SUSTAINABLE PRODUCTION

GUIDE

COLEAD

AVOCADO (PERSEA AMERICANA)

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HOW TO CITE

M. S. Kagumba, M. Allan, O. Stephen, G. Delhove, A. Jacques, P. De Bauw, O. Rennotte, E. Lehmann, 2023, Sustainable Avocado Production Guide, COLEAD, Fit For Market SPS, Brussels, Belgium, 152p

Permanent link to cite or share this item: https://resources.colead.link/en/e-bibliotheque/guide-to-sustainable-production-of-avocado

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1

WHAT DOES AVOCADO NEED?

1.1. INTRODUCTION

Avocado (*Persea americana* Mill.) is a polymorphic tree species that has been known for many centuries, dating back to at least 1519. It is highly regarded today as an important fruit for food and nutrition and has gained a worldwide recognition and significant volume in international trade. The most common English name for this fruit, avocado, is a modification of the Spanish name, *aguacate* or *ahuacate*, derived from the Nahuatl word *ahuacatl*. The common name for the fruit in Dutch is *advocaat* or *avocat*, in German *Abakate*, and *abacate* in Portuguese. Alligator pear and midshipman's butter are somewhat fanciful English names also used occasionally to refer to this fruit (Knight, 2002). Avocado is an ingredient of widely consumed foods in such as guacamole, and is also consumed in salads or is eaten with sugar, or in ice cream or milk shakes in various parts of the world. The fruit is rich in proteins, vitamins, lipids and fatty acids. Avocado is believed to have originated in a broad geographical area stretching from the eastern and central highlands of Mexico through Guatemala to the Pacific coast of Central America. It is therefore suited to grow in varying climatic conditions, under different soil conditions and various nutritional requirements among others.

1.2. CLIMATE

The types of avocado grown for export are suited to a wide range of subtropical conditions. The trees can tolerate low temperatures, high temperatures (but ideally not above 30°C) and a range of rainfall and humidity conditions. The tree has very low frost resistance and as such it will not grow where frost is likely to occur.

1.2.1. TEMPERATURE

Globally, avocados are grown across a wide range of temperatures. There are different temperature requirements for "subtropical" (Mexican, Guatemalan and Guatemalan * Mexican hybrids) and "tropical" (West Indian and West Indian * Guatemalan) cultivars (Wolstenholme, 2002). Hass avocado requires an optimum temperature of 25–28°C. For most avocado varieties, the maximum temperature should be <30°C. Temperatures above 35°C are tolerated but with a negative effect on fruit yield and fruit size.

1.2.2. RAINFALL

Rainfall should not be less than 1,000 mm and should be well distributed. High moisture content and light showers at the time of flowering and fruit set will ensure good yields. Where supplementary water is through irrigation, it should be light and frequent and not more than 50 mm at a time. Where rainfall is very high (> 1,800 mm) with several very wet months (> 300 mm) the risk of root rot is severe.

1.2.3. RELATIVE HUMIDITY

Relative humidity is important in avocado growing through its role in aggravating (low RH) or alleviating (high RH) physiological stress. High RH and cool temperatures during the growing season, result in minimal environmental stress and excellent performance of "Hass", but cause problems with uptake of boron and calcium, which play a key role in fruit growth and quality (Sale, 1997). The beneficial role of high RH in moderating stress, thereby improving photo assimilation opportunities by maintaining a moderate to high stomatal conductivity (Schaffer and Whiley, 2002).

1.3. ALTITUDE

In tropical regions, avocados can be grown at an altitude of about 1,500 to 2,100 meters above sea level (a.s.l.), however, they can grow at any altitude <2,500 meters asl. In Kenya the crop is generally grown in highland areas between 1,200 and 1,800 metres a.s.l..

1.4. WATER

Avocados have variable water requirements depending on varieties or races. In tropical/subtropical areas, a total of 1,000 mm is regarded as the minimum desirable amount of rainfall per annum and should be well distributed. However, supplementary irrigation is often recommended during flowering and fruit set. Too much rain during flowering can also lead to flower shedding and reduced cropping. A "moderate" annual rainfall of 1,250–1,750 mm, preferably with good distribution, with some form of supplemental irrigation for dry periods is recommended (Wolstenholme, 2002). The water should be clean and free from contaminants such as heavy metals and chemicals.

1.5. SOIL

1.5.1. SOIL STRUCTURE, TEXTURE AND DEPTH

The avocado grows successfully in many types of soils provided if the soil is deep, permeable and free draining. Good soil aeration is needed and a depth of at least 1 metre of topsoil is recommended. One soil condition to be definitely avoided is water-logging because root rots such as *Phytophthora* can be a serious problem to avocado trees.

Soil clay content of 20% to 40% is highly recommended. Soils with less than 13% clay content are considered to be "sandy soils", and have limited water-holding capacity, whereas soils with high clay content can easily become waterlogged, which can adversely affect avocado root health.

1.5.2. SOIL PH

Optimum soil pH appears to be around 6.2 to 6.5 but they are grown successfully at pH from 5 to 8. If *Phytophthora* root rot is known to be problem in the area, soil pH should be checked. Gypsum ($CaSO_4$) may be necessary if the pH is higher than 6.5 and soil calcium levels appear to aid suppression. Deep cultivation and supplements of lime (where necessary) and superphosphate are recommended to adjust soil pH before planting.

1.5.3. ORGANIC MATTER CONTENT

A reasonable organic matter content of the soil is good for avocado, but if the levels are a bit low at the stage of planting, this can be supplemented by mulches and manures during the lifetime of the crop.

1.5.4. SALINITY

Avocados are salt sensitive, and are particularly susceptible to excessive chlorine levels. Growing avocados in arid / semi desert conditions increases the risk of high salinity levels in ground water.

1.6. NUTRITION

Plant growth and yield are clearly affected when macro and micronutrient concentrations are inadequate or harmful, as normal plant functions are impaired in both cases.

1.6.1. NITROGEN

Avocado tree growth and development are thought to be heavily influenced by nitrogen (N). Shoot growth is restricted by nitrogen deficiency, which manifests itself in small pale leaves and premature leaf shedding. Leaf veins turn yellow in cases of acute N deficiency (Fig. 1) (Lahav and Whiley, 2002).The leaves are also often slightly rolled inwards as a result of nitrogen deficiency (Fig. 2).

Figure 1 — Reduced chlorophyll on avocado leaf due to Nitrogen deficiency leading to loss of colour. There is slight fading of normal colour at the onset and later stages show uniform loss of colour. There is also retardation in shoot elongation (Photo: Just Avocados ltd, 2018)

Figure 2 — Avocado leaves rolled inwards as a result of Nitrogen deficiency
Photo: Newett *et al.*, 2001

1.6.2. PHOSPHOROUS

Phosphorus (P) deficiency symptoms are uncommon in avocado orchards. Some studies have identified symptoms including decreased vegetative development, burnt leaves/necrotic spots, early leaf shedding, poor fruit development and branch dieback in avocado trees. However, there is still little knowledge on the direct impact of P on avocado yield (Lahav and Whiley, 2002; Spann, 2019).

1.6.3. POTASSIUM

Tiny, thin leaves with brownish-red necrotic spots that grow on older leaves and then coalesce over the entire leaf blade between the main veins are typical potassium (K) deficiency symptoms (Fig. 3). Twigs on highly deficient trees are very small, and there is some dieback or marginal burn (Fig. 4) (Lahav and Whiley, 2002; Spann, 2019). However, K shortage in avocados can be difficult to detect since it manifests as tip and marginal chlorosis and necrosis on older leaves, which is sometimes hidden by chloride toxicity-induced tip burn. Slow growth, weak stems, and undersized fruit are other signs of K insufficiency (Spann, 2019).

Figure 3 — Brownish-red necrotic spots on leaves due to Potassium deficiency (Photo: Newett *et al.*, 2001)

Figure 4 — Marginal burn on avocado leaf due to severe Potassium deficiency (photo: Newett *et al.*, 2001)

1.6.4. CALCIUM

Scorched leaf tips, small leaves and distorted and irregular leaf margins are signs of a calcium (Ca) deficiency (Barnard *et al.*, 1991; Lahav and Whiley, 2002). Ca deficiency and *Phytophthora cinnamomi* both cause root systems to weaken and disintegrate. However, in plants affected by *Phytophthora* root rot, disintegration is accompanied by loss of leaf turgor and a much faster dieback, while in plants affected by Ca deficiency, roots regenerate (Lahav and Whiley, 2002). It is important to note that Ca deficiency appears first in new tissues hence death of growing points including leaves and roots (Spann, 2019).

1.6.5. MAGNESIUM

Magnesium (Mg) is a crucial component of the chlorophyll molecule, which is required for photosynthesis, and it also serves as an activator for a number of plant enzymes that are necessary for optimal plant growth. Mg is a mobile element in plants; thus, symptoms of insufficiency occur first on older leaves. On older leaves, Mg shortage manifests itself as interveinal chlorosis (yellowing between the leaf veins). As symptoms worsen, the edges of leaves may turn totally yellow, leaving green veins running down the center of the leaf (Spann, 2019).

Figure 5 — Interveinal chlorosis on avocado leaves due to Magnesium deficiency (Photo: Dr. Jaume Cots Ibiza)

1.6.6. SULPHUR

Because Sulphur (S) is a component of amino acids, it is required for protein synthesis. Sulphur deficiency symptoms are in many ways similar to those of Nitrogen (Barnard *et al.*, 1991). Sulphur is immobile in the plant; thus, deficient symptoms show up first on young leaves. Slow growth (smaller leaf sizes) and pale green to yellow new leaves are signs of S insufficiency (Spann, 2019).

1.6.7. CHLORINE

Wilting is the most noticeable indication of chlorine shortage. Tip burn is a common occurrence. Varieties appear to have a significant impact on symptoms (Barnard *et al.*, 1991).

1.6.8. MANGANESE

Manganese (Mn) deficiency manifests itself in a variety of ways. The early stages are comparable to iron deficiency. Chlorotic patches appear first around the midrib and subsequently extend outward. The dark regions become dull over time, while the light-yellow areas turn virtually grey. In severe situations, the entire leaf turns a dull yellowish green colour (Barnard *et al.*, 1991).

Figure 6 — Early stages of Manganese deficiency in avocado
(Photo: Barnard *et al.*, 1991)

1.6.9. ZINC

Zinc (Zn) insufficiency is the first factor that affects terminal growth. The leaves have a speckled appearance and are thinner in size than usual (Barnard *et al.*, 1991). Affected leaves exhibit an irregular blotchy yellowing between the veins (Newett *et al.*, 2001). There is only a marginal reduction in the leaf size and shortening of the distance between the leaves on the shoot in mild deficiency (Fig. 7A and B). Significant leaf distortion and yellowing is however observed with more severe deficiency (Fig. 8). In very severe cases, the young leaves at the terminal shoots turn yellow, reduced in size and distorted (Fig. 9) (Newett *et al.*, 2001).

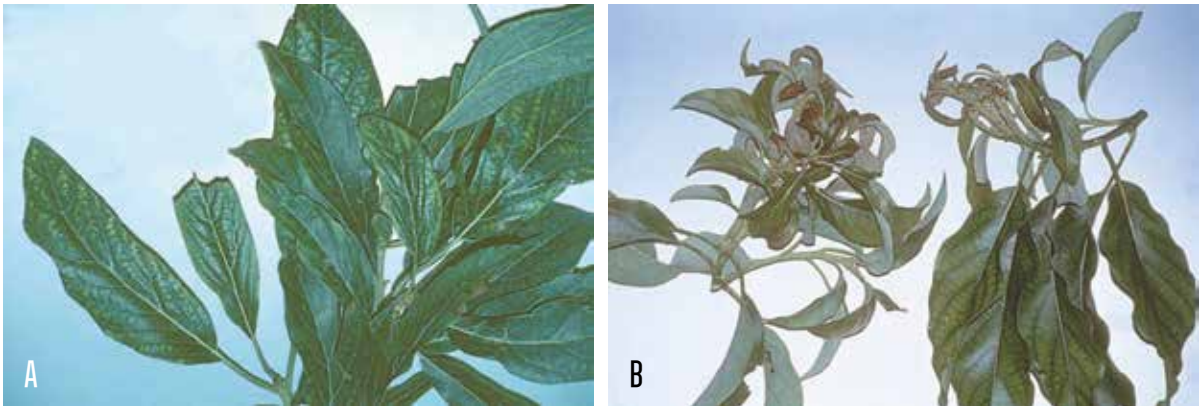


Figure 7 — Marginal leaf reduction and distortion on avocado leaves due to mild zinc deficiency
(Photo: Newett *et al.*, 2001)

Figure 8 — Leaf distortion and yellowing due to severe zinc deficiency
(Photo: Newett *et al.*, 2001)

Figure 9 — Very small, distorted and yellow terminal leaves due to severe zinc deficiency
(Photo: Newett *et al.*2001)

1.6.10. IRON

Chlorosis, a typical symptom of iron (Fe) deficiency, is caused by a decrease in chloroplast concentration. Interveinal chlorosis appears early, with prominent green veins. Later on, the veins turn chlorotic as well, and the leaves may fall (Barnard *et al.*, 1991).

Figure 10 — Extreme iron chlorosis where the leaves are losing their green appearance (Photo: Jaume Cots Ibiza)

Figure 11 — Iron deficiency exhibited by avocado leaves (Photo: Newett *et al.*, 2001)

1.6.11. COPPER

Terminal growth is the first to be impaired by copper (Cu) deficiency. Growing point death is frequently preceded by internode shortening. The growth of new leaves is dormant. They dry and die back very instantly. The veins on older leaves are reddish-brown and dull (Barnard *et al.*, 1991).

1.6.12. BORON

Boron (B) deficiency manifests itself in a variety of ways. Burning, discoloration and deformation of terminal leaves occur. The veins separate and take on a cork-like appearance (Barnard *et al.*, 1991). Affected trees are yellow and stunted. Yellowing is often associated with leaf distortion and holes in the leaves (Newett *et al.*, 2001). The holey leaf symptom is often prevalent in the leaf flush. Boron deficiency also affects the trunk, branches, flowers and fruits. Fruit exhibits a wide range of abnormal symptoms like bumps, sickle-shaped growth and sunken corky lesions (Haifa, 2021).

Figure 12 — Characteristic holey leaves due to boron deficiency (Photo: Newett *et al.*, 2001)

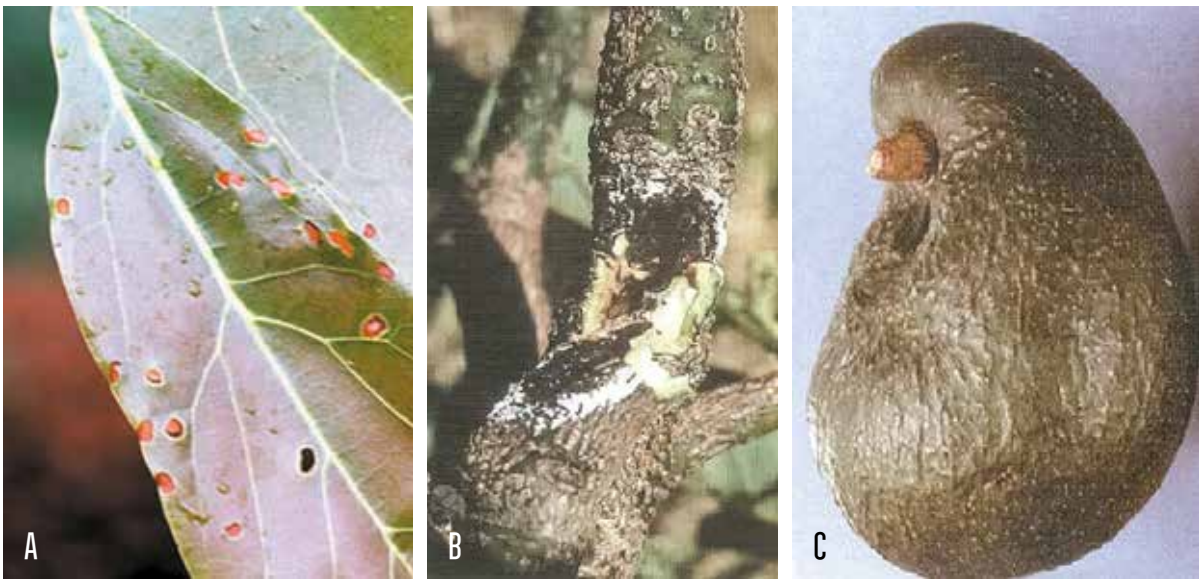


Figure 13 — Holey leaf (A), Necrotic stem (B) and malformed fruit (C) due to boron deficiency (Photo: Haifa Negev technologies ltd)

High uptake of boron from the soil could lead to Boron toxicity. Affected trees have leaves that display a burn margin with a clearly defined edge. There are pale yellow areas within the burnt area with a variety of tiny dark spots (Newett *et al.*, 2001).

Figure 14 — Avocado leaf displaying symptoms of boron toxicity (Photo: Newett *et al.*, 2001)

WHAT DOES AVOCADO NEED?

KEY POINTS SUMMARY

Avocado trees have various essential needs/requirements for them to grow healthy and these include: climatic factors such as:

- **Rainfall:** 1,250–1,750 mm/year with good distribution and supplemental irrigation during dry periods (cfr. chapter "Pre-planting choices – Irrigation)
- **Relative humidity:** moderate
- **Temperature:** 25–30°C
- **Altitude:** 1,200–2,500 m
- **Soil:** deep, permeable and free draining. Clay content of 20–40%
- **pH:** 5–8
- **Salinity:** salt sensitive in arid/semi-desert conditions
- **Nutritional factors**
  - Organic matter content: to be supplemented with mulches and manures
  - Essential minerals such as Nitrogen, Potassium, Phosphorous, Boron etc.: (the required amount is described in the chapter Management of Avocado – Fertiliser")
- Some practices following the agroecology, agroforestry and regenerative agriculture principles will be presented in the following chapters in order to respond to the above mentioned needs of avocado, to conserve a rich soil and to tackle pests and diseases issues.

2

PRE-PLANTING CHOICES

CHOOSE FARMING PRACTICES THAT REDUCE THE IMPACT ON THE ENVIRONMENT

1. Conserve and cultivate **local varieties** and grow **local breeds** that are often more resilient and **resistant to vagaries** since they are more **suited to local conditions**.
2. Maintain species **diversity** in cultivated areas by keeping parcels of land surrounded by **hedges** and by adopting **crop rotation**, **intercropping** and **associated crops**.
3. Avoid destroying natural habitats by land clearance and the use of fire to manage weeds, which lead to the disappearance of beneficial fauna and flora.

PRESERVE UNCULTIVATED AREAS

1. Conserve the **ponds**, **ditches** and areas close to their natural state located between land parcels to foster the development of **predators** that control crop pests.
2. Conserve and maintain **hedges** and other **wind breaks** to serve as safe havens for a whole series of animals, birds and insects.
3. Plant **wildflower strips** to foster the presence of **pollinating insects** and the reproduction of other **predator insects and mite species.**

To know more: browse the COLEAD brochures on the subject.

2.1. CHOOSING A PLOT

Careful site selection can reduce the risk of frost damage in areas where it is likely to occur (Wolstenholme, 2002). Similarly, an area that is prone to flooding should also be avoided.

Avocado trees planted in windy areas of an orchard are frequently stunted and underproduce. They may also be water stressed, which will affect mineral intake, and their roots may be stressed as a result of the wind's constant rocking. Avocado trees have brittle wood that breaks quickly in severe winds. The lengthy stalk of the fruit makes it vulnerable to rubbing and chafing against branches. As a result, in locations where prevailing winds pose a danger of damage, the importance of windbreaks should be emphasized, taking care not to produce "frost pockets," aggravate a light problem, or produce undue competition with orchard trees (Wolstenholme, 2002).

THE NEGATIVE EFFECTS OF WIND ON AVOCADO PRODUCTION CAN BE SUMMARISED AS

1. mechanical wind damage eg. broken branches;
2. poor fruit set due to flowers that are blown off and poor insect pollination;
3. wind induced stress which can hamper fruit development;
4. poor pest/disease control in the orchard;
5. poor external fruit quality due to wind scar;
6. hot wind causes higher rates of evapo-transpiration thereby loss of soil moisture.

Adapted from Holmes and Farrell (1993)

2.2. PLANTING MATERIAL

2.2.1. ROOTSTOCKS AND SELECTION CRITERIA

Avocado can be grown from seed, but most cultivars are grafted or budded onto rootstocks that can improve tree health, yields and adaptability to a wide range of soils. Selection of seeds should be made from trees of hardy varieties known to produce seedlings that make vigorous disease-free trees.

Good quality avocado rootstocks are either grown from:

— **Seedling rootstocks:** Saplings grown from specifically selected seeds from specific trees. Avocado trees propagated on seedling rootstocks are cheaper but exhibit non-uniform growth (Newett *et al.*, 2001).

— **Clonal rootstocks:** A more complex procedure in which plant material from a specific tree is grown into a sapling. Clonal rootstocks have been specifically developed for different growth characteristics. While they are quite costly, clonal rootstocks provide uniform growth and vigour and generally produce smaller trees, making them ideal for high-density plantings (Newett *et al.*, 2001).

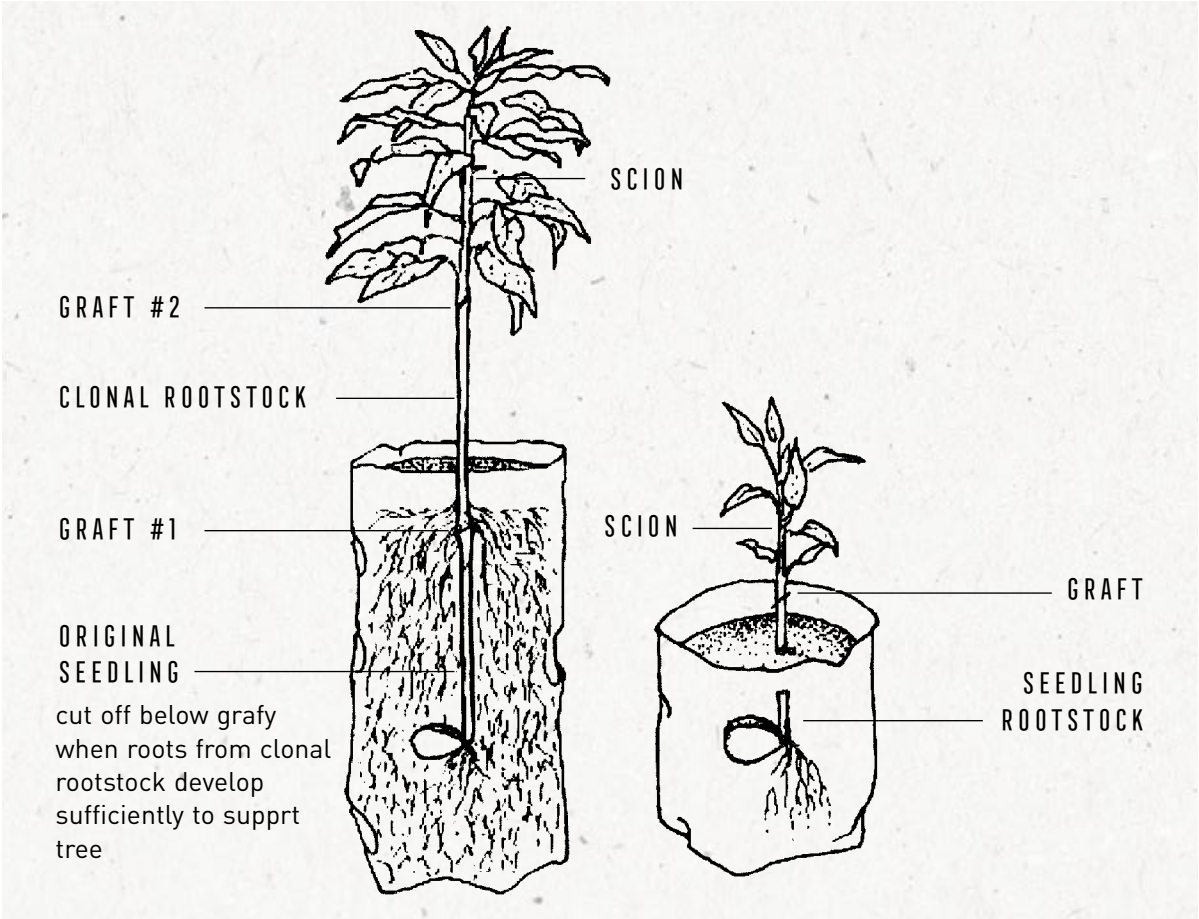


Figure 15 — Clonal rootstock (left) and seedling rootstock (right) (Photo: Newett *et al.*, 2001).

