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NOTES
GENERAL

1. Taxonomy

*Persea americana* Mill., Lauraceae (Myrtle family)

2. Botany

Avocados originated in Central and northern South America and are now widely distributed throughout the tropics and subtropics of the world. There are three horticultural races (subspecies) of avocado, viz. the West Indian race (*P. americana* Mill. var. *americana* (*P. gratissima* Gaertn.)), the Guatemalan race (*P. nubigena* var. *guatemalensis* L. Wms.) and the Mexican race (*P. americana* Mill. var. *drymifolia* Blake (*P. drymifolia* Schlecht. & Cham.)). These races differ with respect to several morphological, physiological and chemical characteristics. The West Indian race (not native to the West Indies) is tropical in nature and intolerant of low temperature storage. The fruit are of a variable size and has a thin, smooth skin, a low oil content (3-10%) and a sweeter flavour. This race is considered by some to have the best flavoured fruit and include varieties such as Maoz, Ruchle and Waldin. The Guatemalan race is subtropical in nature and is therefore more tolerant to low temperatures. The fruit are large and has a rough skin, intermediate oil content (8-15%) and a rich flavour. Varieties that fall into this race include Edranol,
Pinkerton, Reed and Gwen. The Mexican race is most cold tolerant of the three. Its fruit are small, has a high oil content (up to 30%) and a rich, anise-like flavour. Examples of varieties in this race are Duke, Northrop and Zutano. It appears that the popular Fuerte variety (12-17% oil) is a hybrid between the Guatemalan and Mexican races. There is evidence that the widely cultivated Hass variety (18-22% oil) is also a Guatemalan-Mexican hybrid. This variety is popular for its flavour and longer shelf-life. Ryan is another important example of the Guatemalan-Mexican hybrid varieties. Other Hass-like varieties include Grace, Gem, Harvest, Lamb and Maluma.

Avocado trees vary in size and shape from short and spreading to tall and erect. Flowers are small, pale-green or yellow-green in colour and born on racemes (inflorescence with stalked flowers arranged singly along an elongated unbranched axis) near the tips of the branches. The flower has six perianth lobes arranged in 2 whorls of 3 each, 9 stamens arranged in an outer circle of 6 and an inner circle of 3, and a single pistil. The single ovary is superior (attached to the receptacle above the attachment of other floral parts) with one carpel and one ovule. A pair of orange nectar glands is located at the base of the inner stamen circle. Avocado cultivars are classified into Class A or Class B, depending on
the hours of the day when it is receptive to or shedding pollen. Flowers of Class A cultivars will receive pollen in the morning while those of Class B cultivars shed pollen in the morning. The avocado fruit is a berry with a single seed surrounded by a thick fleshy mesocarp (fleshy edible portion derived from the ovary wall). With reference to its respiratory pattern during ripening, avocados are classified as climacteric.

3. Nutrition

The nutritional value* of fresh avocado fruit per 100 g edible portion is:

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>73%</td>
</tr>
<tr>
<td>Calories</td>
<td>170 kcal</td>
</tr>
<tr>
<td>Protein</td>
<td>2%</td>
</tr>
<tr>
<td>Fat</td>
<td>14.7%</td>
</tr>
<tr>
<td>Sugars</td>
<td>0.7%</td>
</tr>
<tr>
<td>Starch</td>
<td>0.1%</td>
</tr>
<tr>
<td>Fibre</td>
<td>6.7%</td>
</tr>
<tr>
<td>Minerals (mg):</td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td>12</td>
</tr>
<tr>
<td>Iron</td>
<td>0.6</td>
</tr>
<tr>
<td>Magnesium</td>
<td>29</td>
</tr>
<tr>
<td>Phosphorous</td>
<td>52</td>
</tr>
<tr>
<td>Potassium</td>
<td>485</td>
</tr>
<tr>
<td>Sodium</td>
<td>7</td>
</tr>
<tr>
<td>Vitamins (mg):</td>
<td></td>
</tr>
<tr>
<td>Vitamin A</td>
<td>146 IU</td>
</tr>
<tr>
<td>Vitamin B₁ (thiamine)</td>
<td>0.07</td>
</tr>
<tr>
<td>Vitamin B₂ (riboflavin)</td>
<td>0.13</td>
</tr>
<tr>
<td>Vitamin C</td>
<td>10</td>
</tr>
<tr>
<td>Niacin</td>
<td>1.7</td>
</tr>
</tbody>
</table>

