruit fly species, since cold tolerance varies.

Suitability as a Fresh-Cut Product

Avocados are not currently marketed as fresh-cut products, but they are marketed as chunks, paste, and guacamole dips.

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