Selection of rootstock is based on the tree size requirements of the grower (some rootstocks produce dwarf plants suited to high density planting - *e.g.*, some of the Mexican rootstocks and the local prevalence of different diseases, especially *Phytophthora* root rot. However, salinity tolerance, resistance to lime-induced chlorosis and partial frost resistance are other useful features partly determined by the rootstock material. Clearly both stock and variety will depend very much on local requirements and compatibility. It is a good idea to try growing different types or experiment with a range of material to find which is best for the individual farm conditions.

Disease resistance has been the focus of commercial breeding work, and resistant rootstocks are available in some markets. Examples of appropriate rootstocks for Kenya are Duke 7 (for Fuerte) and Thomas (for Hass).

Some of the rootstocks used in various countries include: Ashdot, Borchard, Colin V-33, D9, Degania, Maoz/VC 43, Duke 6 and 7, Martin Grande, Thomas, Merensky 1 and 2, Zutano, Topa Topa etc.

Bud or scion stock is also critical to optimum production. It should be taken from a tree which is high yielding, and if possible, certified to be genetically sound and producing fruits true to type.

2.3. AVOCADO VARIETIES

Internationally, there are over twenty commonly grown cultivars or varieties of avocado, ranging from small light types to ones in which a single fruit can weigh one and a half kilos. The two most common export varieties in different regions around the world are Hass and Fuerte.

2.3.1. HASS

Figure 16 — Leaf of Hass avocado (Photo: Newett *et al.*, 2001)

TYPE

— Predomonatly Guatamalan origin

FLOWER TYPE

— Group A

THE TREE

— Medium to large with upright growth habit
— Almost as broad as it is tall with a rounded crown
— Young shoots are light green with no markings
— When crushed, little smell from the leaves
— Can be planted in large blocks because it is self-pollinating

THE FRUIT

— Size: Medium
— Shape: Oval
— Neck: No neck present
— Weight: 150–400g

- Mid-late season maturity
- Flesh: Creamy, yellow flesh
- Flavour: Rich nutty favour
- Oil content is around 25%;
- Dry matter 23–30%
- Good on-tree storage ability;
- "Hass" is precocious and produces regular, heavy crops but late on-tree storage of fruit can accentuate biennial bearing;
- Good post-harvest performance (transport and storage);

SKIN

- Skin medium to thick
- Leathery
- Has coarse corky texture
- Rough and pebbled surface, pebbling is largely absent when grown at high altitude,
- Dark green on tree
- Purplish black when ripe

THE SEED

- Size is medium,
- Round shape;

SUSCEPTIBILITY TO BIOTIC/ABIOTIC STRESSES

- The medium to thick skin gives tolerance to pests and diseases but leaves are susceptible to *Persea* mite;
- Suited to cooler climates since extreme heat coupled with low humidity can result in smaller fruit
- Flowering and fruit set are less sensitive to cold temperatures than "Fuerte" and "Ettinger" but leaves are more cold -sensitive

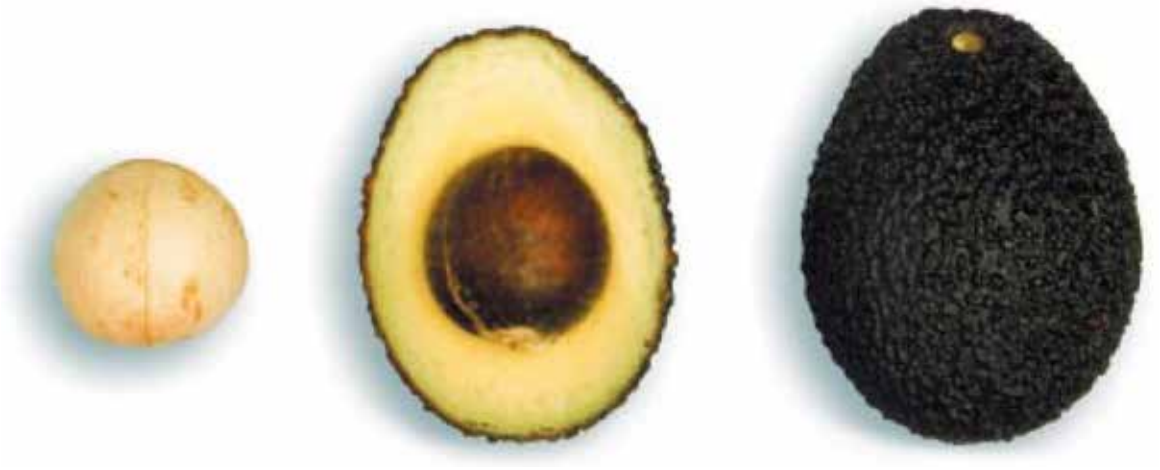


Figure 17 — Hass avocado (Photo: Newett *et al.*, 2001)

2.3.2. FUERTE

Figure 18 — Leaf structure of Fuerte avocado (Photo: Newett *et al.*, 2001)

TYPE

— Mexican x Guatamalan origin

FLOWER TYPE

— Group B

THE TREE

— Trees are large, with spreading crowns,
— Difficult to manage if not pruned
— Young shoots have red blotches
— When crushed, leaves smell aromatic - a little like eucalyptus leaves (aniseed smell)

THE FRUIT

— Size: Medium
— Shape: Pear shaped
— Neck: No neck present
— Weight: 250–450g
— Mid-late season maturity
— Flesh: Creamy, yellow flesh
— Flavour: flavoursome with nutty after-taste
— Oil content is around 20–40%;
— Dry matter 23–30%
— Good on-tree storage ability; but short shelf-life when ripe
— Can fruit Biennially (alternate years only)
— Slow to reach production

THE SKIN

- Pale green
- Smooth and thin skin
- Medium gloss
- Supple leathery texture
- Pimpled surface

THE SEED

- Seed size is medium to large
- Conical with pointed apex

SUSCEPTIBILITY TO BIOTIC AND ABIOTIC STRESSES

- More susceptible than Hass to pre- and post-harvest diseases
- The fruit is susceptible to anthracnose, stem-end rot and insect attack which can cause severe field and postharvest losses
- Tree has tolerance to Persea mite
- Low yields in cooler climates with a marked tendency for erratic cropping
- Sensitive to low temperatures during flowering and fruit set, frost tolerance limit is -2.8°C (Newett *et al.* 2002).

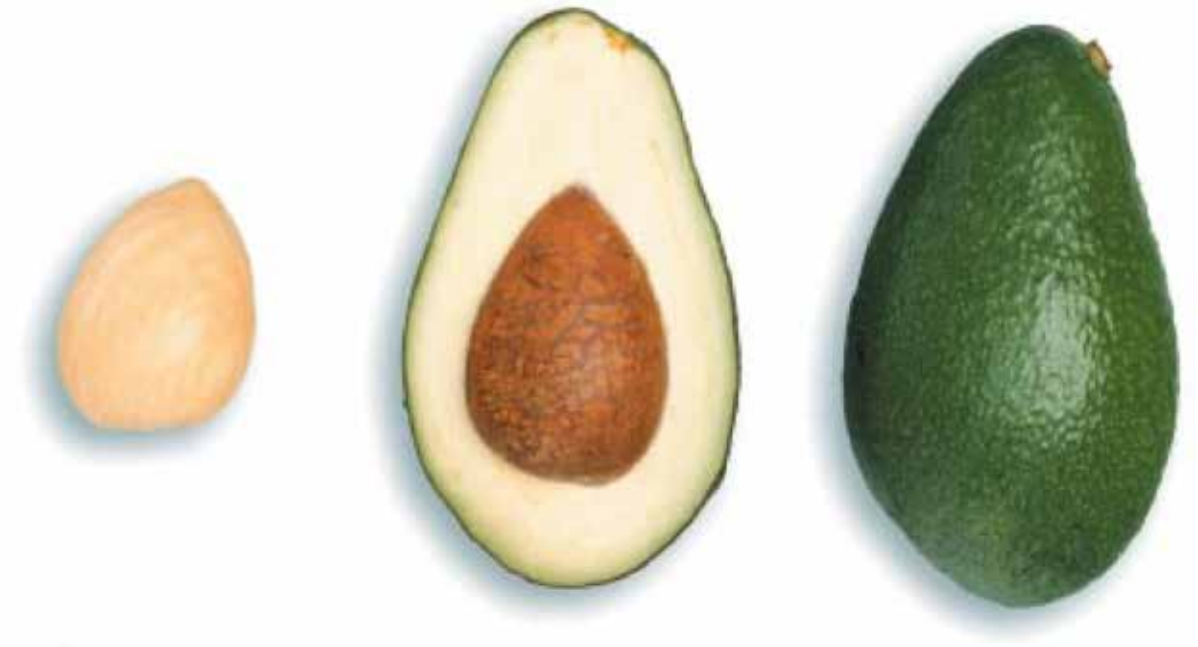


Figure 19 — Fuerte fruit
(Photo: Newett *et al.*, 2001)

2.3.3. BACON

TYPE

— Mexican x Guatemalan hybrid

FLOWER TYPE

— Flower Group B

THE TREE

— Trees tall with pointed crowns
— Leaves have aniseed smell when crushed
— Red flecking on wood of new shoots

THE FRUIT

— Fruit ovate
— Medium to large size
— Weighing 170–510 g
— Early maturing with very pale yellow-green flesh

THE SKIN

— Skin thin
— Green and glossy with leathery texture

THE SEED

— Seed size is large

SUSCEPTIBILITY TO BIOTIC AND ABIOTIC STRESSES

— Cold tolerance is widely reported in many areas; frost tolerance is down to -4.4°C, thus production is suited to colder regions
— Susceptible to insect attack
— Extremely susceptible to anthracnose, unsuitable for humid subtropical areas
— Skin is susceptible to wind scarring, in severe cases fruit splits exposing seed.
— "Bacon" is a successful pollinator for "Hass" (Newett *et al.* 2002).

2.3.4. EDRANOL

Figure 20 — Edranol leaf formation (Photo: Newett *et al.*, 2001)

TYPE

— Guatemalan or Guatemalan hybrid

FLOWER TYPE

— Flower Group B

THE TREE

— Upright vigorous growth habit

THE FRUIT

— Fruit pyriform
— Necky
— Medium to large size
— Weighing 255–500 g
— Buttery yellow flesh
— Good nutty flavour and good flesh quality
— Matures mid-season

THE SKIN

— Skin dark green
— Medium thickness
— Corky texture
— Medium gloss

THE SEED

— Seed size is small to medium

SUSCEPTIBILITY TO BIOTIC AND ABIOTIC STRESSES

— Sensitive to climatic extremes
— Withstands temperatures down to -2°C
— Susceptible to zinc deficiency, grey pulp, skin russetting and anthracnose
— Slow to produce, irregular but heavy production,
— "Edranol" is a successful pollinator for "Hass" (Newett *et al.* 2002).

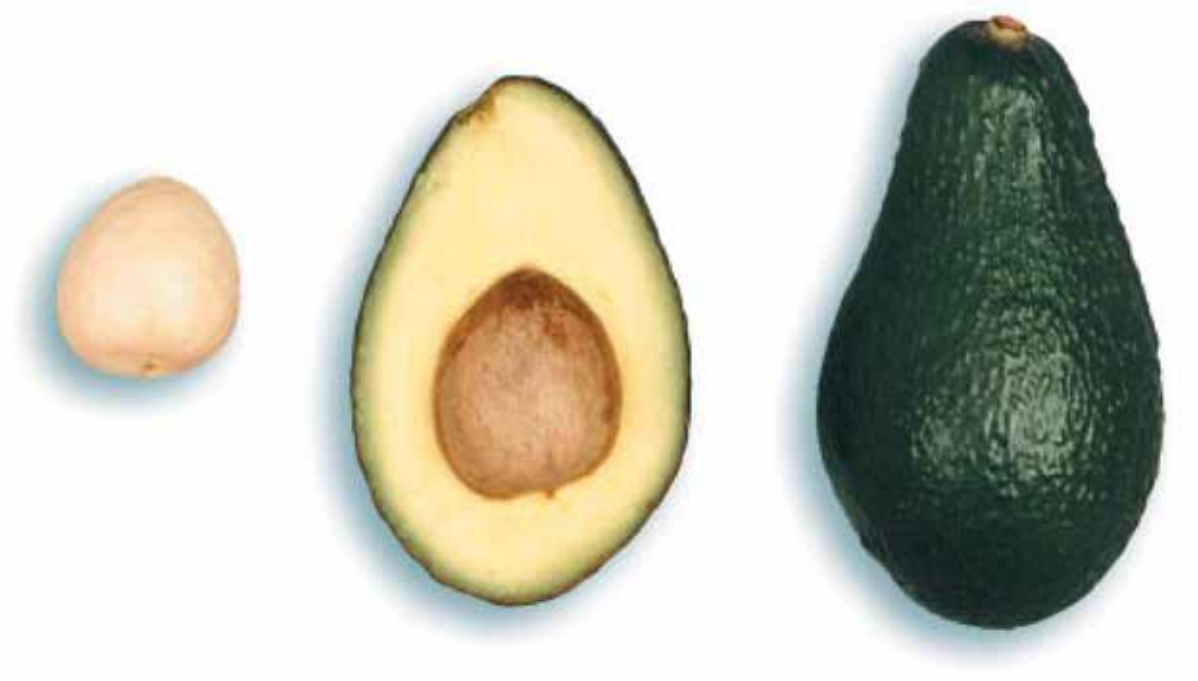


Figure 21 — Edranol fruit (Photo: Newett *et al.* 2001)

2.3.5. ETTINGER

TYPE

— Predominantly Mexican

FLOWER TYPE

— flower Group B

THE TREE

— upright with strong central leader
— leaves have weak aniseed smell when crushed

THE FRUIT

— fruit pyriform
— medium to large size
— weighing 170–570 g
— early maturing with clear light cream to yellow flesh
— soft and melting in texture
— fruit has short on-tree life (skin cracks) but long shelf-life

THE SKIN

— skin bright green
— very thin with slightly rough surface

THE SEED

— seed size is large
— loose in cavity
— seedcoat adheres to the flesh

SUSCEPTIBILITY TO BIOTIC AND ABIOTIC STRESSES

— The tree is more freeze resistant than "Fuerte"
— Severe problems with skin cracking, anthracnose and fruit spotting bug and stem-end rot in South Africa
— more sensitive to chilling injury during storage than "Hass" and "Fuerte"
— Outstanding pollinizer, for "Hass" (Newett *et al.*, 2002)

2.3.6. PINKERTON

Figure 22 — Pinkerton leaves (Photo: Newett *et al.*, 2001)

TYPE

— Guatemalan hybrid;

FLOWER TYPE

— Flower Group A

THE TREE

— Semi-dwarf
— Moderately spreading tree with a growth rate similar to "Hass"

THE FRUIT

— Fruit is pyriform
— Can be excessively "necky" in cool climates
— Medium size
— Weighing 230–425 g
— Fruit retains size when grown in hot, subtropical climates
— Mid-season maturity
— Has an attractive cream-coloured flesh
— Flavour rich and nutty
— Ripens more slowly than most varieties, giving it longer shelf-life

THE SKIN

— Skin of medium thickness
— "Hass"-like
— Dark green
— Prominently pebbled
— Leathery and tough
— Easy to peel

THE SEED

— Seed size is relatively small

SUSCEPTIBILITY TO BIOTIC AND ABIOTIC STRESSES

— Similar cold tolerance to "Hass" and "Reed" tolerating temperatures down to -2°C.
— Relatively resistant to anthracnose, can have high percentage of internal fruit disorders including uneven ripening.
— Extended flowering results in wide maturity differences at harvest.

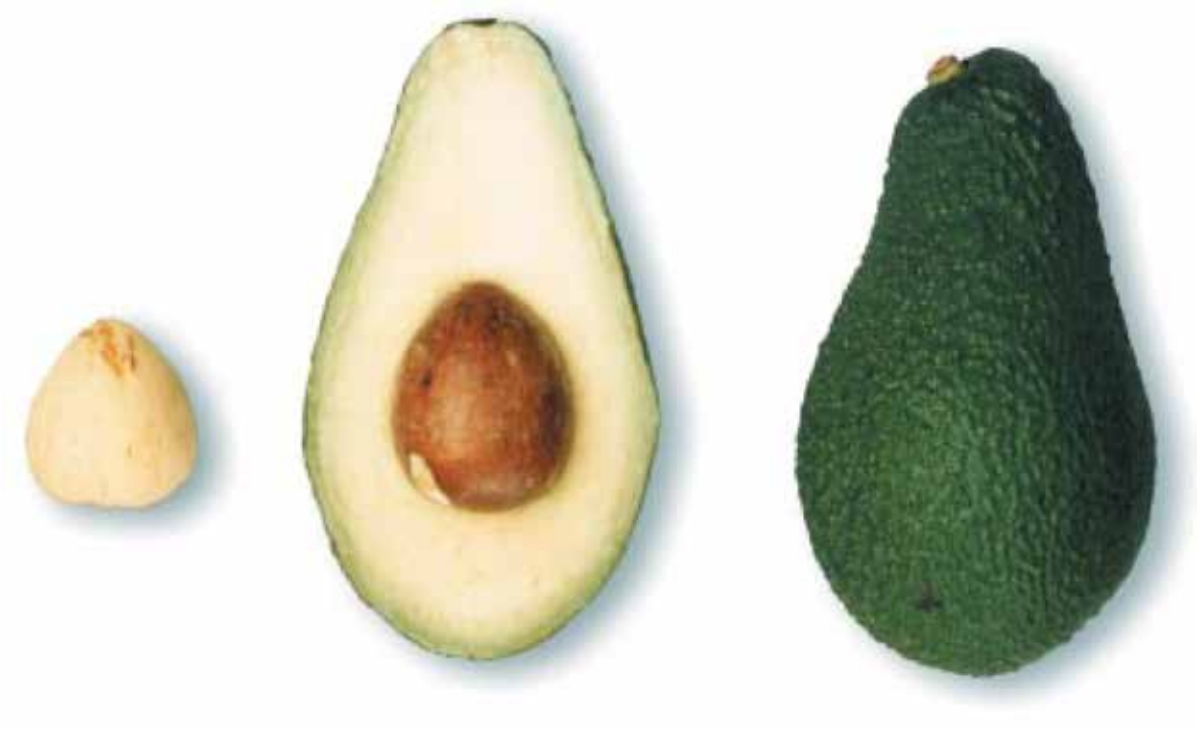


Figure 23 — Pinkerton Fruit (Photo: Newett *et al.*, 2001)

2.3.7. REED

Figure 24 — Reed avocado leaf (Photo: Newett *et al.*, 2001)

TYPE

— Guatemalan;

FLOWER TYPE

— Flower Group A

THE TREE

— Trees are slender
— Distinctly upright
— Downward hanging branches protect fruit from sunburn

THE FRUIT

— Fruit is round
— Medium to large size
— Weighing 270–680 g
— Late season maturity
— Attractive, cream or pale to buttery yellow-coloured flesh
— Rich and nutty flavour
— Cut surface does not darken
— Can be stored postharvest for 1 month longer than "Hass"

THE SKIN

— Skin medium to thick
— Green
— Corky
— Slightly pebbled
— Easy to peel

THE SEED

— Seed size is medium to large
— Rounded

SUSCEPTIBILITY TO BIOTIC AND ABIOTIC

— Cold tolerance down to -1.1°C.
— Has some resistance to Persea mite (Newett *et al.*, 2002).

Figure 25 — Reed avocado (Photo: Newett *et al.*, 2001)

2.3.8. OTHER CULTIVARS

Other cultivars include: Ryan, Sharwil, Shepard, Wurtz, Zutano, Simmonds, Booth 8, Monroe, Lula, Booth 7, Choquette, Nadir, Tower 2, Loretta, Hall, Tonnage, Booth 5, Nesbitt, Lisa, Black prince etc.

2.4. GROWING PERIOD

Avocado can be planted at any time of the year provided irrigation is available. Planting can also take place at the onset of the rainy season to minimize the need for frequent watering of the newly set plants in the field.

2.5. PLANTING METHOD

It is best to plant seed soon after it is removed from the fruit. It should always be protected from drying. Seed may be kept for several months if packed in dry moss, sand or sawdust and placed in a cool location (Johnston and Frolich, 1957).

Seed can be planted directly in the field in nursery rows. This requires special care and does not permit removal of weak and off type seedlings without leaving blank spaces. In addition, sprouting will be slow with some seeds, causing an irregular stand.

2.6. SEEDLING NURSERY MANAGEMENT

2.6.1. LOCATION OF NURSERIES

Avoid locations below established avocado orchards or land formerly planted to avocados where drainage water may carry disease to the nursery.

2.6.2. SOIL

Avocado seedlings should be grown in a soil that has never been planted to avocados or other crops that carry the root-rotting cinnamon fungus or Verticillium wilt fungus. To ensure soil is free from disease, soil treatment with a recognized/ registered product such as Phosphonate fungicides (Potassium phosphite, mono- and di-potassium salts of phosphorous acid, fosetyl-AL or aluminum tris-O-ethyl phosphonate) and Phenylamides (metalaxyl, metalaxyl-M (=mefenoxam), furalaxyl and oxadixyl, benalaxyl and benalaxyl-M (=kiralaxyl) and ofurace) is recommended (Johnston and Frolich, 1957; Swiecki and Bernhardt, 2016). Non-chemical (Physical) methods of soil treatment including heat treatment and vapour treatment are highly recommended.

2.6.3. PLANTING MATERIAL

Since some trees may carry viruses without visible symptoms, it is important to know that seedlings from trees used as a seed source produce disease-free trees when budded or grafted (Johnston and Frolich, 1957). The avocado root rot disease can also be carried by seed. Fruit that has been permitted to contact infected soil will be invaded by the fungus and many of the seeds will carry the disease and infect the nursery. For this reason, it is wise to obtain seed from sound, mature fruit and avoid the use of windfalls. Your farm advisor can assist you in locating reliable seed.

Planting material may need to be checked by the official body with responsibility for plant health and quarantine. This is crucial for stock coming from outside a specific region or country. If stock plants are grown from seed, hot water treatment of seed must be done to reduce disease level. Care must be taken that the water temperature does not exceed 50° Celsius otherwise germination rate will be reduced. Seeds should be sown in a soft substrate such as coffee pulp to allow roots to develop.

2.6.4. PEST FREE PLANTING MATERIAL

Nursery material should be kept free of pests, particularly ones which are difficult to get rid of later, such as scale insects which are easier to control in the nursery than after they have been planted out in the orchard. Insecticidal sprays applied in the nursery will have disappeared long before the trees come into fruit, so the question of residues does not arise.

2.6.5. THE NURSERY

Plants are often raised in containers or seedling bags before being planted in the orchard. An open compost substrate is better than a predominantly clay mixture as a potting media. The containers/bags should be large enough to prevent the roots from becoming crowded together (root bound) to ensure that the roots can grow out freely into the field soil after transplanting and help the plant to establish successfully. Vigorous growth is the aim, and the leaves should be glossy and deep green in colour. Amendment of liquid or solid fertilizers may be needed. For example, yellowing of new leaves indicates a shortage of nitrogen.