4. **Harvesting and Quality Indices**

Avocados do not ripen while still attached to the tree and are hand-harvested when fully mature. Maturation of the avocado is not accompanied by obvious external colour changes and harvest maturity is determined by DAFB (Days After Full Bloom), fruit specific gravity, size (length, diameter, volume) and dry matter or moisture content correlated with oil content. Oil content increases during fruit maturation but remains unchanged during postharvest storage at 0-20°C. Moisture content decreases as the oil content increases during maturation. When harvested immature, avocados will not ripen but become discoloured, shrivelled and rubbery. Eating quality is determined by texture and flavour, and is unfavourably affected by rancidity and off-flavours often caused by on-tree storage. Visual quality is determined by colour, size, shape and freedom from outwardly visible defects, injuries, spray residues and decay. In subtropical regions such as South Africa, early maturing fruit have better quality and postharvest characteristics.

5. **Physiological Disorders**

Due to their tropical and subtropical nature, avocados suffer chilling injury when exposed to low storage temperatures. In general, the Guatemalan and Mexican races are less susceptible to chilling injury than the West Indian race. The
severity of this injury depends on the temperature, duration of exposure, cultivar, maturity at harvest and production area. External symptoms of chilling injury include pitting, scalding and blackening of the skin, increased susceptibility to pathogen attack and failure to ripen. Prolonged exposure to low temperatures can result in brown or greyish discoloration of the mesocarp and off-flavours. The presence of ethylene increases the susceptibility of avocados to chilling injury, while storage in CA reduces the incidence of chilling injury.

Internal darkening is another disorder caused by chilling, waxing and MA. This disorder is characterized by a grey to black discoloration of the pulp, starting at the distal end and around the seed. Internal darkening can be controlled by proper ventilation of shipping containers.

6. Precooling and Storage
Mature green avocados store well for 2-4 weeks between 5 and 13°C at 90-95% RH, depending on the cultivar, maturity at harvest and duration of storage. Harvested fruit should be cooled down soon after harvest to the recommended storage temperature of the cultivar. Precooling is done most effectively by forced-air or hydrocooling. Fruit quality can be maintained by using ‘step-down’ cooling in which the temperature is reduced by 1-2°C per week during shipping to
a final temperature not lower than 3.5°C. The ‘step-down’ protocol differs for each cultivar, time in the season and growing region. Since ripe avocados are less sensitive to chilling injury, they can be stored at lower temperatures ranging from 2-4°C at 90-95% RH for up to 2 weeks. Storage in CA at 2-5% O₂, 3-10% CO₂, 90-95% RH and 5-7°C in the absence of ethylene can extend the postharvest-life of mature green avocados to more than 8 weeks, depending on the cultivar. After storage such fruit can still be ripened to good quality in air. The best ripening temperature after storage is 15-20°C. Avocados can be ‘preconditioned’ to ripen faster and more evenly by treatment with ethylene (see below). Chilling injury in avocados is reduced by storage in CA and treatment with 1-MCP. CA in conjunction with 1-MCP treatment (300-500 nL L⁻¹) is used successfully for long distance marine container transport of Fuerte and Hass avocados. The storage-life of mature green Hass avocados has also been successfully increased through hypobaric storage at 8 kPa (60 mm Hg) and 6°C which reduces respiration and ethylene production.
Fruit ripening is done in specialized airtight rooms equipped with systems and equipment to control ethylene, CO₂, temperature and RH. Air circulation and distribution in the room must be adequate and efficient to evenly distribute ethylene and effectively remove respiration heat. In ordinary ripening rooms (cold rooms with circulating air) boxes are open-stacked on pallets to allow sufficient air circulation around the product (Fig. 1). Ripening with forced-air (pressure ripening) is by far the most reliable way of ensuring that the product temperature remains constant and that ethylene is distributed evenly through the boxes (Fig. 2). Ripening rooms must be designed with wide doors and passages to allow easy access for forklifts (Fig. 3). Since ripening is done at 15-21°C, isolation...
of the room is not as critical as in rooms used for cold storage if the rooms are installed inside a temperature controlled ripening facility. Sufficient space should be available in the room to allow operators to inspect the product with ease.