2.6.6. GRAFTING

The main purpose of grafting is to replicate a plant with identical characteristics. Grafting is the practice of joining two compatible plant parts together permanently. For avocados, identical fruit cultivars are produced by grafting a small shoot or bud the scion from a "mother tree" with desired and known characteristics onto the lower part of another tree (the rootstock) (Figure 26).

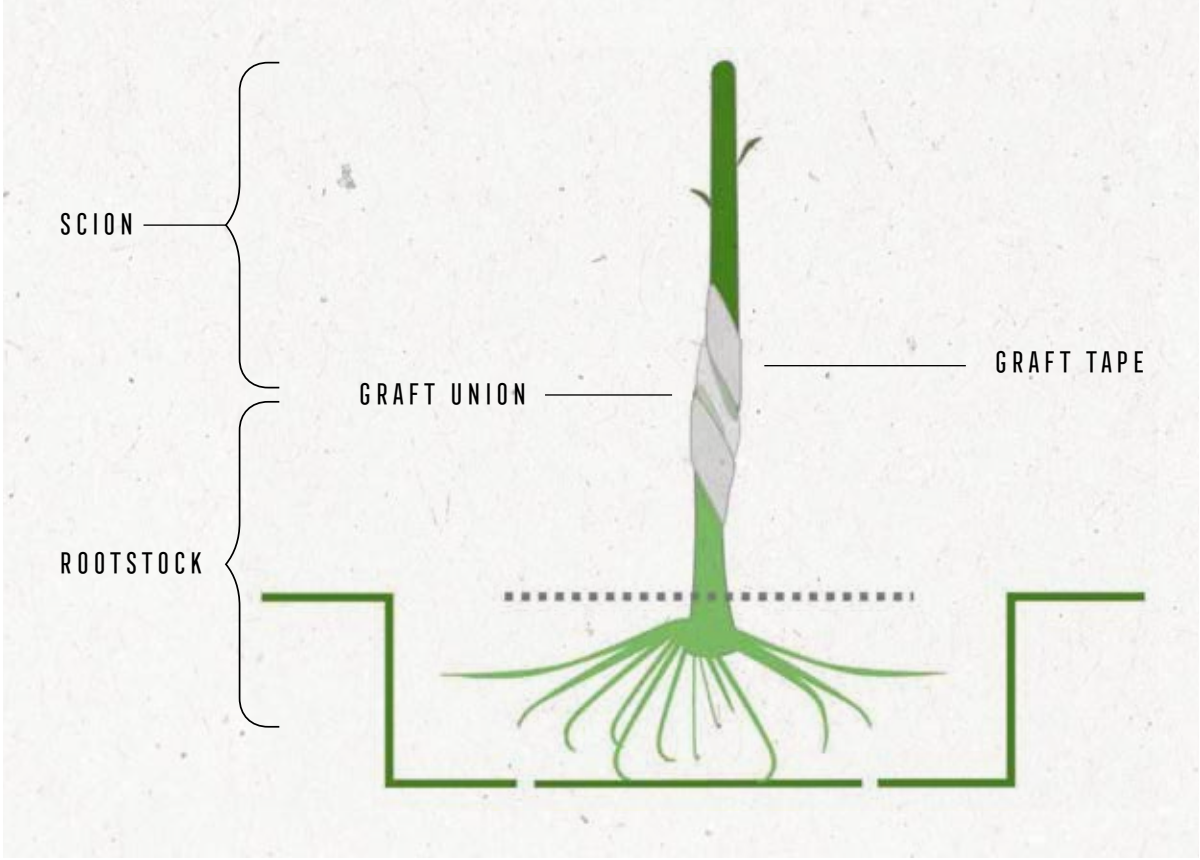


Figure 26 — Components of a graft showing the Scion, rootstock and the graft union (Photo: COLEAD Avocado quality technical training-Cultivars and rootstocks)

Grafting should be done when the seedling has reached the thickness of a pencil. The most successful grafting method is wedge/cleft grafting (Fig. 27–31). Grafting should be done while the rootstock is still tender. At the moment of grafting, the scion should be dormant and the size of the stock should be the same. Wrap the grafting site tightly using a polyvinyl grafting tape, Parafilm or rubber strip to keep moisture out of the union and keep it from drying out (Infonet-biovision, 2021).

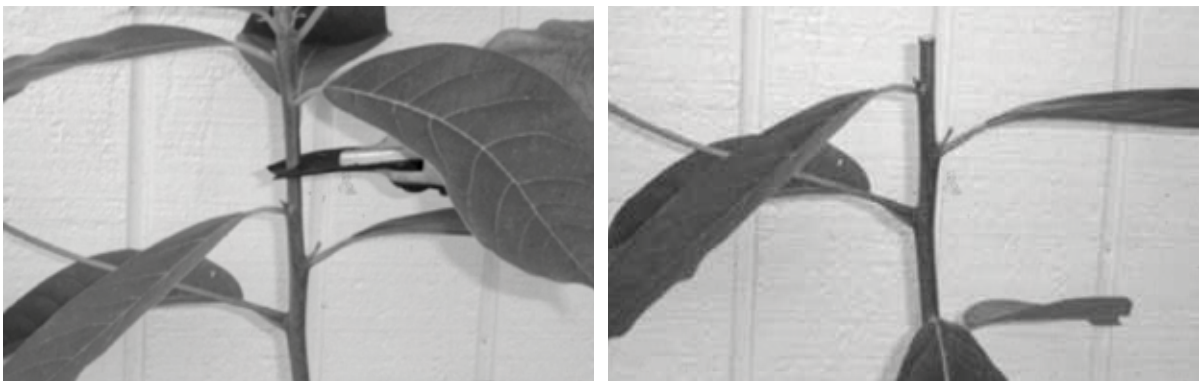


Figure 27 — Cut/remove the apical growing point of the desired rootstock using Secateurs or sharp grafting knife (Photo adapted from Cho *et al.*, 2018)

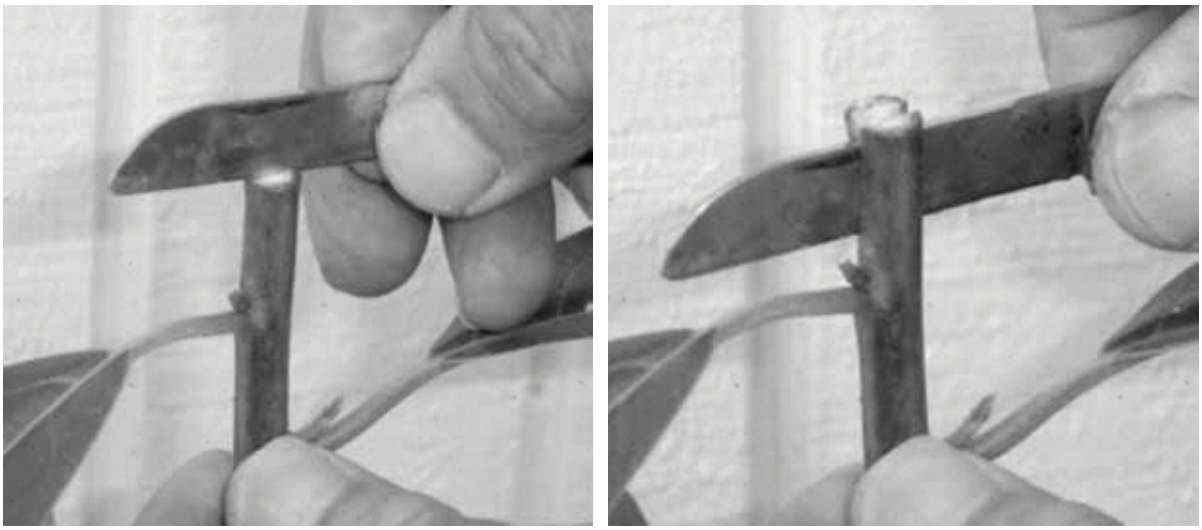
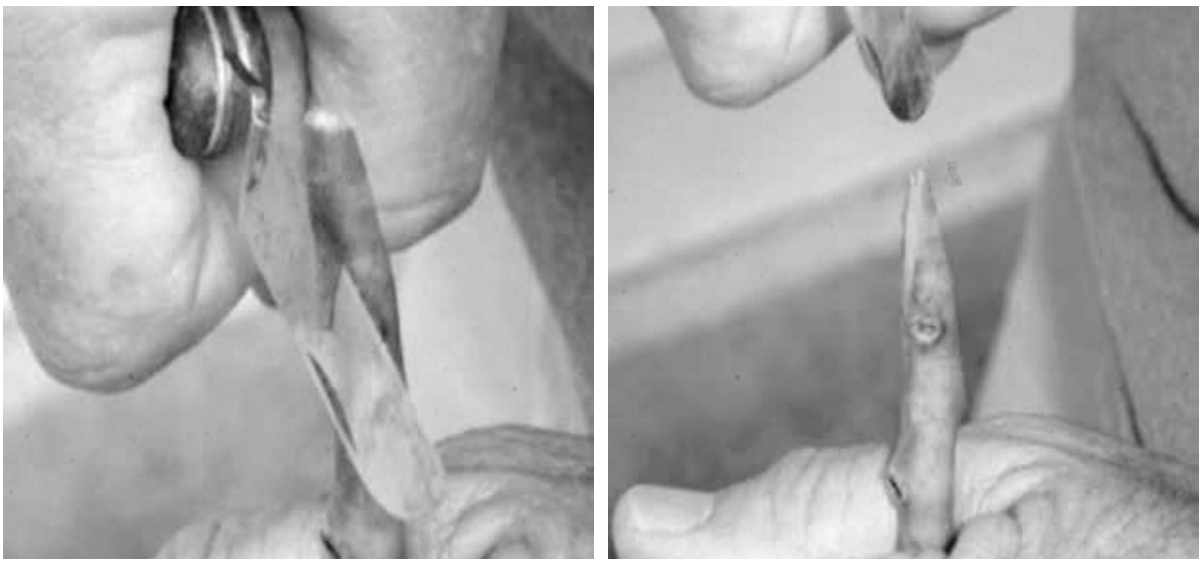


Figure 28 — Make an incision into the rootstock using a grafting knife (Photo adapted from Cho *et al.*, 2018)

Figure 29 — Hold the scion vertically with the growing point facing downwards and slice upwards at an angle of about 30 degrees. ...



... Repeat the same procedure and cut the other side of the scion to achieve a wedge-shaped base on the scion (Photo: Adapted from Cho *et al.*, 2018)

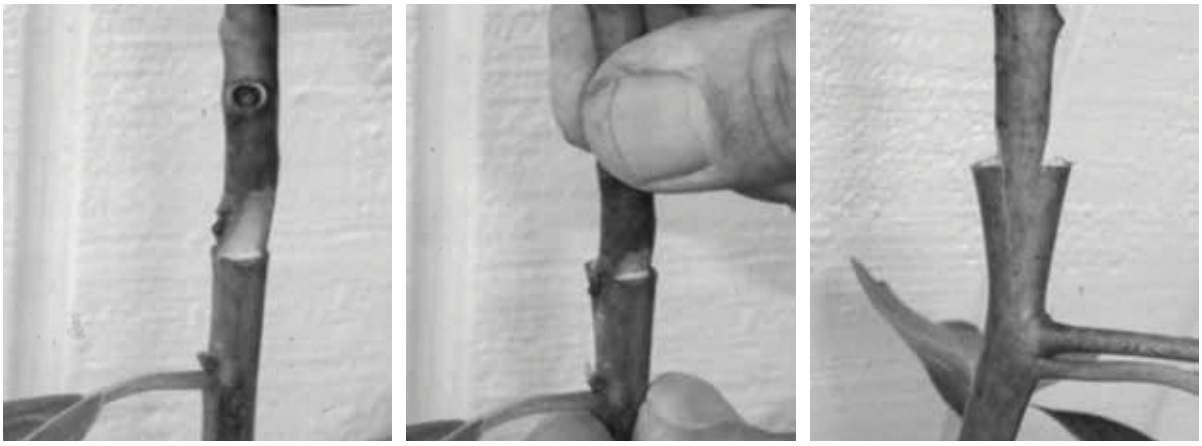


Figure 30 — Pair the rootstock and scion by gently pushing the wedge-shaped base into the slit/cut on top of the rootstock. Ensure the outer edges of the rootstock and scion are matched and that the scion is firmly wedged (Photo: Adapted from Cho *et al.*, 2018)

Figure 31 — Wrap the graft tightly using a grafting tape or rubber strip to hold the graft in place and to help retain moisture in the scion until the graft is successful (Photo: Adapted from Cho *et al.*, 2018)

2.7. IRRIGATION

The correct application of water is a critical management factor for successful avocado production and requires careful planning and execution. It encompasses how much water is required, when and how it is applied and the impact of its quality.

While most avocado growers in the tropical and sub-tropical areas depend on rainfall for irrigation, variations in the quantities and unpredictability of rainfall often necessitate supplementary irrigation. The efficiency of an irrigation system is important and should aim for about 80% efficiency with a high distribution uniformity. This is however difficult to attain if proper care is not taken in selecting the method of irrigation (Mccarthy and McCauley, 2019).

2.7.1. DRIP IRRIGATION

Drip irrigation system can be used to grow avocados, however, in some cases, it is used in response to lower water availability than as a means to boost productivity.

Figure 32 — Drip irrigation for avocado (Photo: Stephen Othim)

2.7.2. UNDER TREE SPRINKLERS

Because they can be configured to wet the entire orchard floor or only a piece of the under-tree canopy region, under-tree sprinklers (micro/mini-sprinklers) are a more desirable watering method. Because water is thrown outside the tree's main root zone, full coverage systems use more water. This does, however, aid in the maintenance of between-row sod (the vegetative cover that grows between rows), which reduces heat reflection. Aiming to apply a relatively even coverage over 100% of the orchard floor is a little excessive.

Figure 33 — Micro sprinkler in an avocado orchard
(Photo: COLEAD Avocado quality technical training-Avocado Characteristics)

A more efficient alternative is to design the system so that your sprinklers have 100% overlap along the rows, but only limited overlap between rows (Figure 34). This can be achieved with the use of wide diameter mini-sprinklers set out along the rows, usually one per tree. The benefit of this system, as opposed to 100% even coverage, is that it delivers more water (and nutrients if you are fertigating) to your trees than the inter row sod yet should still keep your sod growing to maintain the benefits (Mccarthy and McCauley, 2019).

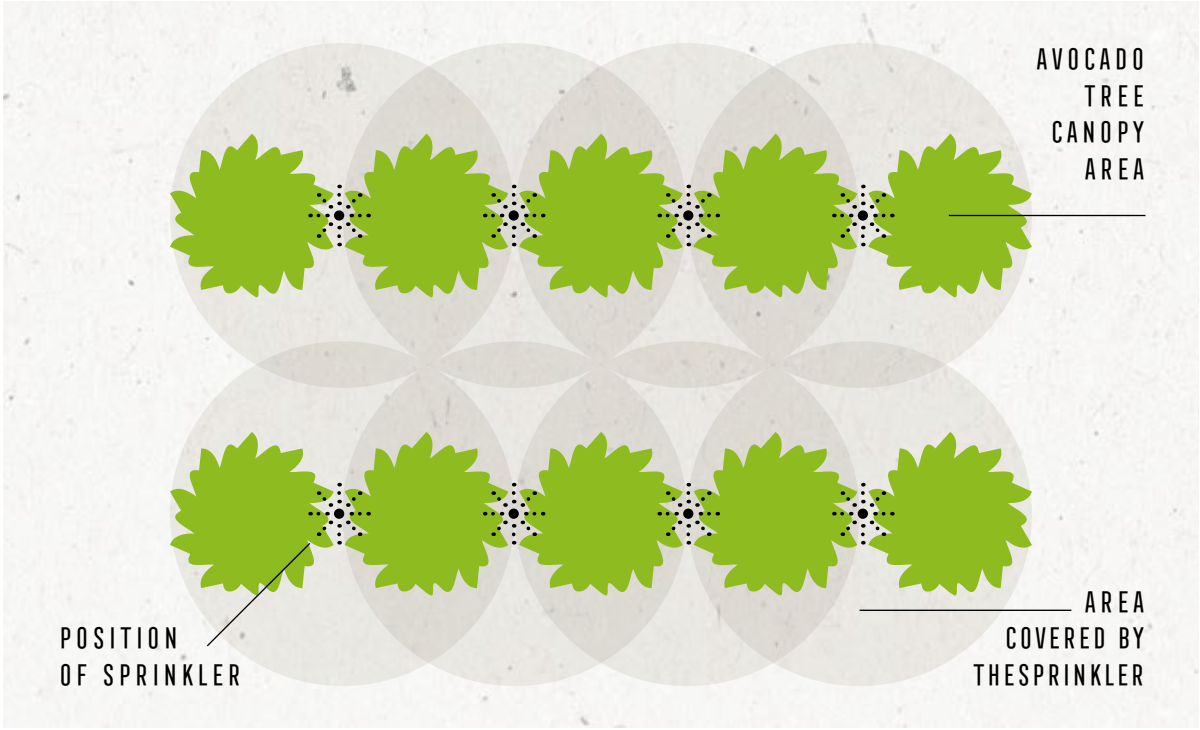


Figure 34 — Schematic picture of a mini-sprinkler set up for an avocado orchard aiming to deliver irrigation to 100% of the orchard floor (Adapted from Mccarthy and McCauley, 2019)

Designing an irrigation system to solely wet the under tree "canopy region" is more usual and efficient in cooler regions where the climate can successfully maintain the inter-row sod, or in heavier soil situations or when there is a need to minimize water use. The goal in this circumstance is to distribute water in an even strip beneath the trees that does not extend beyond the trees canopy. The sprinklers should be in line with the tree row and evenly spaced along the row with the throw of each sprinkler reaching the base of the next one (Figure 35) (Mccarthy and McCauley, 2019).

Figure 35 — Schematic picture of a mini-sprinkler set up for an avocado orchard aiming to deliver irrigation only within the tree canopy (Adapted from Mccarthy and McCauley, 2019).

The orchard should be divided into manageable sized blocks, and should be able to provide different irrigation rates and frequencies to different soil types, different sized trees and ideally different varieties and/or rootstocks (particularly if fertigation is involved). This is because these factors will impact on the volume and frequency of irrigation and fertiliser required (Mccarthy and McCauley, 2019).

2.8. INTERCROPPING AND OTHER ASSOCIATIONS

Legume cover crops such as beans, and stylosanthes and non-leguminous crops such as rye, oats, barley, buckwheat can be intercropped in some young orchards. These crops not only fix nitrogen but also supress weeds and increase soil fertility. The only precaution that should be taken is to ensure to keep a distance between the crops and the avocado plant.

Avocado can be inter-cropped with other perennial crops such as coconut, banana, jackfruit, rambutan, mangosteen, papaya, guava, peach etc to take advantages of the properties of some plants such as the protective or repulsive effects, the attraction effect of auxiliary insects as well as the optimization of the space. It is important that water and nutritional requirements of the crops are met independently.

Table 1 — Example of associations that can be considered with avocado

YEAR	POTENTIAL INTERCROP
1	Beans + Peas + Kales/Cabbage + Tomato can be grown between the rows + Cassava Papaya trees can also be incorporated between the rows
2	Rye grass + Oats + Beans + Kales Papaya still in place between rows
3	Beans + Peas + Buckwheat + Sunflower (Here sunflower to favour pollinators just before avocado begins to flower) Papaya trees can be maintained
4	Stylosanthes + Sod + Desmodium + Rattlepod (Crotalaria retusa)
5	Rye grass

In selecting a cover crop or intercrop, it is critical to consider any pests that may be encouraged with certain species. For example, mealybugs on papaya or fruit flies harboured by guava.

There are other associations that should be avoided. Trees that grow taller or to a similar height as the avocado trees should be avoided as these will tend to shade the crop. Furthermore, certain crops such as coffee have been shown to perform poorly when intercropped with avocado (Mithamo *et al.*, 2017). Care should also be taken to avoid intercropping avocado with crops that require heavy chemical applications.

THE COVER CROPS WILL HAVE MULTIPLE FUNCTIONS, INCLUDING

- Protect the soil (avoid erosion in the rainy season and conserve moisture in the dry season)
- Limit the development of weeds
- Improve soil structure through root development and biomass (organic matter)
- Provide a greater quantity of nitrogen (legume cover crops) to the orchard trees (subject to the presence of nodules, otherwise nitrogen will be taken away)
- Increase the biological life of the soil
- Favour biological control by conservation

Source: translated from « Fiche n°2 : les plantes de couverture sous verger » : https://bsvguyane.wordpress.com/cultivons-autrement-exemples-locaux-de-techniques-agro-ecologiques/

Other than intercropping, a farmer can integrate animals such as chicken, goats, sheep, cattle etc. in the farm. Integration of animals in the farm will provide the farmer with organic manure that can be used to provide nutrition for the trees (see section 5.2.1). In addition, animals such as goats and cattle will be useful to manage weeds in the farm thereby reducing the costs associated with weed management such as synthetic chemicals (see section 5.4.2). Care should be taken to ensure animal wastes are properly managed (*e.g.* properly decomposed before they are used as manure).

PRE-PLANTING CHOICES

KEY POINTS SUMMARY

Bad choices before planting avocado would always result in losses. It is therefore important to carefully consider the choices relating to:

- **Location of the plot:** sensitive to frost and wind → importance of windbreaks
- **Planting material:** both rootstocks and scions selection
  - Disease resistance
  - Salinity tolerance
  - Lime-induced chlorosis resistance
  - Frost resistance
- **Varieties to plant:** over 20 commonly grown cultivars (Hass, Fuerte, Bacon, Edranol, Ettinger, Pinkerton, Reed, ...)
- **Seedling nursery management**
  - Seed source: obtain seed from mature fruit and avoid the use of windfalls
  - Pest free planting material
  - Wedge/cleft grafting method
- **Irrigation methods:** Drip irrigation & under tree sprinklers
  - Sensitive to waterlogging → favorable to water-mould-like fungus
- **Associations**
  - Legume cover crops: beans, stylosanthes, non-leguminous crops (rye, oats, barley, buckwheat)
  - Intercropping with perennial crops: coconut, banana, jackfruit, rambutan, mangosteen, papaya, guava, peach.

Note that the impacts of any wrong selection may sometimes be exhibited several years after planting and leading massive losses.

3

PREPARING THE PLOT

3.1. LANDSCAPING

3.1.1. DRAINAGE

Soil drainage is important and should be the primary consideration when siting an avocado plantation especially in areas of high rainfall. Provided drainage is adequate, the trees will grow well on any type of soil that has good water holding capacity. If water drainage is a problem, then it is recommended that the trees are planted on ridges. During site planning, ensure proper drainage by ripping through any impervious soil layers or hardpan near the surface, installing drains, and grading soil to remove standing water areas. Consider planting trees on a raised soil berm or mound (Fig. 37). Prepare subsurface layers before planting on raised soil to facilitate strong rooting and prevent water logging.

Figure 36 — Avocado orchard landscape with raised berms/mounds
(Photo: COLEAD Avocado quality technical training-Avocado Characteristics)

3.1.2. HEDGES/WIND-BREAKS

Since winds are likely to cause damage to the fruits, it is recommended that wind-breaks are installed to protect the orchards. A wind-break is a barrier that helps to reduce the velocity of wind. The choice of wind-breaks can be natural or artificial (Fig. 37). When considering natural windbreaks, the highest possible biodiversity can be considered. More than one species should be used to provide diversity, and avoid unforeseen problems with suitability to your site. The tree considered should be resistant to pests and diseases and should not be a host of pests and diseases causing damage to avocado. Some examples to consider include Eucalyptus sp, Cypress, Grevillea, Casuarina, Cedar, Spruce, Honey locust, neem etc. Tree bearing edible fruits and are suitable may be preferred as these could provide an extra source of income to the farmer *e.g.* Jack fruit, Mulberry, Jamun, Karonda, Babool etc.

Figure 37 — Windbreaks that can be considered in an avocado orchard, natural (left) and artificial (right) (Photo: COLEAD Avocado quality technical training-Avocado Characteristics)

WINDBREAKS HAVE MANY POTENTIAL BENEFITS FOR ORCHARDS INCLUDING

- Reducing wind damage like leader breaking, graft union twisting, limb rubs on fruit, leaf tears, and desiccation
- Reducing spread of bacterial / fungal diseases during wind storms
- Improving spray coverage by reducing wind disturbance of spray patterns
- Reducing off-site spray drift
- Reducing stress on trellis or tree stakes, especially at full crop load
- Providing refuge for beneficial species
- Reducing wind and water erosion, especially on vulnerable sites with steep slopes and/or sandy soils.

(Leslie Huffman, 2013)

3.2. WEED MANAGEMENT

Weed management should start before planting the orchard. The most successful way to manage weeds is to prevent their introduction or establishment. Before planting, choose a suitable growing site and properly prepare it. Before planting or moving soil around the site, it's particularly important to get rid of perennial weeds; otherwise, these may spread throughout the field (UC-IPM, 2016).

Techniques:

— Mowing: during site preparation, when trees are small or widely spaced, and along roadsides and borders may reduce, if not eliminate, new weed infestations from blown-in or carried-in weed seeds or propagules.

— Repeated dry soil cultivations during the dry seasons before planting, kills vegetative propagules (like rhizomes and stolons) of tough weeds. Other practices to consider include flaming, hand-weeding and mulching to control emerging weeds.

— Chemical control of weeds can also be achieved using synthetic herbicides. Application of a translocating herbicide to perennial weeds before cultivation can help destroy underground structures, preventing the spread of live weeds.

3.3. SOIL PREPARATION

In soils that are not well-drained, the land should be ploughed and harrowed before laying out tree beds or rows and ridges.

Mounding along the row is often used to increase the efficient root zone and boost drainage where soil depth is marginal (less than one metre).

Soil is graded/excavated from the inter row space and placed on the tree row lines to build the mounds (Fig. 38). To minimize the risk of root rot growing and spreading to young trees, any tree stumps or large roots should be removed prior to planting a new orchard.

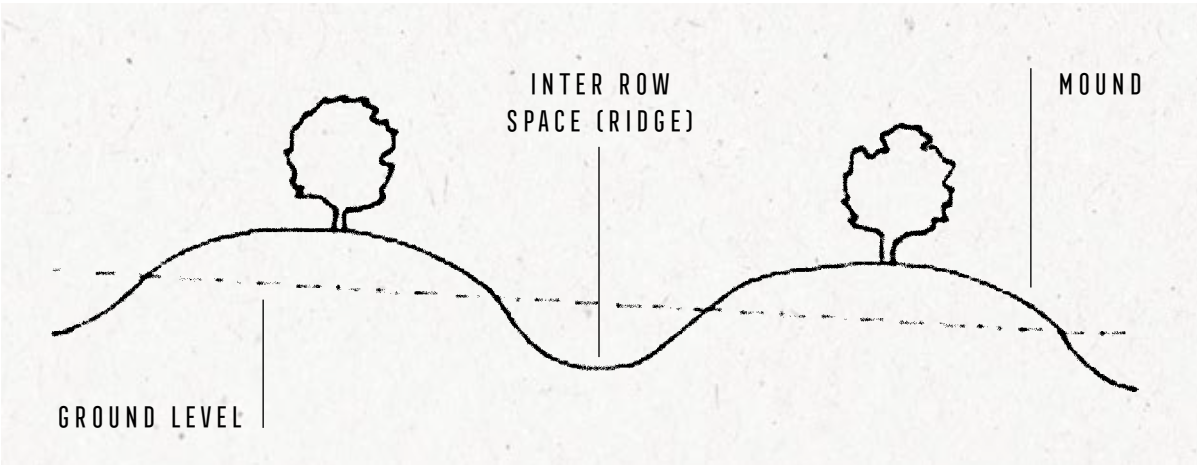


Figure 38 — Cross-sectional view of Mounds created in an orchard (Newett *et al.*, 2001)

3.4. SOIL AMENDMENTS PRIOR TO PLANTING

The pH of the soil should be tested and, if possible, modified to about 5.5 with lime or dolomite. To ensure that liming materials are well absorbed into the soil, they should be applied before the final cultivation. Organic matter (manure) can be turned in during land preparation.

3.5. TRANSFORMATION OF AN EXISTING PLOT

In addition to production of grafted plants, "top-working" can be done on already existing orchards to convert to varieties that are desirable. Almost any size of avocado tree can be top-worked or grafted to change the cultivars. If the tree is vigorous and healthy, it may be cut off just above the ground level, the wound painted and a side-veneer or wedge graft inserted in a new sprout that will grow out (Fig. 39).

Figure 39 — Stamping and grafting an old avocado tree
(Photo: Hofshi R., *et al.*, 2010)

PREPARING THE PLOT

KEY POINTS SUMMARY

- **Landscaping:**
  - Drainage: raised soil berm or mound that facilitates strong rooting and prevents water logging
  - Hedges/windbreaks to protect orchards from wind
- **Weed management:**
  - Mowing during site preparation
  - Repeated dry soil cultivations during the dry seasons before planting
  - Chemical control
- **Soil preparation:**
  - Harrowing before planting
  - Mounding
- **Soil amendments prior to planting:**
  - Lime or dolomite to obtain a pH of 5.5 if necessary
  - Organic manure
- Transformation of an existing plot: "top-working" to convert varieties that are desirable

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PLANTING AVOCADO

4.1. TIMING OF PLANTING

Since planting time is determined by climatic conditions, it varies by region and country. Planting can take place in seasons when temperatures are warm enough for establishment but not so hot that trees become stressed or sunburned. In some areas especially in the tropical regions, avocado can be planted at any time of the year provided irrigation is available. Planting can also take place at the onset of the rainy season to minimize the need for frequent watering of the newly set plants in the field.

4.2. TREE DENSITY

Early in the life of the orchard when the trees are small, the density of trees (number per hectare) should be high. Then when the trees grow and spread, they can be thinned out to reduce the density, so that the ones left are not crowded together, and remain vigorous. When laying out the planting pattern, things to be considered are soil quality (rich soils in areas of reliable rainfall can support higher densities) tree type and size (keeping the trees a manageable size will make the orchard operations such as picking and spraying much easier), machinery access and irrigation.

Initial spacing at a density of 800 trees per hectare is appropriate for smaller varieties such as Edranol or Pinkerton (Approx 4 × 3 m) but 500 of the varieties Hass or Fuerte is plenty (Approx 5 × 4 m). Plantings of 6 metres × 4 metres or 3 metres are also commonly used by some farmers (Fig. 40). If the rows are oriented in the direction of the prevailing wind, air circulation will be better. The trees are thinned (alternate trees removed) after around 8 years giving a density of around 250 per hectare. Later in the life of the orchard, depending on the pruning regime, the density may be reduced to as little as 120 trees for Fuerte, but this will be after 12 to 15 years.

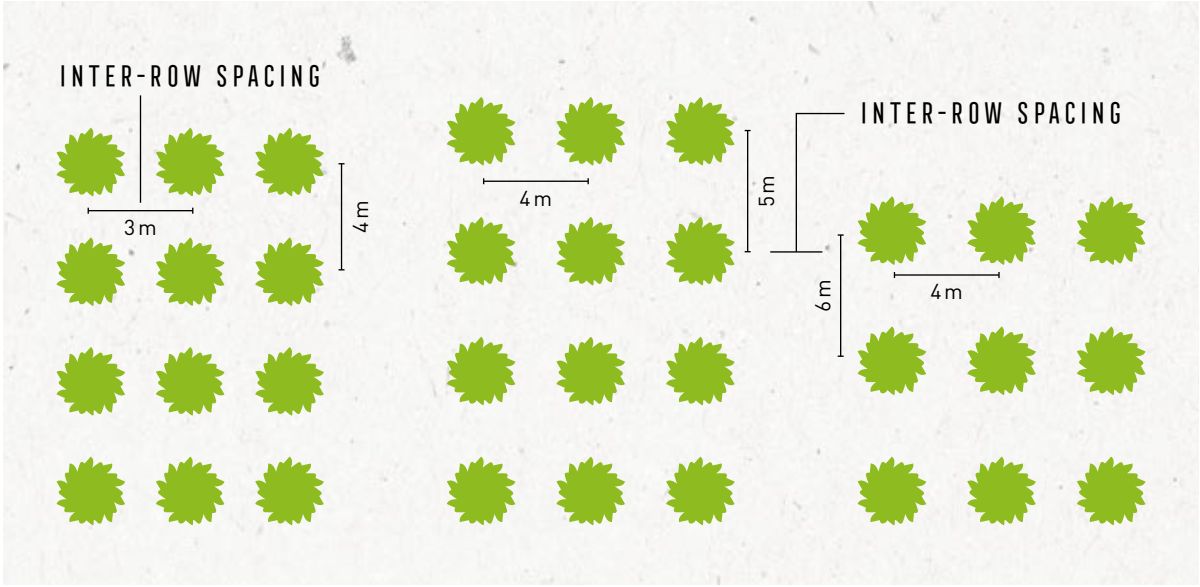


Figure 40 — Different considerations for tree spacing (density) at planting

4.3. PLANTATION LAYOUT

Trees should be planted in rows running North-South to allow for maximum sun exposure from East and West. The optimal tree shape is broadly pyramidal or conical. It is also important to space the trees to ensure that trees in each row do not shade the trees in the adjacent rows. Tree spacing should be standard within the same orchard.

Where machinery access and irrigation are anticipated, a rectangular hedge type of layout is preferred (Fig. 41). Space between rows ("Work Row") should be sufficiently large to allow tractors, spray carts and other agricultural machinery to drive through freely without damaging trees or compacting soil (= damaging roots).

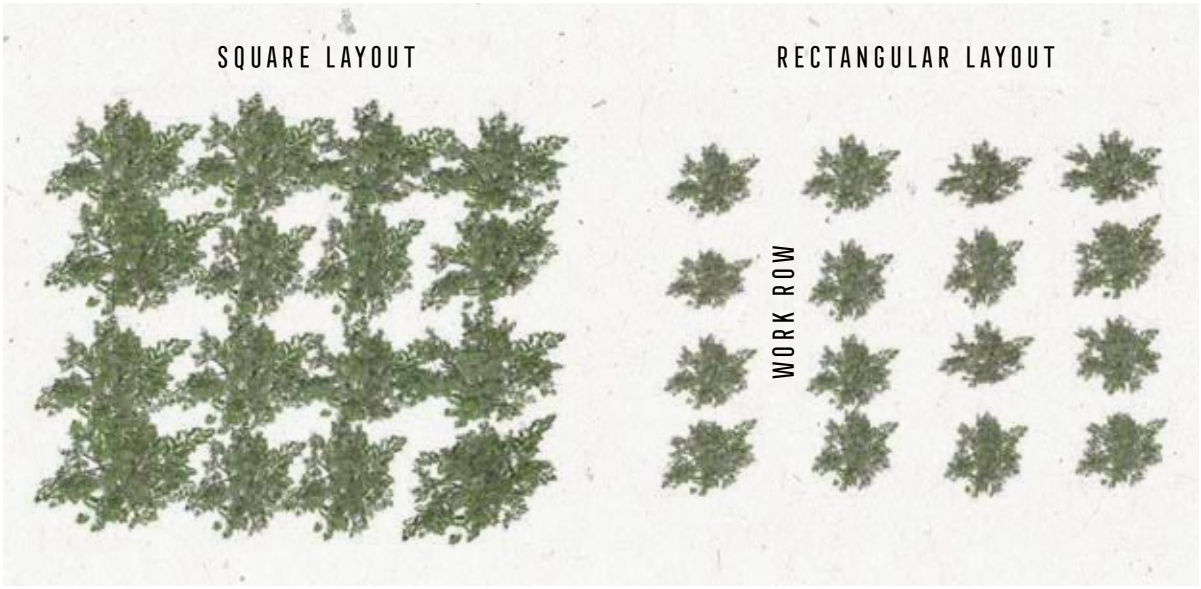


Figure 41 — Square (left) vs. rectangular (right) hedge type of layouts in avocado

4.4. PLANTING METHOD

4.4.1. PLANTING HOLE

Planting holes should be dug after the irrigation system has been installed and the tree spacing has been determined. Pre-irrigate the soil to make digging easier and to prevent the soil from sucking water from the damp root ball. A tractor-mounted post-hole digger can be used on flatter ground; steep slopes are usually dug by hand. A shovel can also be used in digging the holes (Fig. 42). Dig the hole to a depth of about 15 inches, or the same as the root ball. The width of the hole should be about 2–3 times the diameter of the pot or sleeve (Bender, 2015).

Figure 42 — Using a shovel to measure the size of the planting hole (Photo: Bender S. Gary)

4.4.2. PLANTING

It is always tempting to lift the trees to the planting location by holding the trunk, however, this presents a risk to the scion which may break off at the graft union and damage the tree. Large chunks of soil and roots may also break off if the sleeves have an open bottom. It is advisable to carry a tree at a time, with one hand supporting the bottom of the root ball and the other hand holding the side of the root ball.

In case the tree was grown in an open-bottomed, polythene sleeve, the tree is placed into the hole with the sleeve intact to support the roots. Once it is positioned so that the ball is resting on firm soil, and the top of the potting mix is slightly above the soil line, the sleeve is then slit with a knife and is removed (Fig. 43). If the tree was grown in a pot with a bottom, the tree is gently pulled out of the pot after rolling the pot on the ground to separate the roots from the side of the pot. Then the root ball is gently placed into the hole.

4.4.3. EARLY CARE OF THE TREES

Establishment in the orchard will be good if the nutrition in the nursery has been managed and roots are not crowded in the containers before the trees are transplanted. This stage is critical to avoid a check in growth. Even for rain-fed orchards, irrigation should be given for several weeks after transplanting so that the plant can survive before the roots extend into the orchard soil. As much as 50 litres per plant may be needed. Plants should be tied to sticks to support them in this period.

4.4.4. PLANT SUPPORTS

Avocado seedlings require support after transplanting to ensure they grow strong and healthy. Staking is one way of supporting the young avocado plants as they grow in your orchard. The stake can be made from wood, bamboo or metal depending on the farmer's choice and the tree should not be tied more tightly to the stake than is necessary. The trunk should be tied to the stakes as low as possible without flopping over. You'll be able to tie reasonably low if the trunk is already fairly heavy. If the trunk is weak, however, you'll have to tie higher or even at two tiers.

Figure 43 — Planting avocado (Adapted from New Zealand Avocado)

PLANTING AVOCADO

KEY POINTS SUMMARY

Plant density will depend on variety and tree spacing within the orchard. Planting should be done carefully to avoid breakage of seedlings and to ensure the plant is properly positioned in the hole.

- **Timing**: according to the onset of rains if provision for irrigation is not available.
- **Density**: depending on variety and tree spacing within the orchard.
- **Plantation layout:**
  - Rows running North-South, space the trees to avoid shading of the adjacent rows.
  - Maximum tree height: 5.5 m
  - Rectangular layout is preferred to enable operations
- **Method:**
  - Planting hole: after the irrigation system has been installed and the tree spacing determined.
  - Handle one tree at a time and provide support the root ball while carrying the seedling
  - Irrigate the young seedling foe several weeks after transplanting to enhance survival of the plant
  - Provide support to the young plant by tying it to stakes

5

MANAGEMENT OF AVOCADO

5.1. WATER

A hectare of mature avocado trees can need up to 8,000 m^3 (cubic metres) of water per year. Most avocados in the tropics are rain-fed and receive their water needs without additional irrigation. If the soil is particularly dry in the two months after pollination, young fruits will be shed and the yield will be reduced. If irrigation is available, this is the critical period. There are various methods to calculate how much water to apply, based on soil probes or evaporation calculations.

The choice of method of irrigation will also guide on the frequency and intensity of irrigation that a farmer requires (refer to section 2.7). Irrigation can either be automated or manual depending on a famer's preference.

5.1.1. EXCESS IRRIGATION

It's crucial to note that the avocado tree is extremely prone to waterlogging. After just 24 hours in waterlogged soil, avocado trees might start to exhibit signs of root damage. When the soil is saturated, there is a lack of oxygen in the soil. The heavier the soil (the higher the clay content), the more likely it is to be saturated for long periods of time. This is due to the slower infiltration rate of heavier soils resulting in the water taking longer to drain away. The other main risk of excessive watering is that it might promote the establishment and spread of *Phytophthora cinnamoni*, also known as dieback. This water-mould-like fungus thrives in moist, warm soil, and trees that have been stressed by waterlogging are far more vulnerable to attack. Therefore, it is important to let the soil dry to your chosen refill point rather than irrigating too frequently (Mccarthy and McCauley, 2019).

IMPROVE THE WATER RETENTION OF SOIL

1. Increase the **organic matter content** and maintain the **lumpy texture** of the soil.
2. Reduce loss through evaporation by **covering** the soil with **mulch**.
3. **Hoe** the soil surface to break up the crust that contributes to water evaporation.

MANAGE LAND PARCELS TO REDUCE THE WATER REQUIREMENTS

1. Install **wind breaks** to reduce evaporation and produce a bedding.
2. On flat ground, arrange the surface to foster the **infiltration** of water.
3. On sloping ground, arrange the slope to **slow run-off**.

REDUCE WASTAGE OF IRRIGATION WATER

1. Roughly estimate the **soil humidity** (the soil water content).
2. **Adapt input** strictly to the needs of the plant, on the basis of its state of growth and the crop density.
3. Adapt the surface areas to be irrigated to the water resource available and use the most **efficient technique** to avoid over-exploiting this resource (sustainable water management).

DIVERSIFY AND PROTECT WATER RESOURCES

1. To avoid water loss, carefully **maintain equipment** and irrigation systems (clean filters, channels and drippers, replace worn or defective items).
2. Diversify and exploit **different water sources** (including rain water and water used to wash fruit and vegetables); making sure that water contaminated with microbes (faecal contamination) or hazardous products is not used. Never use used domestic waste water: it contains bacteria that are dangerous to human.
3. **Protect** wells from all pollution (organic or chemical) and ensure that watering places and wet areas (ponds, pools and creeks) are kept **clean**.

To know more: browse the COLEAD brochures on the subject.

5.2. FERTILISER

Soil, leaf and fruit sample analysis should be conducted by growers before making a decision on type and quantity of fertiliser to apply. This is the only way of ensuring that the trees are receiving the correct nutrition. However, if the facility to conduct such analyses is not available, it is recommended that the farmer should add a balanced fertiliser containing nitrogen, potassium and phosphorous (NPK), starting the year the trees are planted.

IMPROVE SOIL FERTILITY

1. Apply **rational inputs** of **organic manures** and **minerals** to offset losses arising from harvesting.
2. Opt for **associations** that are beneficial to cultivated plant nutrition (development of bacteria and fungus on roots, certain bacteria fixing nitrogen from the air in the soil).
3. Adopt **sustainable agricultural practices** that protect the soil and foster microbial life.

PROTECT SOIL FERTILITY

1. **Avoid salinisation** of the soil due to irrigation with salt water and the use of certain forms of fertiliser (KCl).
2. **Avoid soil loss through erosion**. Retain trees in cultivated land parcels to exploit deep mineral resources and cover the surface.
3. **Avoid soil compaction** through trampling or the passage of machinery that destroys the structure and prevents air and water circulating.

OPTIMISE SOIL FERTILITY

1. Before applying the appropriate inputs, **estimate the need for nutrients** in the soil by observing plants indicative of low fertility and through laboratory **analysis**.
2. **Avoid** all **shortages** and **over-applications** of mineral and organic inputs since this favours the development of crop pests (white flies, leaf diseases).
3. **Combine mineral inputs with organic inputs** (combine forms of nutrient inputs to avoid excess and leaching).

To know more: browse the COLEAD brochures on the subject.

Bear in mind when making calculations that the following elements are taken out of the field during harvesting:

- 4.5 kg of nitrogen per ton of fruit
- 0.8 kg of phosphate per ton of fruit
- 6.5 kg of potassium per ton of fruit

The amounts of fertiliser to be added can be calculated from these data. Note that the amounts to replenish depend on the initial natural nutrient status of the soil. As an example, in Kenya, since many soils have low phosphate levels, the amount to be amend per tonne of harvested fruit should be increased to 1.2 kg.

When applying fertiliser, an NPK ratio of 2:1:4 is recommended. For example, in the first year the recommendation is for 40g of available nitrogen, 20g of phosphorus and 80g of potassium. Bear in mind that a typical nitrogenous fertiliser might contain only 20 to 30% nitrogen, so a plant in year 1 would need around 150g of such a fertiliser to provide the required quantity (40g) of nitrogen, and the same applies for the other macro-nutrient elements. In subsequent years as the leaf area and volume of the tree increases, more fertiliser will be needed, see figure 44.

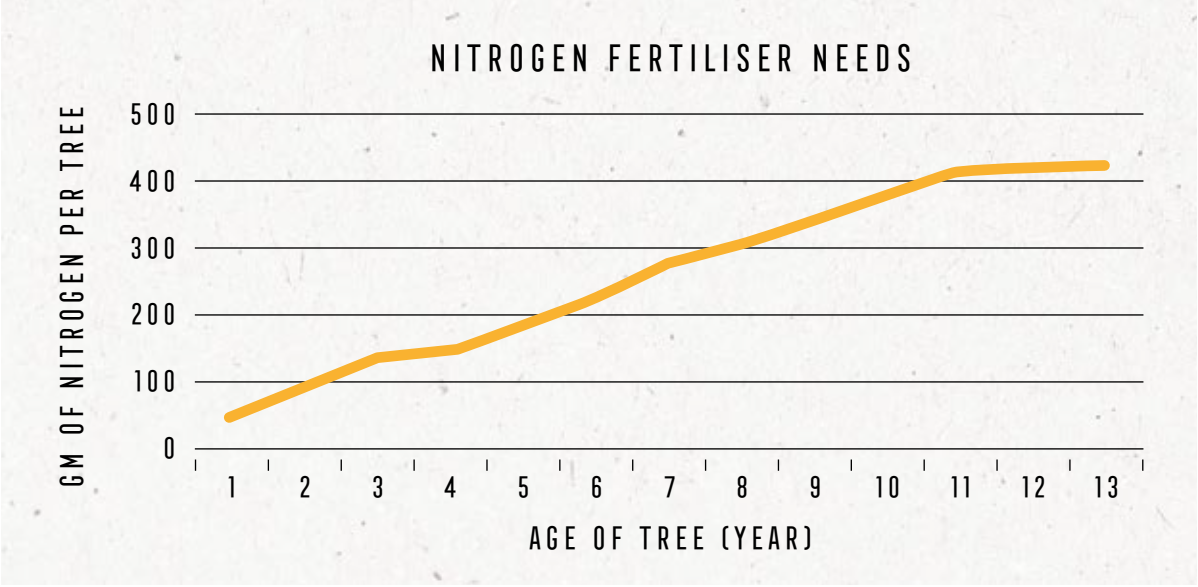


Figure 44 — Changing nitrogen needs (grams per tree) as tree grows. Note that needs of phosphorus and potassium also increase proportionally with tree age, in the ratio of 2:1:4 for N, P and K respectively.

Some oligo elements or micro-nutrients may need to be added as in some cases their absence can produce physiological disease symptoms. Micro-nutrients can be applied by foliar spray if needed.