Ripening is usually done at temperatures higher than the optimum storage and transport temperatures. During ripening, the room temperature is gradually increased from the storage temperature to the specified ripening temperature, after which the temperature is held constant until the required stage of ripening is reached. The higher the temperature within the physiological range, the faster is the rate of ripening and the shorter is the time period for which the product is held at the ripening temperature. Thereafter, the temperature is lowered again to the desired storage temperature. It is essential to monitor the pulp temperature of the fruit continually during ripening, since the rate of ripening is to a large extent controlled by the pulp temperature. Since the rate of respiration increases during the climacteric stage of ripening, heat production will increase during this stage also and...
sufficient air circulation must be provided to effectively remove the extra heat. Forced-air systems usually provide sufficient air circulation to ensure adequate temperature control. However, the efficiency of a forced-air system depends on the ease with which the air is forced through the packages. For example, some forced-air ripening rooms are designed to force the air vertically from the bottom to the top of the stack (through the height of the stack). Due to the high resistance to airflow in these vertical systems, heat removal and ethylene distribution is much less efficient (causing heat damage and uneven ripening) than in systems that employ a horizontal air flow in which the path of air flow (the width of the stack), and thus the resistance to airflow, is much less (Fig. 4). Horizontal airflow systems are, therefore, much more effective and reliable to accurately control fruit ripening than vertical

![Figure 4: Comparison of the control of banana pulp temperature in vertical (a) and horizontal (b) forced air systems.](image-url)
systems. A relative low rate of airflow is required to evenly distribute ethylene in the ripening room. However, the flow rate required for heat removal is much higher than for ethylene distribution. The pressure difference between the two sides of the stack must be at least 250 Pa to accommodate both processes. Airflow for produce with a high rate of respiration such as avocados must be between 0.35 and 1 L sec$^{-1}$ kg$^{-1}$. These flow rates are more than adequate for heat removal and ethylene distribution and to ensure sufficient air movement around the pallet stacks and through the boxes where the resistance to air flow is highest.

Ripening is usually done at a RH ranging from 85 to 95%. A lower RH results in excessive moisture and weight loss. Low humidity in the ripening room also causes desiccation of the fruit peel resulting in a dull colour. Humidifiers should be used to raise the RH in the room atmosphere to the required level. Wet coil refrigeration units can also be used to keep the humidity high. The strength of fibreboard boxes must be sufficient to withstand the deterioration caused by moisture absorption.

As soon as the product has reached the desired ripening temperature, ethylene is released into the ripening room from pressurized gas cylinders (injection system, Fig.5) or a
generator that converts ethanol to ethylene. Ethylene stimulates fruit ripening at concentrations ranging from 0.1 to 1.0 µL L⁻¹. However, the ethylene concentration in the ripening room is often set at around 100 µL L⁻¹ (ppm) to ensure that all the fruit are constantly saturated with ethylene for the duration of the exposure period and to make provision for possible leakages from the room. After the product has been exposed to ethylene for 24 to 48 hours, the ripening room is ventilated to get rid of excess CO₂ in the atmosphere, since ethylene action is inhibited by high levels of CO₂. Levels higher than 1% inhibit the effect of ethylene in initiating ripening. After ethylene exposure, the room is ventilated continuously at a rate of 1 room volume every 2 to 6 hours to maintain the CO₂ levels below 5%. If the room is not equipped with a continuous ventilation system, ventilation can be done by opening the door for 10 to 20 minutes once or twice a day while the refrigeration fans are running. However, this practice can result in undesirable temperature fluctuations.
that can interferewith the exact control of the ripening process. Once the product has reached the desired colour or stage of ripening, the room temperature is lowered again to the normal storage temperature before the product is removed to storage, transported to the market or processed.