Conducting soil analysis is highly recommended to support effective fertigation programmes (*e.g.* adapted to local conditions). Monitoring soil properties and nutrients helps meeting plant requirements by avoiding deficiency or excess and associated negative environmental and economic impacts (poor yield and unnecessary additional costs).

An example of a fertiliser regime from the South African Avocado Growers Association (SAAGA) is shown in Table 2.

Table 2 — An example of a fertiliser regime from the south African avocado growers' association (SAAGA)

PRODUCT (TRADE NAME)	CONCENTRATION (%)	APPLICATIONS	G OR ML / TREE	TOTAL G OR ML / TREE
NITROGEN (N)				**410**
Manure	1.4%	1	10,000	140
L.A.N.	23.0%	6	40	55.2
Ammonium Sulphate	20.6%			0
Calcium Nitrate	19.5%	3	367	214.7
M.A.P.	12.0%			0
Potassium Nitrate	13.5%			0
Magnesium Nitrate	10.0%			0
PHOSPHATE (P)				**98.2**
Manure	0.4%	1	10,000	39
Single Super P	11.3%	2	250	56.5
M.A.P.	37.0%			0
Phosphoric Acid (20%)	6.7%	2	20	2.68
POTASSIUM (K)				**197**
Manure	2.0%	1	10,000	197
Potassium Nitrate	38.0%			0
Potassium Sulphate	42.0%			0
Potassium Chloride	48.0%			0
CALCIUM (CA)				**292**
Manure	1.2%	1	10,000	121
Calcium Nitrate	15.5%	3	367	170.66
Lime (Calsitic)	30.0%			0
Lime (Dolomitic)	20.0%			0
Gypsum	23.0%			0
Calsi Max	10.0%			0
Cal Trac	40.0%			0
MAGNESIUM (MG)				**56.5**
Manure	0.6%	1	10,000	56.5
Lime (Dolomitic)	9.0%			0
Magnesium Nitrate	9.5%			0
Magnesium Sulphate	10.0%			0
SULPHUR (S) 0				**0**
Manure		1	10,000	0
Ammonium Sulphate	24.0%			0
Single Super P		2	250	0

PRODUCT (TRADE NAME)	CONCENTRATION (%)	APPLICATIONS	G OR ML / TREE	TOTAL G OR ML / TREE
SULPHUR(S)				**0**
Potassium Sulphate	18.0%			0
Magnesium Sulphate	13.0%			0
Manganese Sulphate				0
Gypsum	16,5%			0
ZINC (ZN)				**0.99**
Manure	0.01%	1	10,000	0.985[1]
Zinc Sulphate	35.00%			0
Zinc Max	13.00%			0
Zinc Trac	70.00%			0
COPPER (CU)				**0.28**
Manure	0.00%	1	10,000	0.28
Copper Oxichloride	50.00%			0
SODIUM (NA)				**0**
Manure		1	10,000	0
CHLORINE (CL)				**0.01**
Manure	0.00%	1	10,000	0.0075
Potassium Chloride	50.00%			0
IRON (FE)				**85**
Manure	0.85%	1	10,000	85
BORON (B)				**0.56**[2]
Manure	0.01%	1	10,000	0.56
Solubor	21.00%			0
Borax	10.00%			0
MANGANÈSE (MN)				**2.5**
Manure	0.03%	1	10,000	2.5
Manganese Sulphate	32.00%			

Footnotes

1. *Zinc is a critical micro nutrient and can be applied by foliar sprays in the form of zinc sulphate or zinc nitrate. However, it must only be applied when there is a flush of young leaves because it will not be taken up by old leaves. Alternatively, it can be applied as granules around the trunk of the tree.*
2. *Boron is also critical and must be not less than 40 ppm. It can be applied by fertigation (fertiliser applied with the irrigation water).*
3. L.A.N - Limestone Ammonium Nitrate
4. M.A.P - Monoammonium Phosphate

5.2.1. ORGANIC/ANIMAL MANURE

Animal manure should be used with caution because of high salt, nitrogen and phosphate content. It should also be noted that some manures, such as chicken manure, generally have very high phosphate and nitrate contents, which can lead to nutrient imbalances in orchards.

The soil properties should be checked annually (laboratory analysis) to decide the appropriate amount of manure to apply; otherwise, organic farmers may use the following table as a guide for manuring individual trees (Table 3).

Table 3 — Sample plan of animal urine-based manure application and other natural products

AGE OF TREE (YEARS)	NITROGEN AND POTASSIUM Litres animal urine mixed 1:4 with water in split applications	MIJINGU ROCK PHOSPHATE	ADDITIONAL POTASSIUM ASHES (HANDFULS)	MANURE OR COMPOST DECOMPOSED
1–3	8	500 g	-	15 Kg
4–5	16	900 g	-	15 Kg
6–7	30	1.4 Kg	1	30 Kg
8–9	46	1.4 Kg	2	30 Kg
10–14	60 (three 20 litre buckets/year, mixed with 12 buckets of water, divided into several applications)	2 Kg	4	30 Kg
15+	80 (four 20 litre buckets/year mixed with 16 buckets of water, divided into several applications			

Adapted from Infonet-biovision

If chicken manure is available, it can be used instead of animal urine in the following way, but be sure to spread it far enough away from the tree stem to prevent burning it (Table 4).

Table 4 — Sample plan of chicken manure application and other natural products

AGE OF TREE (YEARS)	CHICKEN MANURE KG/ TREE/YEAR	ADDITIONAL MIJINGU ROCK PHOSPHATE	ADDITIONAL POTASSIUM ASHES - (HANDFULS)	COMPOST DECOMPOSED
1–3	1.5	150 g	-	15 Kg
4–5	3	300 g	-	15 Kg
6–7	6	450 g	1	30 Kg
8–9	9	450 g	2	30 Kg
10–14	12	800 g	4	30 Kg
15+	15	1 Kg	8	30 Kg

Adapted from Infonet-biovision

5.3. GROUND COVER

5.3.1. MULCHING

Mulching is the process of covering the soil next to the crop with organic material such as compost or crop residues. Mulching:

- increases the organic content of soil
- improves moisture retention
- promotes good growth.
- reduces weed growth

Mulching is also believed to reduce harmful nematode levels and transmission of diseases spread by rain splash. Mulching is particularly beneficial to avocado because of the predominantly shallow root system. Soil diseases used to be controlled by mulching before fungicides became widely used some 30 years ago, and this useful technique is under-used today. Choice of material is important as some organic substances such as sawdust may lead to nitrogen drawdown (the bacteria and fungi which break them down, take up a lot of nitrogen that the tree could have used, so will have deleterious effects). All naturally fallen avocado leaves and healthy pruning material from trees can be left on the soil to provide a certain amount of mulch. Most plant material (*e.g.* dried grass clippings, straw, plant foliage, domestic vegetable matter) can be used as a mulch (Fig. 45–47). Pruned avocado branches should be chipped before being used as mulch material.

Figure 45 — Dried grass used as mulch in avocado orchard (Photo: Simon Newett)

Figure 46 — Wood or bark-based mulch applied around avocado tree (Photo: Bender S. Gary)

Figure 47 — Plant foliage mulch on avocado (Photo: Thomas Nelson)

5.3.2. COVER CROPS

In young groves and among older trees that have been heavily pruned, cover crops are beneficial. Cover crops can also be maintained along grove boundaries and along roadsides. A cover crop can be made up of resident vegetation (the cheapest option), one or more seeded annual species, or a combination of both. Cover crops such as cow peas, velvet beans, faba beans, sunflower, mustard, rye grass, triticale grass and pigeon peas (Rowe-Fish and Faber, 2021) provide shelter for beneficial insects while also reducing dustiness, which is conducive to mite outbreaks. Weeds are kept at bay by competition from suitable cover crop species.

5.4. WEED MANAGEMENT

Weeds often compete with trees for water and nutrients, particularly in the early years of the orchard's growth. In healthy, mature orchards with thick mulch and a dense canopy that covers the land, weeds are typically a minor issue. Weed competition may be an issue in nurseries and older groves where trees have been heavily pruned or are unhealthy, resulting in a thin canopy that allows more light to reach the ground.

An integrated weed management program that comprises multiple strategies to manage weed numbers in an economically and environmentally sound manner should be considered. These strategies usually combine cultural, mechanical, chemical, and biological methods of weed management.

5.4.1. WEED MONITORING

Regularly tracking weed species and numbers can aid in the selection of successful weed control methods as well as determining when further action is required. Identify new weed species and weeds that have escaped previous management efforts and keep track of them. This would inform what products to consider and when these can be applied in management of weeds (UC-IPM, 2016).

5.4.2. CULTURAL AND MECHANICAL PRACTICES

5.4.2.1. SANITATION

Avoid introducing weeds and get rid of conditions that encourage the growth of weeds. To avoid the spread of weed seeds and perennial structures, clean equipment after working infested land. Planning can be done such that the most infested sites are worked last or equipment thoroughly cleaned between sites if multiple sites are being worked on.

5.4.2.2. IRRIGATION

Weed growth is heavily influenced by irrigation system and frequency. When water is spread over a greater surface area and more often when sunlight enters the soil, the frequency of weed control activities increases. Since the soil surface within the tree row remains drier, weed control is needed less frequently when trees are planted on berms.

5.4.2.3. MULCH

Weed control is best achieved with a layer of coarse organic material that is 4 to 6 inches (10 to 15 cm) thick. Mulch may be made from bark, greenwaste (residential yard trimmings), grass, and wood chips. Apply organic mulch to a several-foot-wide area around freshly planted avocado trees, keeping mulch thin near the trunks or about 6 inches away to prevent crown disease problems. During the first few years of tree growth, reapply mulch once a year. If the natural leaf mulch becomes inadequate later in the trees' lives, consider adding additional organic mulch at least once every few years to keep a thick enough layer to keep weeds at bay, particularly if the leaf mulch has been blown or washed away (UC-IPM, 2016).

Organic mulch has many benefits in addition to weed control, such as eliminating *Phytophthora* root rot, conserving soil moisture, and steadily improving soil quality.

Weed fabrics (water-permeable polypropylene or polyester mulches) have some advantages over organic mulch and are occasionally used around young trees. Perennials that can flourish through organic mulch are suppressed by weed fabrics.

5.4.2.4. COVER CROPS

Weeds are kept at bay by competition from suitable cover crop species such as rye grass (refer 5.3.2).

5.4.2.5. USING ANIMALS

In small orchards, animals such as goats can be allowed to graze and feed on the weeds in the orchard thereby hindering the growth of the weeds (Fig. 48).

Figure 48 — Animals (goats) feeding on weeds

5.4.2.6. HAND-WEEDING

Avocados are typically weeded with a handheld string trimmer or mechanical weed whip, hoeing, using a machete, and hand-pulling big weeds. Hand-weeding removes vegetation near trunks, such as scattered weeds that sprout in mulch and tall weeds or problem species growing near the mulch's edge, to keep them under control. Care should be taken to avoid injuring tree by using trunk guards and reapplying mulch within the drip line.

5.4.3. CULTIVATION

Cultivate, along boundaries, and possibly in the middles when trees are young. Cultivation is advisable when weeds are no more than four inches long. For perennials like nutsedge, dallisgrass, and Johnsongrass, cultivating soon after emergence is critical. These weeds produce underground tubers or rhizomes from which they can regrow after cultivation once they have produced more than a few leaves (UC-IPM, 2016).

Cultivating too close to the tree row risks cutting feeder roots that can reduce water and nutrient uptake. Cultivation can also spread root pathogen propagules and perennial weed vegetative structures. Excessive cultivation leads to increased dust, erosion, and soil moisture loss, as well as damage to soil structure and decreased water infiltration. Stop cultivation when the trees are around 6 to 8 feet tall to avoid damage to root systems.

5.4.3.1. MOWING

Where possible, mow or flail along grove borders and margins, and in the middles between young trees. Mowing prevents erosion and helps the roots of cover crops or resident plants to retain good water penetration as compared to cultivated or bare soil. Dusty conditions are minimized in dry weather. Mowing equipment are less costly and simpler to use than cultivators. Since the equipment is lighter, soil compaction is reduced. In the tree row, special mowers may be used to mow weeds around the trunks or blast cuttings from the middles into the tree row to provide mulch. Good cover crops, when mowed, are more resistant to new weed invasion than resident plants (UC-IPM, 2016).

5.4.3.2. FLAMING

Specially made flamers, most of which use propane, can be used to control weeds. Hot water or steam applicators, as well as infrared instruments, are examples of non-open flame equipment. Flamers come in a variety of sizes and can be carried or mounted on a handcart or tractor. Tiny devices typically have a single flame source, while mechanized flamers have several burners (UC-IPM, 2016).

Flaming has many benefits, including broad-spectrum broadleaf weed control, low cost (depending on fuel and labor costs), and no chemical residue. There are a number of drawbacks, including a lack of residual power, poor control of certain grasses and perennial weeds, the need for precise scheduling to ensure proper weed control, the dangers of handling pressurized flammable gas, the risk of damaging irrigation tubing, and the risk of fire when used on steep hillsides.

Mulching and hand weeding offer the easiest and safest weed control around young trees. Exclude weeds as groves mature by offering proper cultural care and favourable growth conditions for trees. Healthy, productive trees create a dense canopy that shades the soil and provides natural mulch through leaf fall.

5.4.4. CHEMICAL CONTROL

Chemical control should be considered as a last resort.

5.4.4.1. HERBICIDES

When using herbicides, choose materials and rates based on the weed species to be controlled, your soil type, irrigation system, and the potential for tree damage. Since no single herbicide controls all weed species, combinations of materials or sequential treatments with different materials are often required when herbicides are used.

5.4.4.2. PRE-EMERGENCE HERBICIDES

Pre-emergence herbicides destroy susceptible plants during and shortly after germination; however, most of them are ineffective against emergent weeds. Most pre-emergence herbicides need to be introduced into the top one or two inches of soil by rain, light irrigation of about 0.5 inch, or cultivation in order to be safe. To prevent losing effectiveness, some pre-emergence herbicides must be transferred into the soil immediately, while others can stay on the surface for a short time before being incorporated, and still others lose effectiveness if the soil is cultivated after application. Follow the instructions on the label for the process and timing of incorporation before rain or irrigation (UC-IPM, 2016).

5.4.4.3. POST-EMERGENCE HERBICIDES

Herbicides that are sprayed on the leaves and stems of newly emerging weeds are known as post-emergence herbicides. Herbicides are graded as either contact or systemic in most cases. Contact herbicides destroy only the parts of the plant that are sprayed, so getting a good spray coverage is crucial, particularly for large weeds or dense infestations. On seedlings and young weeds, contact herbicides are most effective (UC-IPM, 2016).

Herbicides that are translocated or systemic, travel across the plant's vascular system from the treated foliage to other areas of the plant, including roots and rhizomes. They are the most effective for managing perennial weeds and are more effective on actively growing plants. Systemic herbicides, on the other hand, pose a greater risk of phytotoxicity to avocado than contact herbicides.

If certain weeds have already emerged, a mixture of pre-emergence and nonselective post-emergence herbicides is often used. (UC-IPM, 2016).

5.5. PRUNING

Pruning means planned removal of material from the tree. Its purposes are to:

- Improve light penetration.
- Provide a strong tree structure.
- Open up the tree so flowers and fruit are exposed to air and light.
- Control size and vigor.
- Maintain yield and quality.
- Bring neglected trees back into condition.

To give the tree a good start, and reduce water loss in the critical early weeks, branches are cut back by a third of their length. If there are several horizontal shoots near to each other, the weaker ones can be removed. Early in the tree life the main aim is to produce the basic framework of the tree, known as training. This is normally done to encourage side branching (Fig. 49) or to maintain a central leader (Fig. 50) in some varieties.

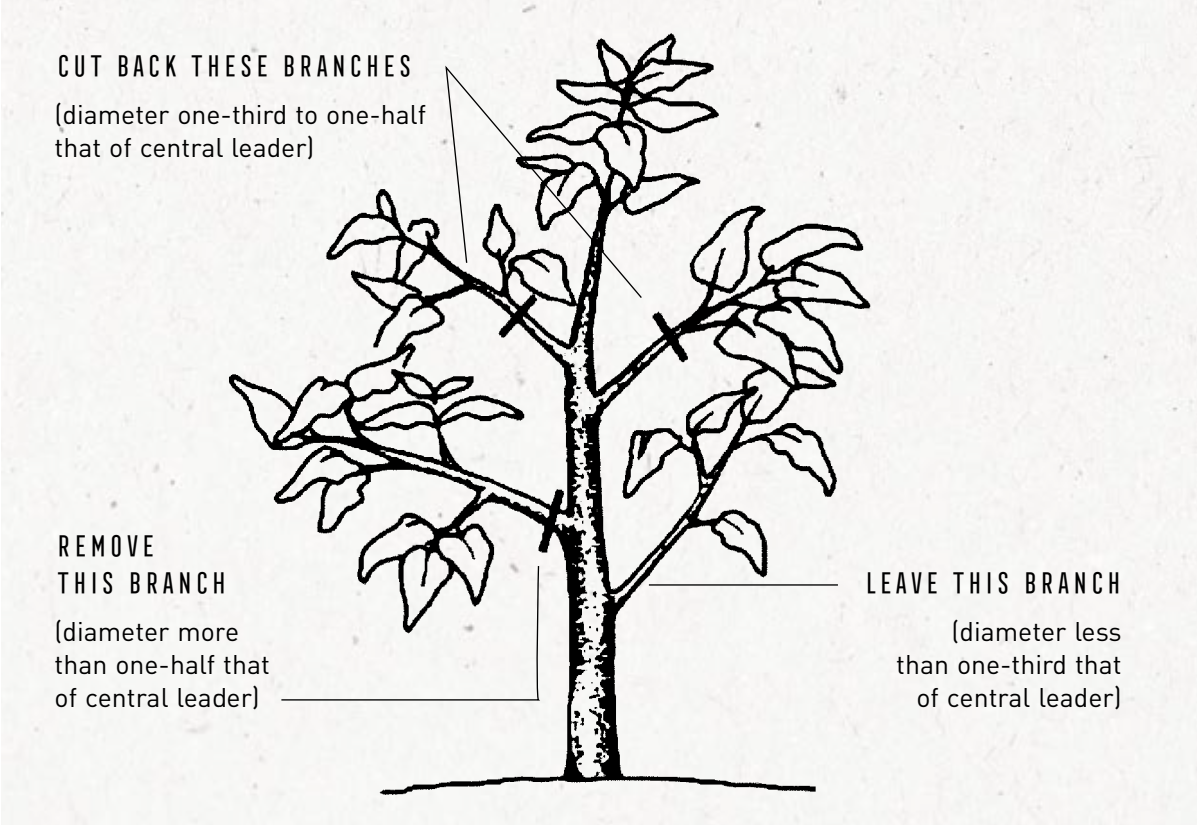


Figure 49 — Tip pruning of young avocado plants to encourage side branching (Photo: Newett *et al.*, 2001)

When the tree is fruiting the pruning is to remove weak or dead material and control or encourage vigour. This pruning is known as renewal pruning. If there are too many vertical shoots, some will be removed. If the tree is growing too tall, the strong vertical growth is cut or headed back. Preferred tree shapes and heights vary according to the management regime.

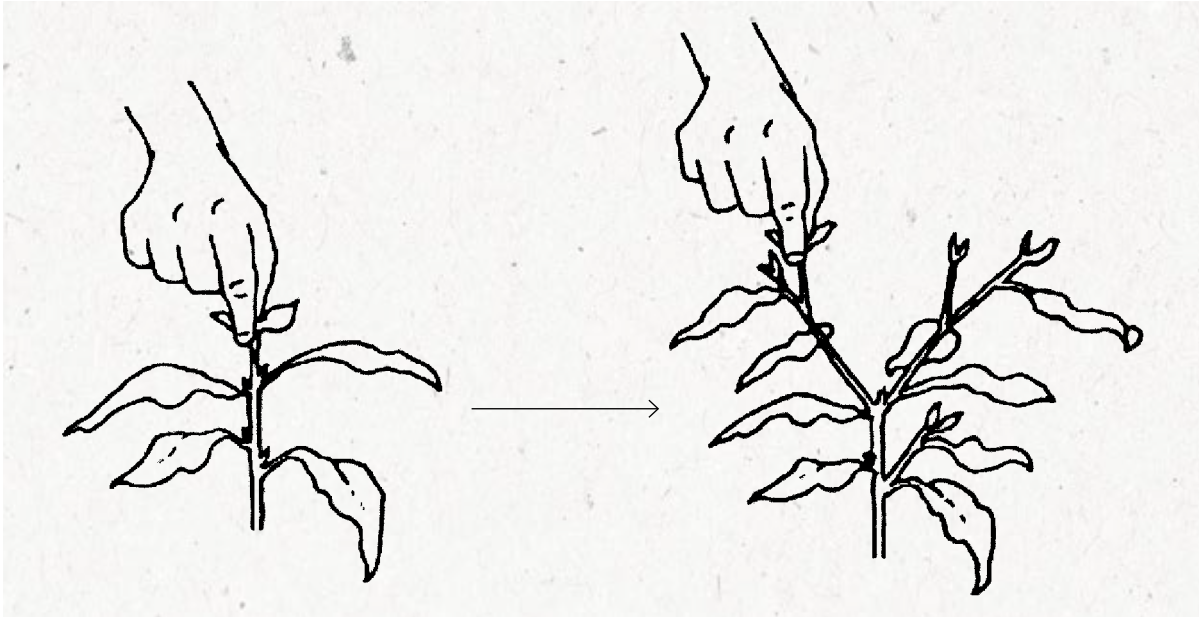


Figure 50 — Pruning a young avocado tree to maintain a central leader (Photo: Newett *et al.*, 2001)

Pruning is usually carried out following completion of harvest and before flowering. A guide is to prune so that canopy height becomes 70% of row width, with a triangular shape for best light interception (This is also called hedgerow pruning) (Fig. 51). It is sometimes a good idea to prune alternate sides of the tree each year. If trees are to be sprayed, the architecture must be compatible with good spray distribution and penetration and height should not exceed 5.5 metres. In cases where growth is very vigorous, pruning can be done several times in a year.

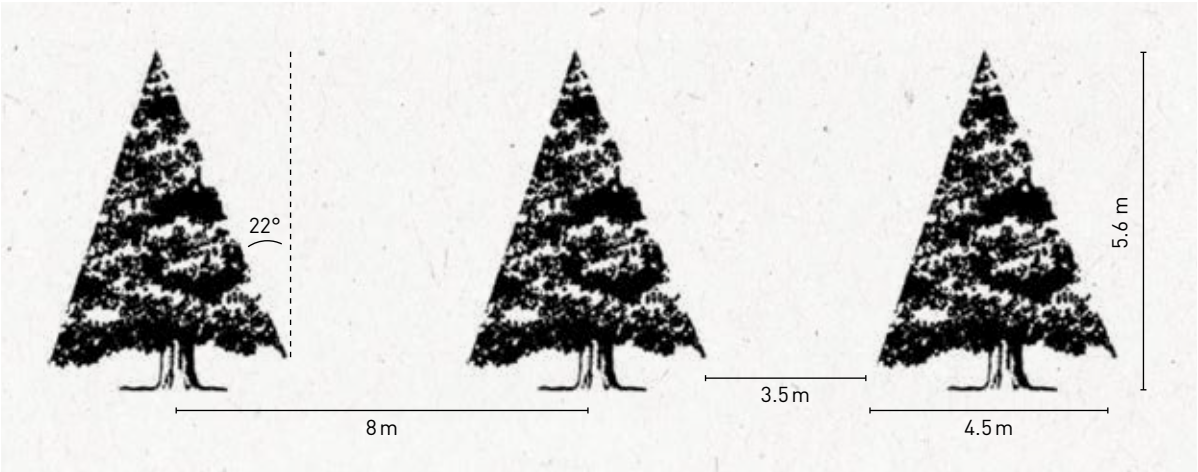


Figure 51 — How the trees should look like following hedge row pruning (Photo: Newett *et al.*, 2001)

Mature trees that have become too large to allow for effective management can also be pruned back to a stump of about 1 m high and allowed to regrow. This is called stag-horning (Fig. 52).