Avocado ripening rooms must be cleaned and disinfected regularly to prevent infection of the fruit. Room surfaces must be scrubbed down with a suitable disinfectant as prescribed by the manufacturer.

GENERAL RIPENING PROCEDURES

• Quickly load product in the ripening room and gradually raise the flesh temperature to the ripening level.
• Temperature monitoring is critical. Flesh temperature must be accurately maintained during ripening.
• Treat with ethylene for 24-48 hours.
• After this, ventilate continuously.
• Lower the flesh temperature to storage temperature when the desired ripening stage is reached.
AVOCADO RIPENING

Ethylene

Fruit ripening is a genetically programmed process that is controlled by plant hormones and accelerated or retarded by certain environmental factors. Plant hormones control the expression or suppression of specific genes involved in these processes. Some plant hormones delay ripening, while others such as ethylene accelerate the process in climacteric commodities. Ethylene is a unique gaseous plant hormone. It stimulates respiration, accelerates fruit softening as a result of cell wall hydrolysis due to the stimulation of the transcription of cell wall degrading enzymes such as polygalacturonase, causes degreening due to the stimulation of chlorophyll breakdown, causes decompartmentation of the cell due an increase in membrane permeability, changes the metabolism of organic compounds such as carbohydrates, organic acids and proteins and stimulates the production of aroma volatiles.

In climacteric fruit ethylene production follows a similar pattern to the climacteric pattern of respiration. During the pre-climacteric phase, ethylene is produced at very low levels, followed by a sharp increase just prior to or during the climacteric rise in respiration to reach a peak just before, coincident with or just after the peak in respiration rate. Many
researchers maintain that ethylene initiates the changes associated with ripening during the pre-climacteric phase as soon as the sensitivity to ethylene starts to increase.

Avocados are climacteric fruit and as such show a marked increase in ethylene production during ripening concomitant with the climacteric rise in respiration rate. Ripening of avocados is accelerated by treatment with 10-100 µL L⁻¹ (ppm) ethylene at 17-20°C for 12 to 48 hours after harvest. Careful attention should be paid to temperature and CO₂ management during ethylene treatment and ripening. Early-season fruits require longer exposure to ethylene than mid or late-season fruits. Exposure to ethylene stimulates ethylene production by the fruit and removal of ethylene from the storage atmosphere increases storage-life. In CA, the low O₂ and high CO₂ levels suppress ethylene production by the fruit. Treatment with 1-MCP greatly delays ripening of avocado fruit as indicated by a delay in softening and colour change. It also reduces internal chilling injury in very susceptible cultivars.

*Ripening Rooms*
Avocados should preferably be ripened in a forced air room to prevent heat build-up and facilitate even distribution of ethylene gas. Although banana ripening rooms can be used
for this purpose it should be noted that cooling could be slow due to the high production of respiration heat by ripening avocados (avocados produce 2-3 times more heat than bananas). The refrigeration equipment must be adequate to raise or lower the temperature between 18°C and 5°C in 4–16 hours. Air circulating fans must be strong enough to provide an air flow rate of 0.014 m³ per minute per 16 fruit in the room. Although avocados can be ripened in non-forced air store rooms, it is best to use forced air rooms for this purpose since they provide for more accurate temperature control and even distribution of ethylene in the room. When ordinary cold stores are used, boxes should be stacked in an open stacking pattern such as chimney stacking where an open chimney is left in the center of the pallet to improve air flow during ripening and storage. It is also important to leave adequate space between the pallets to allow for unrestricted air circulation since cooling of the pallet is mostly by conduction.