Figure 52 — An avocado orchard that has been pruned through stag-horning (Photo: A.W. Whiley)

Remove dead wood and fruit mummies (old, dry fruits) from orchard (Fig.53). These are a source of fungal infection.

Figure 53 — Dead fruit on the tree
(Photo: COLEAD Avocado quality technical training-Avocado Characteristics)

With grafted plants, suckers (shoots growing from the rootstock) must be removed (Fig. 54). Any damaged or broken growth must also be removed using secateurs, a sharp panga (machete) or pruning saw.

Figure 54 — Shoots/suckers growing from the rootstock of a grafted avocado tree (Photo: COLEAD Avocado quality technical training-Avocado Characteristics)

Pruning to manage the size of the plant is also important. Avocado trees become tall if structural pruning is not carried out. Varieties such as Fuerte can reach a height of 10 metres, which makes harvesting difficult and dangerous. Moreover, if the trees are very tall, the harvest operation damages a lot of fruit that accidentally falls to the ground. Tall trees also rule out spraying with cheap and simple spraying equipment. Pruning also gives an opportunity for promoting health - if branches are crowded together the incidence of diseases such as Anthracnose increases because the micro-humidity around the flowers is raised, providing good conditions for fungal spores to penetrate the embryonic fruits. Pruning should open up the canopy to allow air to penetrate to the flowers (orientation of rows along the direction of the prevailing wind also helps air circulation).

Sterilisation of pruning tools prevents spread of internally translocated diseases from tree to tree. It means dipping pruning tools in a disinfectant or 20% household bleach solution between trees to prevent any sap-borne diseases such as viral infections or fungal problems like *Phytophthora*, being spread from an infected plant to healthy ones. In practice the viral diseases are the ones which really dictate that tools need to be sterilised because they are easily transferred into the vascular system of uninfected plants.

5.6. FRUIT SETTING

5.6.1. POLLINATION

Avocados have a specific flowering pattern to reduce the risk of self-pollination. Depending on agroecological region, peak flowering times vary with cultivar, and the fruits develop at different rates. In Kenya, for example, Fuerte and Hass have different peak flowering and maturity times, see below.

Table 5 — Peak flowering periods for Hass and Fuerte varieties in Kenya

CULTIVAR	PEAK FLOWERING	PEAK HARVEST
Fuerte	September/October	March to May
Hass	October	June to September

Avocado flowers need to be pollinated before the fruit will set. Flowers are either male or female (Figure 55), so pollination requires transfer of pollen from a male flower to the stigma of a female flower, even when a variety is self-fertile.

Figure 55 — Functionally female flower (left) and Functionally male flower (right)
(Photo: COLEAD Avocado quality technical training-Avocado Characteristics)

There are two types of avocado varieties whose flowers are fertile at different times of the day (termed A and B types) see table below (Tables 6 & 7). Growers who use pollinating trees should be aware of this list because an "A" type tree pollinates a "B" type best and vice versa, giving good fertilisation, fruit set and yield. All varieties yield better when pollen comes from a different variety, and this even applies to Hass, which is sometimes considered to be highly self-fertile.

Table 6 — Avocado varieties of flowering types A and B

"A" VARIETIES	"B" VARIETIES
Hass	Bacon
Gwen	Ettinger
Lamb	Fuerte
Pinkerton	Sharwil
Reed	Sir Prize
GEM	Walter Hole
Harvest	Zutano
Anaheim	Edranol

Table 7 — Avocado flower opening sequence under "ideal" temperatures (maximum 25°C and minimum 20°C) for flowering types A and B

AVOCADO FLOWER OPENING SEQUENCE UNDER "IDEAL" TEMPERATURES (MAXIMUM 25°C AND MINIMUM 20°C) FOR FLOWERING TYPES A AND B				
Flower type	Day 1 Morning	Day 1 Afternoon	Day 2 Morning	Day 2 Afternoon
A	female	closed	closed	male
B	closed	female	male	closed

Type A flowers open first in the morning and close before noon, they will then open the following day as male with the cycle lasting 30–36 hours. Type B flowers remain closed in the morning of day 1 but open in the Afternoon of the same day as female. They subsequently open during the morning of day 2 as male and remain closed in the afternoon (Gazit and Degani, 1998).

Hence, planting some trees of a different flowering type in an orchard may increase chances of successful pollination. Whereas, there is currently no determined planting ratio between polliniser trees and the main avocado variety in an orchard, one in nine is common, with trees evenly spaced within the orchard to minimise the distance between polliniser trees and the main variety. An example of the planting layout is shown in the figure below (Fig. 56) (Mccarthy and McCauley, 2014).

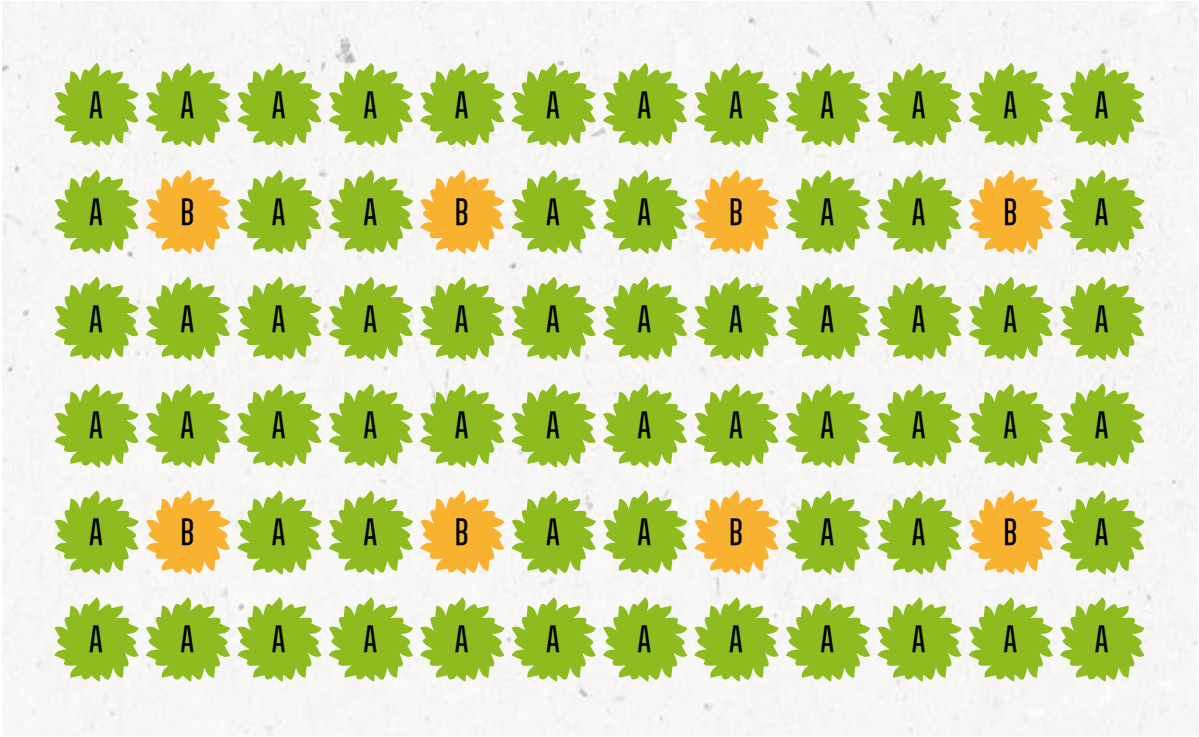


Figure 56 — A one in nine planting ratio of polliniser trees (B/yellow) to the main variety (A/green) (Adapted from Mccarthy and McCauley, 2014)

Ettinger is a particularly good pollinator for Hass. Pollination is usually carried out by insects, and if they are experimentally excluded from flowers, no fruit sets. Honey bees have been found to be the most important pollinators, even when wasps and flies are abundant, so the presence of honey bee hives in or near the orchard is recommended. The placement of the bee hives within the orchard also needs to be considered. They are best placed in small groupings relatively evenly scattered within the blocks flowering, at a rate of two to five hives per hectare. Hives should not be placed on the outside of the blocks as the scout bees might find alternative flowers faster and ignore the avocado trees (Mccarthy and McCauley, 2014).

Figure 57 — Honey bee foraging on the flowers of an avocado plant
(Photo: COLEAD Avocado quality technical training-Avocado Characteristics)

Depending on climatic conditions, certain cultivars such as Pinkerton, Mendez and Hass have two or more flowerings per year. The time period from pollination to harvest is usually about 10 months (range from 6 to 14 months). Thus, fruits from two or more flowerings can be present simultaneously.

Figure 58 — Avocado flowering while fruit from previous flowering still on the tree
(Photo: COLEAD Avocado quality technical training-Avocado Characteristics)

5.7. FLORAL INDUCTION

Poor pollination can be the result of several issues, including lack of pollen, pollen transfer or pollen viability. Weather conditions during flowering also have a significant effect.

A period of low temperature (below 20°C) and short-day length (less than 10 hours) is required to initiate the transition from vegetative bud to floral bud.

Manipulating the intensity of flowering can manipulate the size of the crop. Manipulation of flower intensity can be achieved by removal of flowers mechanically (flower pruning) or by chemical application. Chemical flower thinning is achieved by the application of gibberellic acid (GA3). Depending on the timing of its application, it could result in no flowering, reduced flower intensity, a change in the ratio of determinate and indeterminate inflorescences, or advanced vegetative flush. When applied during the floral initiation period it results in those flowers already initiated continuing to develop, but stops further initiation of new flowers (Mccarthy and McCauley, 2014).

It has been demonstrated that an increase in water stress on avocado leads to a reduction of the vegetative flush. Therefore, ensuring adequate moisture levels are maintained during the warm or dry seasons would be one way to improving vegetative flush. Improved vegetative flush would result in improved flowering intensity and fruit set.

Selective timing of nitrogen fertiliser application can also modify yields and the severity of alternate bearing. Applications after irreversible commitment to flowering resulted in increased fruit size at harvest. While applications after anthesis assisted in reducing the severity of alternate bearing.

5.8. FRUIT SETTING

The avocado tree is noted for having large numbers of flowers in some seasons and yet setting very light crops. There are several factors that affect fruit set. First, as discussed above, there is the requirement for pollen to be transferred onto the stigma (female parts) of the flower while it is receptive. There is evidence that increasing the number of pollen grains deposited onto a receptive stigma will increase the likelihood of effective pollination — hence the benefit of increasing the number of pollinators and or pollinisers (Mccarthy and McCauley, 2014).

Temperature and humidity are also important factors. Temperature affects the rate of growth of the pollen tube — the lower the temperature the slower the growth rate. Cold temperatures alter the flowering cycle by delaying the normal opening and closing routine of the avocado flower, extending the overall period of flowering, delaying the release of pollen, slowing pollen tube growth and reducing the number of flowers open on a given day.

Rain and nutrition can also impact on pollination. Rain during the day will reduce the activity of bees, affecting pollen collection and transferral. It is also possible that rain may wash pollen from flowers, thus reducing the amount of pollen available. This is similar for cold daytime temperatures as bees are reportedly much less active at temperatures below 16°C.

Having adequate levels of boron in the floral organs during flowering is reported to assist in improving fruit set. If low levels are monitored, then foliar application of boron before flowering may assist.

5.9. THINNING FRUIT

Larger fruits are preferred by the market, but when a tree bears a very high number of developing fruits they tend to be smaller. Removing (thinning out) some of the developing fruits will tend to produce the desirable heavier avocados. This process also discourages biennial bearing, which is a tendency for some trees to produce bumper crops one year and poor ones the next. One thing which must be born in mind in thinning is that if a farmer is paid by the number of fruits, it encourages him to produce small fruits. Paying a size and quality premium to smallholders will stimulate production of market-preferred grades.

MANAGEMENT OF AVOCADO

KEY POINTS SUMMARY (1)

Avocados need to be properly managed to guarantee good quality yields. Irrigation and fertilization schedules should be in place in addition to other good agricultural practices such as mulching, weed management and pruning.

Pollinators such as bees can be incorporated to ensure proper fruit setting. In addition, intercropping varieties of different flower types is important for pollination success.

- Water:
  - Tree is extremely prone to waterlogging
- Fertiliser:
  - NPK ratio of 2:1:4
  - Organic/animal manure
  - "Integrated soil fertility management" based on soil analysis
- Ground cover:
  - Mulching
  - Cover crops
- Weed management:
  - Weed monitoring
  - Cultural and mechanical practices
    - Sanitation
    - Irrigation
    - Mulch
    - Cover crops
    - Animals
    - Hand-weeding
    - Cultivation before planting
    - Mowing
    - Flaming

MANAGEMENT OF AVOCADO

KEY POINTS SUMMARY (2)

- Chemical control: pre-emergence, post-emergence herbicides (as a last resort)
- Pruning:
  - Improve light penetration.
  - Provide a strong tree structure.
  - Open up the tree so flowers and fruit are exposed to air and light.
  - Control size and vigor.
  - Maintain yield and quality.
  - Bring neglected trees back into condition.
- Fruit setting: planting some trees of a different flowering type in an orchard may increase chances of successful pollination.
- Fruit set: factors:
  - Temperature & Humidity
  - Nutrition
- Thinning fruit: removing (thinning out) some of the developing fruits will tend to produce the desirable heavier avocados.
- Floral induction: A period of low temperature (below 20°C) and short-day length (less than 10 hours) is required to initiate the transition from vegetative bud to floral bud.
  - Manipulation of flower intensity can be achieved by removal of flowers mechanically (flower pruning) or by chemical application (gibberellic acid (GA3)).

6

AVOCADO PESTS AND DISEASES

6.1. KEY PESTS AND DISEASES

Summary of key pests and diseases affecting avocado with indication of crop stages.

Table 8 — Key pests and diseases affecting avocado with indication of crop stages affected

PEST OR DISEASE	NURSERY	YOUNG PLANTED TREES	VEGETATIVE STAGE	FLORAL BUDS AND FLOWERING	FRUIT ENLARGEMENT	FRUIT MATURITY / HARVESTING	POST-HARVEST
Bactrocera dorsalis (Oriental fruit fly)	0	0	0	0	++	+++	+++
Ceratitis capitata (Mediterranean fruit fly)	0	0	0	0	++	+++	+++
Ceratitis rosa (Natal fruit fly)	0	0	0	0	++	+++	+++
Ceratitis cosyra (Mango fruit fly)	0	0	0	0	++	+++	+++
Thaumatotibia leucotreta (False codling moth)	0	0	0	0	++	+++	+
Heliothrips haemorrhoidalis (black tea thrips/greenhouse thrips)	++	+++	+++	+++	+++	+++	+++
Selenothrips rubrocinctus (red-banded thrips)	++	+++	+++	+++	+++	+++	+++
Aleurodicus dispersus (Spiraling whitefly)	++	+++	+++	+++	++	++	++
Trialeurodes vaporariorum (Westwood whitefly / greenhouse whitefly)	++	+++	+++	+++	++	++	++
Euwallacea perbrevis (tea shot-hole borer)	0	++	+++	0	0	0	0
Euwallacea fornicates (Polyphagous shot-hole borer)	0	++	+++	0	0	0	0
Xylosandrus compactus (Shot-hole borer)	0	++	+++	0	0	0	0
Nezara viridula (Green stink bug)	0	0	0	++	+++	+++	++
Hemiberlesia lataniae (Latania scale)	0	++	+++	+++	+++	0	0

Legend: 0 = no impact; + = weak impact; ++ = medium impact ; +++ = important impact

PEST OR DISEASE	NURSERY	YOUNG PLANTED TREES	VEGETATIVE STAGE	FLORAL BUDS AND FLOWERING	FRUIT ENLARGEMENT	FRUIT MATURITY / HARVESTING	POST-HARVEST
Coccus hesperidum (brown soft scale)	++	++	+++	+++	+++	0	0
Polyphagotarsonemus latus (Broad Mite)	++	++	+++	+++	+++	0	0
Pratylenchus vulnus (walnut root lesion nematode)	+++	+++	+++	0	0	0	0
Anthracnose (*Colletotrichum gleosporioides)*	+	+	++	+++	++	+++	+++
Fruit rot (Dothiorella)	0	0	0	++	++	+++	+++
Phytophthora root rot (*Phytophthora cinnamomic*)	+++	+++	+++	0	0	0	0
Verticillium wilt of lucerne (*Verticillium albo-atrum*)	+	+++	+++	+++	0	0	0
Cercospora spot /Spot blotch (*Pseudocercospora purpurea*)	+++	+++	++	+	+++	+++	+++
Stem end rots (*Lasiodiplodia theobromae, Neofusicoccum parvum, Nectria pseudotrichia, and Fusarium solani)*	+	+	++	++	++	+++	+++
Avocado scab (*Sphaceloma perseae*)	+	++	++	+++	+++	+++	+++
Bacterial canker (Xanthomonas campestris)	+++	+++	+++	0	0	0	0
Avocado sunblotch viroid (ASBVD)	+++	+++	+++	+++	0	0	0

Legend: 0 = no impact; + = weak impact; ++ = medium impact ; +++ = important impact

6.2. INTEGRATED PEST MANAGEMENT

IPM is a strategic approach towards crop protection which focuses on effective and feasible approaches that safeguard the quality and quantity of the agricultural produce while minimizing the impact of pesticide use on human health and the environment. IPM is part of a more comprehensive concept of Integrated Production that targets overall sustainability of the agricultural production on farms (Wijnands and 2012). IPM includes judicious/wise use of chemical inputs, natural environment controls and cultivation practices, including traditional controls which farmers have developed through trial and error, often over centuries and therefore it is not synonymous with ban on chemical use as it is mistakenly defined. IPM is based on the principle that each control method used will influence the potential role of other methods, with pesticides and other chemicals envisaged as last-resort tactics.

The objectives or priorities of an IPM program will vary depending on:

a) the developers involved b) the needs of the growers and c) the crops and pests involved. These key objectives are often interdependent or integrated themselves and include:

- To reduce the reliance on pesticides as the sole means of controlling pests;
- To reduce pesticides application while maintaining or improving upon the status quo of pest management i.e. crop health, and crop profitability;
- To increase yields or reducing costs of production:
- To provide pest control with minimal disruption of the environment, and reducing risk to public health;
- To provide a self -supporting, sustainable approach to pest and diseases management.

To know more, browse the COLEAD brochures *on the subject.*

6.3. THE PRINCIPLES OF IPM, DESIGN OF IPM STRATEGIES

When designing an IPM strategy for a specific region, farm or cropping system, the following principles should be followed. The order of the principles follows the general IPM strategy.

6.3.1. ENVIRONMENTAL CONSIDERATIONS

Considering environmental risks in pest management is critical for sustainable management approaches. Many interventions with pesticides can be replaced or supported by non-chemical alternatives that are environment friendly. Considerations of bioaccumulation and persistence of pest control products in the environment as well and contamination of ground and surface water are important. The effect/ impact of pest control options on biodiversity that also includes non-target beneficial organisms are also key factors to consider when developing IPM strategies for pest management. Since IPM does not mean non-use of pesticides but rather their

judicious use. When pesticides are used, chose those with minimum side effects and with minimal interference with preventive and non-chemical control methods.

Therefore, optimization of their application technique and timing as well dosages are key to prevent or delay/prevent development of resistance.

6.3.2. ROLE OF SURVEILLANCE AND MONITORING IN IPM

Plant pest surveillance data is highly valuable because it underpins many other aspects of the biosecurity. A well-run IPM program includes regular monitoring for pests, diseases, nutrient deficiencies, irrigation problems, sanitation etc. because all these factors influence development and spread of pests and pathogens. General surveillance programs raise awareness about pests with growers and the wider community and rely on people to look for and report anything unusual that they find during their day-to-day activities. Surveillance involves regular checking of a crops for early detection, proper identification of the pests or diseases as well as taking actions early enough to avoid damage. Regular and consistent surveillance and monitoring allows for early detection of new pests. Taking appropriate actions prevents spread of pests further improving pest management. Monitoring can include routine inspection/checking of crops for signs and presence of pathogens and pests. It can also involve use of surveillance tool such as traps *e.g.* pheromone, sticky, fit fall, light traps, use of models to predict diseases and pest outbreaks etc. The choice of monitoring and surveillance tools depend on availability, affordability, knowledge required for their use etc.

6.3.3. MANAGEMENT OF NATURAL ENEMIES

Conservation and management of natural enemies is a key component of IPM. Under natural environment, natural enemies such as predators, parasitoids and pathogens control and maintain pest populations below damage threshold. However, in intensive production systems, this balance is disrupted mainly through planting of monoculture crops, intensive use of non-selective/broad spectrum pesticides among other activities. Natural enemies complement other control strategies by maintaining pests below damage threshold. Therefore, effective IPM strategies should adopt practices that promote and conserve natural enemies under their natural environment. Such practices include but not limited to intercropping (where compatible), use of specific pant protection products that do not harm these natural enemies among others.

6.3.4. CULTURAL PRACTICES

These are an important component of IPM strategies. These practices include crop rotation with non- or poor hosts, use of resistant varieties where available, water and nutrition management, field sanitation, intercropping, use of repellant crops, mulching, organic soil amendments etc. These practices enhance pest and diseases management by either slowing down their movement (intercropping),

creating unfavourable environment for their breeding or starving them (use of poor hosts or non-hosts or resistant varieties), enhance and boost plant defence against pests and diseases (nutrition and water management). Use of cultural practices is not only affordable and compatible with most productions systems but they also do not require special skills to apply. They are part of routine activities carried out by farmers in crop production.

6.3.5. RATIONAL USE OF PLANT PROTECTION PRODUCTS

Use of plant protection products (PPP) is the most popular and widely used approach to pest management. Farmers prefer it because of its almost immediate control of pests and diseases. However, indiscriminate or injudicious use of PPPs has resulted in more damage than good.

6.4. PRELIMINARY NOTE

In view of the evolving regulations and phytosanitary standards governing the use of plant protection products, including changes in European Union (EU) and Codex Alimentarius Maximum Residue Limits (MRLs), COLEAD launched the E-GAP database in 2018 as a tool to support technical pathways.

The E-GAP brings together the MRLs set by the EU and Codex Alimentarius for key horticultural crops in ACP countries. It also includes the good agricultural practices (dose, interval between treatments, pre-harvest intervals, etc.) that ensure compliance with these MRLs. Additional information such as the type of pesticide, the authorization status of the active substance in the EU, the classification recommended by the World Health Organisation (WHO) and the resistance group (FRAC code for fungicides; IRAC classification for insecticides) are also available.

To date, the E-GAP is one of the only databases to provide information specifically dedicated to supporting the horticultural sector in ACP countries. Data on Good Agricultural Practices (GAP) is obtained from a combination of sources, including COLEAD PPP field trials, PPP manufacturers' data and scientific literature.

The E-GAP is available to all COLEAD members and beneficiaries in the e-service section of the COLEAD website: here.

Note that before deciding to use a PPP, producers should always refer to their national or regional regulations and certification specifications, as well as the regulations of the destination market.

Phytosanitary protection must be reasoned, i.e. it must be based on a good knowledge of the orchard and a detailed observation of the evolution of diseases and pest populations.

The good practices for the safe use of pesticides are available on the COLEAD e-library: here.

6.5. INSECT PESTS OF AVOCADO

6.5.1. FRUIT FLIES

SCIENTIFIC NAME

1. *Bactrocera dorsalis* (Oriental fruit fly)-Major pest
2. *Ceratitis capitata* (Mediterranean fruit fly)-Major pest
3. *Ceratitis rosa* (/Natal fruit fly)-Minor pest
4. *Ceratitis cosyra* (Mango fruit fly)-Minor pest

LIFE CYCLE AND BIOLOGY

1. *Bactrocera dorsalis* (Oriental fruit fly)

Figure 59 — Bactrocera dorsalis lifecycle (Image credits: Adapted from various sources)

STAGE	DESCRIPTION
Egg	They are 0.8 mm long and 0.2 mm wide, with the micropyle protruding slightly at the anterior end, and white to yellow-white. The chorion is reticulate (requires scanning electron microscope examination).
Larva	*B. dorsalis* third-instar larva: medium-sized: 7.5–10.0 mm long and 1.5–2.0 mm wide. Head: Has stomal sensory organ with three to four sensilla.
Pupa	Barrel-shaped with most larval features unrecognisable, the exception being the anterior and posterior spiracles, which are little changed by pupariation. White to yellow-brown. Usually approximately 60–80% the length of the larva.
Adult	*B. dorsalis* belongs to a subgroup that has yellow postpronotal lobes, parallel lateral vittae, and femora not extensively marked. Within this group it is distinguished by its short to long aculeus/aedeagus; tomentum with no gap; narrow costal band; generally narrow but sometimes extensive abdominal markings.

Figure 60 — Adult *B. dorsalis* (https://biology.stackexchange.com/questions/71882/help-me-identify-species-of-fruit-fly)

2. *Ceratitis capitata* (Mediterranean fruit fly)

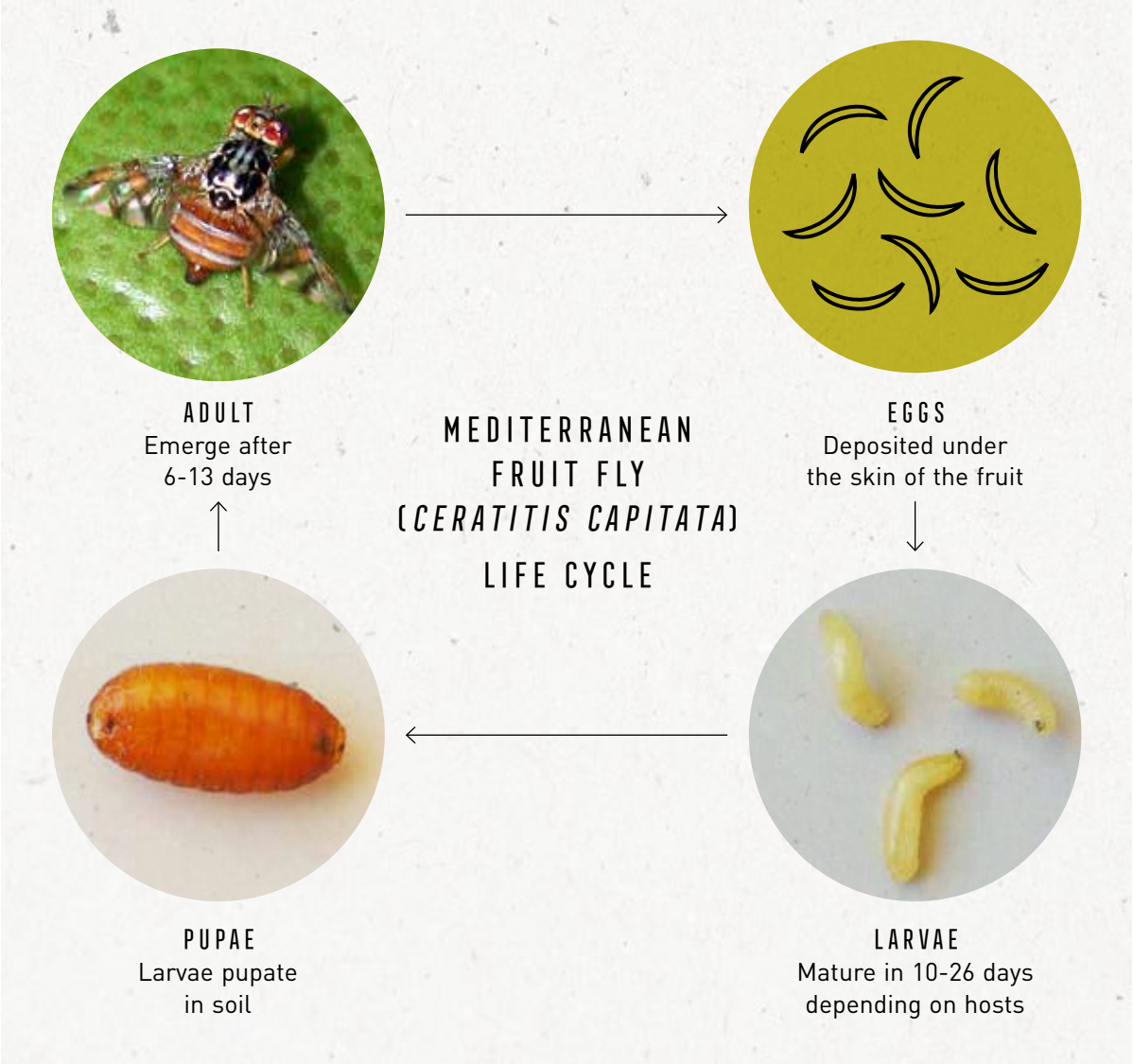


Figure 61 — Ceratitis capitata life cycle
(Source: Biovision, *Larvae* & *Pupae*: Daniel Feliciano, Adult: Imrich. Wikimedia Commmons)

STAGE	DESCRIPTION
Egg	The egg is very slender, curved, 1 mm long, smooth and shiny white. The micropylar region is distinctly tubercular.
Larva	Larva are white with a typical fruit fly larval shape, i.e., cylindrical maggot-shape, elongate, anterior end narrowed and somewhat recurved ventrally, with anterior mouth hooks, and flattened caudal end. The last instar is usually 7 to 9 mm in length, with eight ventral fusiform areas. The anterior buccal carinae are usually nine to 10 in number. The anterior spiracles are usually nearly straight on dorsal edge of tubule row. There are usually nine to 10 tubules, although there may be seven to 11.
Pupa	The pupa is cylindrical, 4 to 4.3 mm long, dark reddish brown, and resembles a swollen grain of wheat.
Adult	The adults are readily recognisable by external morphology, particularly thoracic and wing patterns. The males have a characteristically shaped pair of lower orbital setae, the apex black and diamond-shaped.

Figure 62 — Dorsal view of adult male Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann) Photograph by Scott Bauer, USDA.

3. *Ceratitis rosa* (Natal fruit fly)

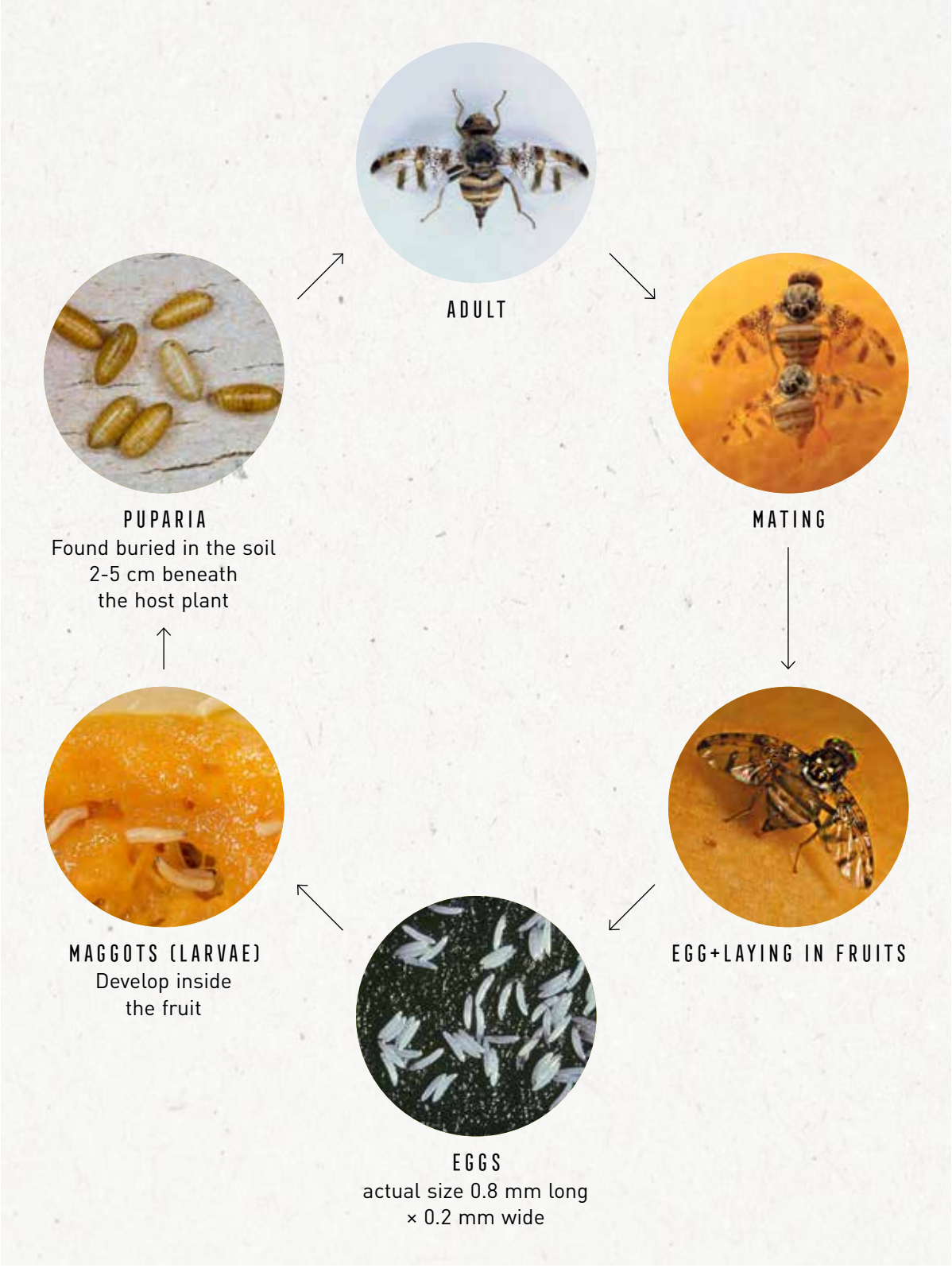


Figure 63 — Lifecycle- of tephritid fruit fly (Ceratitis rosa) (Natal fruit fly)
https://infonet-biovision.org/PlantHealth/Pests/Fruit-flies

STAGE	DESCRIPTION
Egg	Eggs are smooth, white and long and slender.
Larva	White, cylindrical with anterior end narrowed with mouth hooks. Last instar is 7–9 mm in length. Subapical tooth present on mandible.
Pupa	No published description.
Adult	Length of 4 to 5.5 mm. Main colour is yellowish with brown tinges. Lower corners of face with white setae. Ocellar bristles present. Male does not have a pair of bristles with enlarged spatulate tips near the inner margins of eyes (like *C. capitata*). Thorax creamy yellow with dark blotches. Arista of antenna plumose. Scutellum with 3 black/

Figure 64 — *Ceratitis rosa* adult
https://infonet-biovision.org/PlantHealth/Pests/Fruit-flies

4. *Ceratitis cosyra* (Mango fruit fly)

Lifecycle is similar to that of *Ceratitis capitata*

STAGE	DESCRIPTION
	Ceratitis cosyra differs from the Natal fly, the latter being larger, lacking black spots laterally (postpronotal) on the thorax, and the costal band and discal crossband are not joined. Also, males of *Ceratitis cosyra*, as members of the subgenus Ceratalaspis, lack capitate setae such as are present in subgenus Ceratitis (*e.g.*, Medfly), and they lack feathering of the tibia as in the subgenus Pterandrus (*e.g.*, Natal fly).
Egg	No published description.
Larva	As with larvae in the Tephritidae family, the larva of *C. cosyra* is between 6.5 and 7.0 mm in length and has a flat rear end. The posterior spiracles have three elongate slits which are nearly parallel. The mouthhook of the third-instar larva of *C. cosyra* has a small preapical tooth.
Pupa	No published description.
Adult	Body and wing color yellowish; sides and posterior of thorax prominently ringed with black spots, dorsum yellowish except for two tiny black spots centrally and two larger black spots near scutellum; scutellum with three wide, black stripes separated by narrow yellow stripes; wing length 4–6 mm, costal band and discal crossband joined. Adults are similar in size, coloration, and wing markings to Medfly. However, the thorax of Medfly has much more black, and the apex of its scutellum is solid black; the costal band and discal crossband of the Medfly wing are not joined.

Figure 65 — Dorsal view of *Ceratitis cosyra (Source; R. C. Copeland, icipe)*

AFFECTED STAGES OF THE CROP

NURSERY	YOUNG, PLANTED TREES	VEGETATIVE STAGE	FLORAL BUDS AND FLOWERING	FRUIT ENLARGEMENT	FRUIT MATURITY / HARVESTING	POST-HARVEST
0	0	0	0	++	+++	+++

SYMPTOMS AND DAMAGES

FRUIT Necrosis around the puncture mark ("sting"). This is followed by decomposition of the fruit., Internal feeding, lesions: black or brown, premature drop.

IMPACT ON YIELD AND QUALITY

Fruit flies are serious wide variety pests of fruits and vegetables throughout its range and damage levels can be anything up to 100% of unprotected fruit.

TYPE OF IMPACT	DESCRIPTION
Economic Impact	As a result of widespread distribution, pest status, invasive ability and potential impact on market access fruit flies are considered to be a major threat to many countries, requiring costly quarantine restrictions and eradication measures. Farmers also lose millions of dollars in lost export and local markets thus worsening income, food and nutrition insecurities and poverty. Where high populations occur on preferred hosts, and where these are uncontrolled or the effective natural enemy complex is disrupted, fruit flies can still reduce crop yields.
Environmental Impact	Displacement of indigenous fruit fly species especially when new more aggressive and invasive species like *B. dorsalis* are introduced in new environments thus causing disturbance of biodiversity. Where chemical control is used, there is risk to human health, environment and non-target species.
Impact on Biodiversity	The environmental impact is rated high because the establishment of fruit flies would likely trigger the initiation of chemical and/or biological control programmes. Chemical control would harm native insects and species of conservation significance.
Social Impact	Human health and tourism would be affected if plantations treated with insecticides are close to habitat and touristic resorts.

QUARANTINE ORGANISM

The oriental fruit fly (*Bactrocera dorsalis*) is an A1 quarantine pest in EU according to Regulation (EU) 2016/2031 (("Plant Health Law") that replaced directive 2000/29/EC which was repealed in 2019.

Mediterranean fruit fly (*Ceratitis capitata)*: It is an A2 pest ((A2 pests are locally present in region or country but recommended for regulation as quarantine pest) in East Africa, Egypt and South Africa, Argentina, Bahrain, Turkey, APPPC, EAEU, EPPO, OIRSA, PPPO. A1 pest. A1 pest (Absent from the country or region and recommended for regulation as quarantine pests) in: China, Kazakhstan, Uzbekistan, Georgia, Moldova, Russia, Ukraine. Quarantine pest (A pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled) in Mexico, Belarus and New Zealand).

Natal fruit fly *(Ceratitis rosa*): Wide spread in Africa, absent in Oceania, in Europe it is only present in in The Netherlands, Belgium and Slovenia (CABI, 2021). It is an A 1 pest in EPPO region.

Mango fruit fly (*Ceratitis coysra*): Wide spread in Africa, in Europe it is present in Belgium while in the Oceania it is only present in New Zealand.

FAVORABLE CONDITIONS TO THE INFESTATION

TYPE	FAVOURABLE CONDITION	IMPACT / EXPLANATION
The oriental fruit fly (*Bactrocera dorsalis*)	Rainfall: 250–2,650 mm/annum; Temperature:18- 27°C; Altitude: 1,500–2,000 m. a.s.l.	In tropical environments, Oriental fruit flies breed throughout the year. A female fly can lay between 1,200 to 1,500 eggs in her lifetime (1–3 months). The oriental fruit fly has been recorded from 478 kinds of fruit and vegetables (USDA 2016).
Mediterranean fruit fly (*Ceratitis capitata*)	Temperature: Region of the Earth between 23.5 degrees North and 60 degrees North (between the Tropic of Cancer and the Arctic Circle) and between 23.5 degrees South and 60 degrees South (between the Tropic of Capricorn and the Antarctic Circle).	The pest completes several generations in a year. In absence of pest control interventions, yield losses can be 100%.
Natal fruit fly (*Ceratitis rosa*)	Rainfall: 60 mm precipitation driest month (in winter) and < (100 - [total annual precipitation{mm}/25]). Temperature: Warm average temp. > 10°C, Cold average temp. > 0°C, wet all year, warmest month average temp. > 22°C	Mature females of *Ceratitis* oviposit into fruit, usually at the start of ripening (this may vary with fly or host species); there are three larval instars and depending on temperatures they develop over a period ranging from 6 to 33 days (temperatures ranging from 14 to 30°C). Several generations are completed in each year. *C. rosa* is a polyphagous species attacking a wide variety of unrelated fruits, including several commercial fruits. It can cause severe damage to commercial fruit crops, resulting in heavy losses. This indicates that it can be a serious pest species with high economic impact.
Manngo fruit fly (*Ceratitis cosyra*)	At the temperature of 25° C and RH at 75%, the lifecycle adopts the following pattern: eggs (2–3 days), larvae (5–15 days), pupae (8–12 days), adults (40–90 days). Ceratitis species are multivoltine (i.e., several generations / year).	It is a pest throughout the year since it has many hosts.

MONITORING

The males of *B. dorsalis* are attracted to methyl eugenol (4-allyl-1,2-dimethoxybenzene), sometimes in very large numbers. Monitoring is largely carried out by traps baited with methyl eugenol male lure (see Early Warning Systems) set in areas of infestation. However, there is evidence that some fruit flies have different host preferences in different parts of their range and host fruit surveys should also be considered as part of the monitoring process.

Males of *Ceratitis cosyra*, *C. capitata* and *C. rosa* adults may be attracted to Terpinyl acetate, but not to Trimedlure or Methyl Eugenol.

Monitoring can also be done by collecting fallen fruits and incubating them for emergence of fruit fly if infested.

CONTROL BY GOOD CULTURAL PRACTICES

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT/IMPACT
PRE-PLANTING CHOICES		
None. The pest attacks mature fruits		
PREPARING THE PLOT (ORCHARD)		
None. The pest attacks mature fruits		
PLANTING		
None. The pest attacks mature fruits		
ORCHARD MANAGEMENT		
Pruning	Smaller crop yields are more manageable. Helps eliminate potential sources of fruit fly infestations from unharvested fruit left high up on tree branches. Smaller fruit trees gives you the option of planting more, different varieties.	Allows easy management and effective use of resources.
Field sanitation	Field sanitation is a technique that either prevents fruit fly larvae from developing or sequesters young emerging adult flies so that they cannot return to the crop to reproduce.	Break the fruit fly cycle by elimination of larvae and pupa.

HARVESTING AND POST-HARVEST HANDLING		
Sorting and grading	Sort to eliminate infested fruits and dispose appropriately *e.g.* by putting them in Augmentorium to allow parasitoids to escape while larvae are killed.	Reduction of fruit fly population.
Post -harvest treatment	Store harvested fruit in cool place or cold storage. The recommended cold-based quarantine treatment (storage at 1.1°C for 14 days) for 5 days (Sivankalyani *et al.*, 2015). Hot water treatment-recommended - 46°C for 20 min (Vieira *et al.*, 2010).	This method kills fruit fly and therefore reduces damage since they are not feeding after hatching.

BIOLOGICAL CONTROL

— By conservation of natural enemies

This approach involves use of control methods that do not kill or harm natural enemies of fruit fly for example use of specific rather than broad spectrum pesticides, use of biopesticides like entomopathogenic fungi based biopesticides such as *Metarhizium* and *Beauveria*, as well as nematodes such as *Heterorhabditis amazonensis* and *Steinernema carpocapsae*. Use of botanicals and biopesticides that do not kill natural enemies. This allows natural multiplication of natural enemies like parasitoids and predators that attack and kill frut fly. Parasitoids known to control *Bactrocera spp* include: *Biosteres arisanus/Opius oophilus*, *Fopius arisanus*. The parasitoid *Fopius arisanus* (Sonan) is key parasitoid of fruit flies and, it is an egg parasitoid and has a wide range of potential fruit fly hosts. It has been a successfully used for biological control of fruit flies in multiple tropical regions.

Introduced natural enemies have not been successful in controlling *Ceratitis* species.

An augmentorium can be set up by farmers to allow development of parasitoids.

Figure 66 — Augmentorium (left) and parasitoids emerging from infested mango fruits (right) (Biovision)

— **By release of natural enemies**

This involves mass rearing of natural enemies like parasitiods in laboratory and introducing or releasing them into the field. The success of this strategy depends on successful establishment of the released natural enemies. Therefore, careful use of pesticides is a requirement. The use of specific rather than broad spectrum pesticides before and after release/introduction of natural enemies is required.

— **Male annihilation/suppression technique**

Trap flies using commercial pheromone traps - Methyl Euginol (Bactrolure liquid) *B. dorsalis* and Terpinyl acetate for *Ceratitis* species at 20 traps per acre.

CONTROL WITH PLANT PROTECTION PRODUCTS

- Malathion is a broad-spectrum nerve poison that is incorporated in pheromone based traps/baits or food (protein) baits used in spot applications to manage fruit fly populations.
- Spot treat affected trees with poison baits of molasses with deltamethrin
- Use pyrethrin extract
- Spray neem extracts
- Spraying trees with Spinosad

TIMING OF APPLICATIONS

Start applications shortly after flowering.

TIME OF THE DAY FOR THE APPLICATIONS

Pesticides should be applied early in the morning or late in the evening. The wind direction should be observed when spraying to reduce risk of inhalation. Use of protective clothing during spray application is compulsory.

MODE OF APPLICATION

- Foliar spray
- Drenching around avocado trees to kill emerging larvae and or adults in the soil and litter.

The application rates will depend on the manufacturer's recommendations, the calibration of the material and the regulations of the destination market (MRL, etc.)

RESISTANCE MANAGEMENT

Rotate pesticides with different modes of action to avoid resistance development.

OTHER CONTROL METHODS

— Fruit bagging: One of the most effective control techniques against fruit flies in general is to wrap fruit, either in newspaper, a paper bag, or in the case of long/thin fruits, a polythene sleeve. This is a simple physical barrier to oviposition but it has to be applied before the stage at which the fruit is attacked.

Figure 67 — Netted fruits to protect them from fruit flies

— Racking can also be done to expose pupae to sunlight and predators.