**Ripening Protocol**
Upon arrival at the ripening room, boxes should be selected from the middle of each pallet and the pulp temperature of a fruit from each box checked (min. 5°C/max. 10°C). The stage of maturity should be determined with a penetrometer or densitometer and/or dry matter (17-25% depending on the cultivar, e.g. a minimum of 19-20% for Fuerte and 20.8-23%
for Hass and Ryan) in order to plan the correct ripening schedule. Dry matter can easily be determined by collectively grating a ten gram sample from each of ten fruit, spreading it on an open dish and drying it in a microwave oven for a few minutes.

After determining the maturity, pallets are placed in the ripening room and the air circulation system turned on. The fruit is heated or cooled to the desired ripening temperature (16ºC - 20ºC, do not exceed 21ºC pulp temperature during the ripening cycle). Temperature controls the rate of ripening and temperatures above 25ºC will stop ripening. As soon as the pulp has reached the set temperature, ethylene is introduced into the ripening room with an ethylene generator or bottled ethylene to maintain the levels at 10 – 100 ppm. The duration of ethylene treatment ranges from 2-3 days for early season fruit and 1-2 days for mid and late season fruit. The room should be vented at least two times per day for 20 minutes or continuous with exhaust fans to keep the CO₂ levels below 1%. CO₂ levels above 1% will inhibit the ripening process. After ethylene treatment the fruit should be kept at the required temperature until it has reached the desired stage of ripeness. Pulp temperatures must be recorded throughout the room on a daily basis and the relative humidity should be kept at 90-95% throughout the ripening cycle. Once
the fruit has reached the desired level of ripeness (desired firmness), it should be cooled down to 5°C–5.5°C to slow ripening, and placed in a cold store at 5°C–5.5°C. Ripened fruit are less prone to chilling injury than unripe fruit. Further ripening after storage can be controlled by time and temperature. The higher the pulp temperature, the shorter is the time required to reach eat ripeness. The pulp temperature should never be allowed to rise above 21°C during ripening.

**Uneven Ripening**
Uneven ripening in a box, pallet or load is a common problem encountered in fruit that are ripened after harvest. The most common causes of uneven ripening are improper ripening techniques, insufficient ethylene levels, incorrect exposure time, incorrect ripening temperature, RH below 90%, temperatures above 21°C during ripening, improper air circulation, excessive holding periods before the start of the ripening cycle, variable fruit age, variable fruit maturity, wide variations in pulp temperature upon arrival at the ripening room, exposure to temperatures below 5°C prior to ripening and exposure to extreme high temperatures prior to ripening (heat damage).
POSTHARVEST PATHOLOGY

Anthracnose, caused by *Glomerella cingulata*, is an important disease of avocado. Infection can occur during the growing season after which the fungus remains quiescent until the fruit begins to soften during ripening. Infected fruits initially show circular black or brown spots which, in humid conditions, can later become covered with pink spores. At this stage the underlying flesh of the fruit undergoes rapid decay and become brown with a rancid flavour. Control of this disease requires fungicide sprays in the field during fruit development. Postharvest control methods include fungicide treatments, prompt cooling to correct storage temperature, temperature maintenance during storage and marketing, and minimization of handling damage.

Stem-end rot is another important disease of avocado. This disease is caused by several fungal and bacterial species, including the fungus *Lasiodiplodia theobromae* (syn. *Botryodiplodia theobromae* and others). These fungi are saprophytes that inhabit soil, senescing flowers, dead branches and bark and injured fruit. Their spores are dispersed by wind and splashing rain drops. Decay begins at the stem-end (stem button) of the fruit and becomes visible
as a small ring of brown tissue that spreads throughout the entire fruit. Since *Lasiodiplodia* is a wound parasite, most infections occur at harvest when the fungi enter the freshly cut stem. This disease is controlled by preharvest fungicide sprays, field-dipping of the cut end in fungicide wax, postharvest fungicide dips, removal of dead branches and twigs from the tree, removal and destruction of leaf litter, pruning and harvesting during dry conditions, and prompt precooling and cold storage.

Other postharvest diseases of avocado include *Alternaria* rot, blue mold rot, *Fusarium* rot, *Pestalotiopsis* rot, pink mold rot, and *Rhizopus* rot.