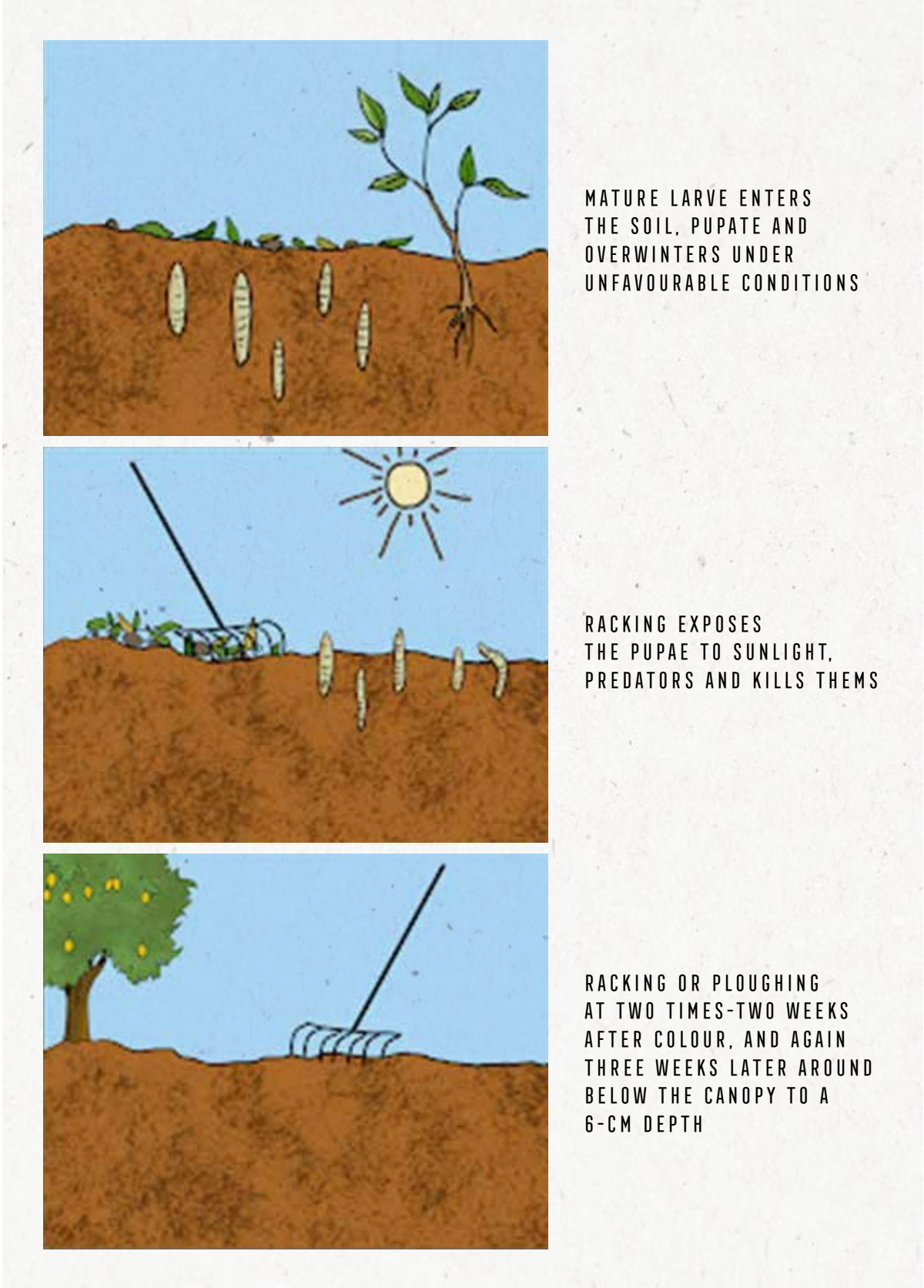


Figure 68 — Cultural control of fruit fly (Source: Biovision)

- Collected infested fruits can be destroyed by putting them in tied black plastic bags and exposing them to the heat of the sun for a few days until the fruits are rotten and all the maggots in the bags are dead.
- **Burying**: Collected infested fruits can be destroyed by burying. Ensure that the fruits are buried at least 50 cm (about two feet) deep to prevent emerging adult flies from reaching the soil surface.
- **Burning**: Collected fruits can be destroyed by burning.
- **Use of infested fruits as animal feed**: Collected infested fruits can be fed to animals (pigs, cows, etc.). Do not leave fruits piled for more than one day.

REGULATORY CONTROL

Regulatory control is the prohibition of the import of susceptible fruit without strict postharvest treatment having been applied by the exporter. This may involve fumigation, heat treatment (hot vapour or hot water), cold treatments, insecticidal dipping, or irradiation.

Note: Use only approved post-harvest treatment methods and substances in the destination market.

6.5.2. FALSE CODLING MOTH

SCIENTIFIC NAME

Thaumatotibia leucotreta (Meyrick) (Lep., *Tortricidae*) (False codling moth (FCM))
It is a **major pest** of avocado.

LIFE CYCLE AND BIOLOGY

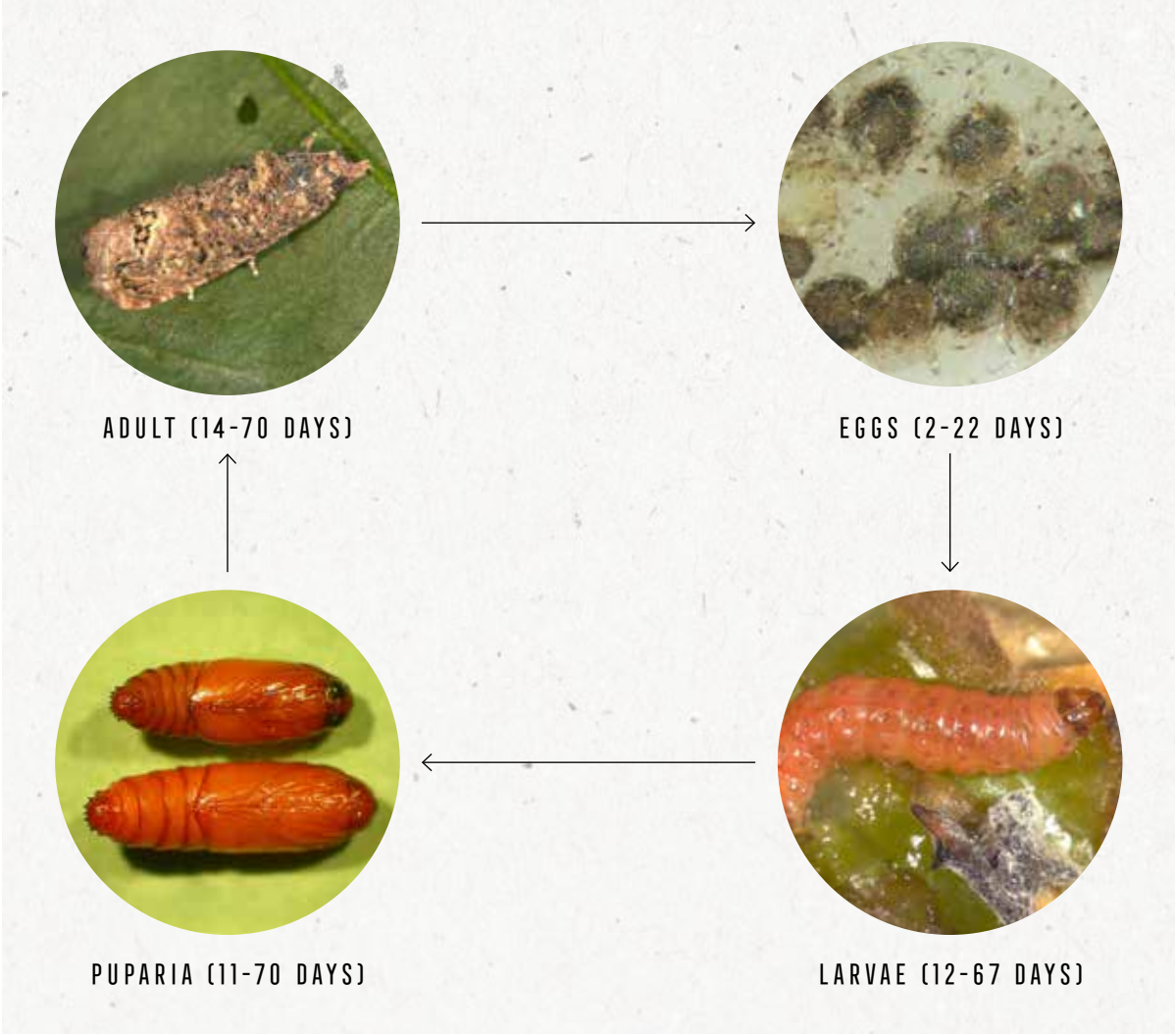


Figure 69 — False codling moth lifecycle (Syngenta)

STAGE	DESCRIPTION
Egg	Are flattened, oval, diameter 0.9 mm. Eggs might be difficult to see, as they are small, flattened and initially opaque. However, as they develop, they become pink, and eventually dark in colour, making them more conspicuous.The eggs are found on the surface of avocado fruits.
Larva	When young, creamy-white with brown to black head capsule. The full-grown larva is 15–20 mm long, bright red or pink, head prothoracic plate and pinacula yellow-brown. Can be differentiated from certain other closely related species by the presence of an anal comb; an enlarged, but unsclerotized, L group pinaculum on the first thoracic segment, extending below the spiracle; and the latter with 3 setae.
Pupa	Contained within a tough silken cocoon amongst debris or in the upper layer of soil.
Adult	Strongly dimorphic: Male wingspan 15–16 mm, female 19–20 mm. In both sexes the forewing pattern consists of a mixture of grey, brown, black and orange-brown markings, the most conspicuous being a triangular marking in the outer part of the wing, against the hind margin, and a crescent shaped marking above it. The male is distinguished from all other species by its specialised hindwing, which is slightly reduced and has a circular pocket of fine hair-like black scales overlaid with broad weakly shining whitish scales in the anal angle. It also has a heavily tufted hind tibia.

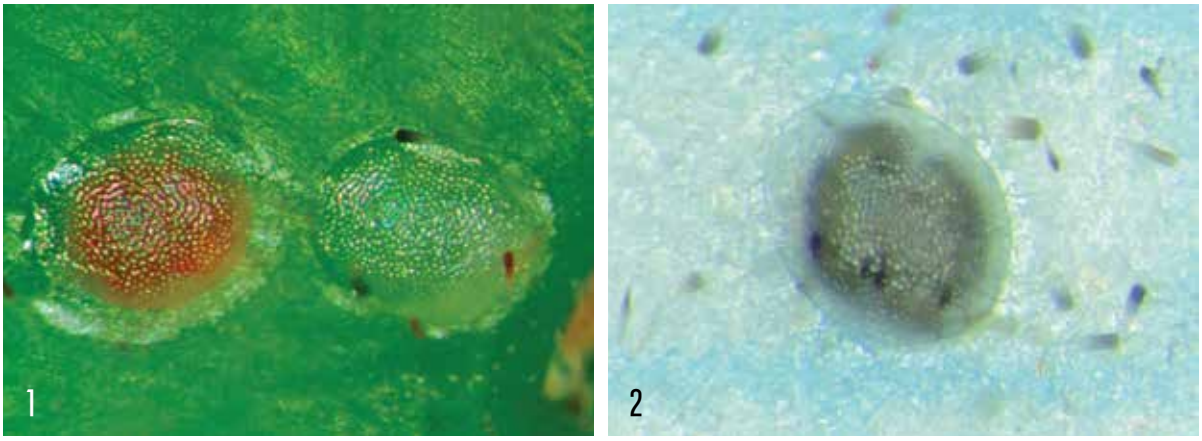


Figure 70 — FCM eggs on avocado (zookeys.pensoft.net)

AFFECTED STAGES OF THE CROP

NURSERY	YOUNG, PLANTED TREES	VEGETATIVE STAGE	FLORAL BUDS AND FLOWERING	FRUIT ENLARGEMENT	FRUIT MATURITY / HARVESTING	POST-HARVEST
0	0	0	0	++	+++	+

SYMPTOMS AND DAMAGES

- Larval penetration holes in the fruit can only be found through thorough inspection
- Larvae burrow at the stem end into the fruit and cause damage by feeding from inside the fruit.
- Damaged fruit are exposed to secondary infections by fungal and bacterial pathogens.
- FCM is an internal feeder and therefore few symptoms are visible on the surface
- Brown spots on fruit and dark brown frass are visible signs of an infestation.
- When larvae exit the fruit to pupate, the skin around the point of infestation will turn yellowish-brown as the tissue decays and collapses.
- Exit holes are approximately 1 millimeter in diameter.
- Infested fruit may also develop spots and mold.
- Premature ripening and fruit drop can also occur with infestations.
- An infested fruit usually falls from the tree 3–5 weeks after penetration by the larvae.
- Penetration of larvae is superficial and larvae are mostly found in the area just below the skin.
- Larval entrance holes on the fruit can be identified by the white exudate and granular excreta.

Figure 71 — FCM lesion on an avocado fruit and FCM larvae on avocado fruit
Source: https://www.litchisa.co.za/wp-content/uploads/2019/06/Pg-36-39-False-Codling-Moth.pdf

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Economic Impact	The pest is listed as a minor pest in avocado but has potential to cause serious damage not only in avocado and other hosts such as citrus, citrus, corn, cotton, and macadamia. The impact is likely to be magnified where is grown in close proximity with these crops. Recorded damage range between 1.3–4% (Dennill and Erasmus, 1991).
Environmental Impact	When chemical control is used, there is risk to human health, environment and non-target species.
Impact on Biodiversity	Chemical control would harm native insects and species of conservation significance.
Social Impact	Human health and tourism would be affected if plantations treated with insecticides are close to habitat and touristic resorts.

QUARANTINE ORGANISM

The false codling moth (*Thaumatotibia leucotreta*) is an A2- pests recommended for regulation as quarantine pests quarantine pest in EU according to Regulation (EU) 2016/2031 ("Plant Health Law") that replaced directive 2000/29/EC which was repealed in 2019.

False codling moth *T. leucotreta* is endemic to sub-Saharan Africa but has also been reported in other parts of the world including Israel.

FAVOURABLE CONDITIONS TO THE INFESTATION

TYPE	FAVOURABLE CONDITION	IMPACT / EXPLANATION
Temperature	12–40°C	Estimation of generation time is 450 degree days. Therefore, temperature influences number of generations in a year. 2–10 generations are possible in a year. At an optimum temperature of 25°C females can lay three to eight eggs per fruit (nuts, pods, seeds, grain heads, and berries) and up to 800 over her life span. If there are numerous females, many eggs can accumulate on the fruit. However, only a few can survive due to lack of food and cannibalism. Eggs are extremely sensitive to cold temperatures and extended periods of low humidity. Temperatures below freezing over a 2 to 3 day period can kill eggs (Blomefield 1978; Daiber 1979).
Rainfall	Tropical rainfall conditions	Heavy rainfall reduces severe infestation. Larvae and Pupae are destroyed by heavy rainfall.
Relative humidity	Optimum 80%	Low relative humidity does not favour egg development.

MONITORING

Use traps baited with pheromone and/or visual inspection and/or soil sampling to capture specimens. Install traps; inspect plants, fallen fruit, etc.; or sample soil at suspect locations. The traps should be placed on branches high enough and out of reach of children. They should also be placed in sheltered areas.

Moth counts can be useful to monitor population fluctuations and for seasonal comparison. For monitoring purposes, 4 traps per acre are recommended.

Trap catches can be used as an aid in deciding whether or not intervention is required and for the prioritization of orchards. Monitoring can also assist in the timing of treatment applications. A trap and lure combination are commonly used to survey for this pest. *e.g.* E-8-dodecen-1-yl acetate + Z-8-dodecen-1-yl acetate + E-8-dodecen-1-ol.

Figure 72 — Pheromone trap used for the monitoring of FCM in avocado orchard (Source: Farmtrack consulting ltd)

Trapping FCM is an indirect method of monitoring and many factors influence the trapping of moths. Therefore, a good correlation between trap catches and fruit infestation does not always exist. Thus, trapping data must be interpreted with fruit inspection data. Trapping remains the most practical way of predicting the risk of fruit infestation.

CONTROL BY GOOD CULTURAL PRACTICES

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT/IMPACT
PRE-PLANTING CHOICES		
None. The pest attacks mature fruits		
PREPARING THE PLOT (ORCHARD)		
None. The pest attacks mature fruits		
PLANTING		
None. The pest attacks mature fruits		

ORCHARD MANAGEMENT		
Sanitation	Although the avocado is not a good host for the development of FCM, it can develop in soft fruit. If a high number of FCM is found in orchards, sanitation will contribute towards the suppression of the population. It is important to remove all fallen fruit from orchards.	If a high number of FCM is found in orchards, sanitation will contribute towards the suppression of the population. The purpose of sanitation is to eliminate FCM larvae which may be present in such fruit. After collection, fallen fruit must be destroyed. Weekly orchard sanitation can reduce FCM larvae infesting fruit by 75%. Orchard sanitation is considered as the backbone for effective control of FCM.
HARVESTING AND POST-HARVEST HANDLING		
Sorting and grading and storage	Sorting and grading removes infested /damaged fruits. The fruits damaged by FCM are susceptible to pathogens that cause and accelerate rotting.	Improve quality and marketability of fruits. Enhances trade transparency.
Post-harvest treatment	Avocado fruits can be stored at temperatures of 5°C – 7°C and a relative humidity of 85% – 95% for three to four weeks.	FCM eggs, larvae and pupae are susceptible to low temperature exposure (Myburgh, 1965).

BIOLOGICAL CONTROL

— By conservation of natural enemies

Use of "soft chemicals" that do not kill natural enemies of FCM. Biopesticides and botanicals can also be used where applicable.

Bacillus thuringiensis (B.t.)*:* produces toxins that are lethal to caterpillars but have no effect on natural enemies. It is available in various formulations including dry flowable granules, emulsifying suspension and wettable powder. It can be applied as a cover spray at any time of the season when infestation occurs (ensure that B.t. is authorised in your area before use).

— By release of natural enemies

Mass release of the parasitoid *Trichogrammoidea cryptophlebiae* has been shown to be effective in management of FCM. *Trichogrammatoidea cryptophlebiae* (Nagaraja), *Agathis bishopi* (Nixon), and *Apophua leucotreta* (Wilkinson) are the most effective larval and egg parasitoids on FCM. Parasitoids are currently commercially available for augmentation and have been shown to reduce *T. leucotreta* infestation by up to 60%.

USE OF PREDATORS

Predators known to feed on FCM pupae are *Anoplolepis custodiens* (Smit) and *Pheidole megacephala* (Fabricius). Farmers should adopt practices that promote these predators rather than killing them *e.g.* use of soft chemicals.

MATING DISRUPTION

Mating disruption is a pest management technique designed to control insect pests by introducing artificial stimuli that confuse the individuals and disrupt mate localization, thus preventing mating and blocking the reproductive cycle. Mating disruption should be initiated early in the season while FCM levels are still low. Large areas should be treated in order to minimize the edge effect of mated female moths moving into treated areas from outside and laying viable eggs on the fruit. Mating disruption works by trapping males using commercial female pheromones. This reduces male to female ratio increasing chances of females laying unfertilized eggs. This eventually reduce FCM population. Four mating disruption products are registered for use on avocado.

CONTROL WITH PLANT PROTECTION PRODUCTS

Although several plant protection products are registered for management of FCM, attaining complete control is difficult since the most destructive larval stage of the pest resides inside the fruits and is fully covered. *T. leucotreta* insecticide resistance has been reported for the older chemical control options (Hofmeyr and Pringle, 1998). Moore *et al.* (2015a) showed that the more recently registered chemicals, such as methoxyfenozide (an ecdysone receptor agonist that affects ecdysteroid signaling in target insects, disrupting the molting process by initiating premature molt) and spinetoram (has neurotoxic mode of action) are also effective in controlling *T. leucotreta* infestation.

The chemicals should also be used sparingly in order to preserve natural enemy populations.

Active ingredients that could be used against FCM:

— **Acetamiprid**

Mode of action: a systemic insecticide that has contact and stomach poison action.

Application: apply it as a foliar spray at flowering and fruit set.

— **Acetamiprid + lambda-cyhalothrin**

Mode of action: this combination consists of a systemic and non-systemic insecticide with contact and stomach poison actions.

Application: apply it as a foliar spray.

— **Azadirachtin (neem extract)**

Mode of action: neem oil extract acts by causing insects to reduce or cease feeding, prevent larvae from maturing, reduces or interrupts mating behavior and, in some cases, the oil coats the breathing holes of insects and kills them.

Application: apply neem oil extract at first sign of insect. This product is most effective in controlling insects when applied on a 7–14 day schedule (check information on the label). For heavy insect populations, apply on a 7-day schedule. Spray to run off. Complete coverage for all plant tissue is necessary for control.

— **Chlorantraniliprole**

Mode of action: it has both stomach and contact action.

Application: apply it as a full cover foliar application. Ensure thorough coverage of the foliage and developing fruit.

— **Cypermethrin**

Mode of action: it is a non-systemic with contact and stomach action. Sodium channel modulator.

Application: Foliar spray

— **Deltamethrin**

Mode of action: a broad spectrum insecticide that acts by contact and by ingestion leading to paralysis in the insect.

Application: apply at first sign of infestation as a foliar spray and repeat if necessary. Repeat applications may be necessary to control re-infestations, as residual control is limited.

— **Emamectin benzoate**

Mode of action: a non-systemic insecticide that penetrates the leaf tissue (translaminar) and acts through ingestion to cause paralysis in insects.

Application: apply it as a foliar spray. Ensure thorough coverage of the foliage and developing fruit.

— **Lambda-cyhalothrin**

Mode of action: a non-systemic insecticide with contact and stomach action.

Application: apply it as a foliar spray.

— **Malathion**

Mode of action: a broad spectrum non-systemic insecticide that combines contact, stomach and respiratory action.

Application: apply as a cover spray when the pests are noticed.

— **Maltodextrine**

Mode of action: the mode of action is purely physical, substance coats and dries on target pest blocking the spiracles and leading to death by suffocation. Also has entrapment properties.

Application: Foliar spray

— **Methoxyfenozide**

Mode of action: an insect growth regulator that disrupts the process of moulting. It is most effective when ingested by the target caterpillar, but it also has some topical and ovicidal properties.

Application: Apply it at 8 and 4 weeks prior to harvest or when infestations are expected to occur. Do not apply more than three (3) times per season to any block of avocados.

— **Spinosad**

Mode of action: it acts by ingestion and contact and causes paralysis in insects.

Application: carefully monitor crops for eggs and immature stages of pest species by regular field scouting. Target sprays against mature eggs and newly-hatched larvae when numbers exceed spray threshold. The rates will vary depending on the product, on the crop stage, the calibration of the equipment's and other parameters such as the temperature.

— **Tebufenozide**

Mode of action: an insect growth regulator that disrupts the process of moulting (moulting accelerator).

Application: start monitoring from pre-bloom and apply at first sign of pest incidence. Additional applications may be required if reinfestation occurs. Treatments per season not limited.

Note: rotate active ingredients with different modes of action to avoid resistance development.

VIRUSES

The *Cryptophlebia leucotreta* granulovirus (CrleGV) against FCM acts by producing toxins once ingested by the FCM larvae. The success of using the virus depends on the correct application of the granulovirus, the timing of its application against the susceptible host life stage, the correct time of day to ensure optimal persistence, due to its ultraviolet (UV) sensitivity, the provision of adequate coverage, and the addition of appropriate adjuvants. It is formulated as a suspension concentrate. Standard dosage is 200–330 ml/ha (depending on crop stage and calibration of the equipment). Addition of sugar or molasses enhances its efficacy. Applied as a spray at 10 ml per 100 litres of water with 0.25% molasses and a wetter, as a full cover film spray.

ENTOMOPATHOGENIC FUNGI (EPF)

Entomopathogenic fungi *Beauveria bassiana* and *Metarhizium anisopliae* achieve more than 80% reduction of FCM infestation in a single application. However, their success depend on prevailing environmental conditions like humidity, temperature and sunlight. There are a number of EPF based commercial products that farmers can use.

REGULATORY CONTROL

This employs systems approach that includes preharvest controls and measurements and postpicking sampling, inspection, and packinghouse procedures; postpacking sampling and inspection; and shipping conditions. Evidence has shown that the maximum potential proportion of fruit that may be infested with live *T. leucotreta* after application of the systems approach is no greater than the proportion of fruit that may be infested after application of a Probit efficacy postharvest disinfestation treatment to fruit with a 2% pre-treatment infestation.

6.5.3. THRIPS

SCIENTIFIC NAME

Heliothrips haemorrhoidalis (black tea thrips/greenhouse thrips) – Major pest

Selenothrips rubrocinctus (red-banded thrips) – Minor pest

LIFE CYCLE AND BIOLOGY

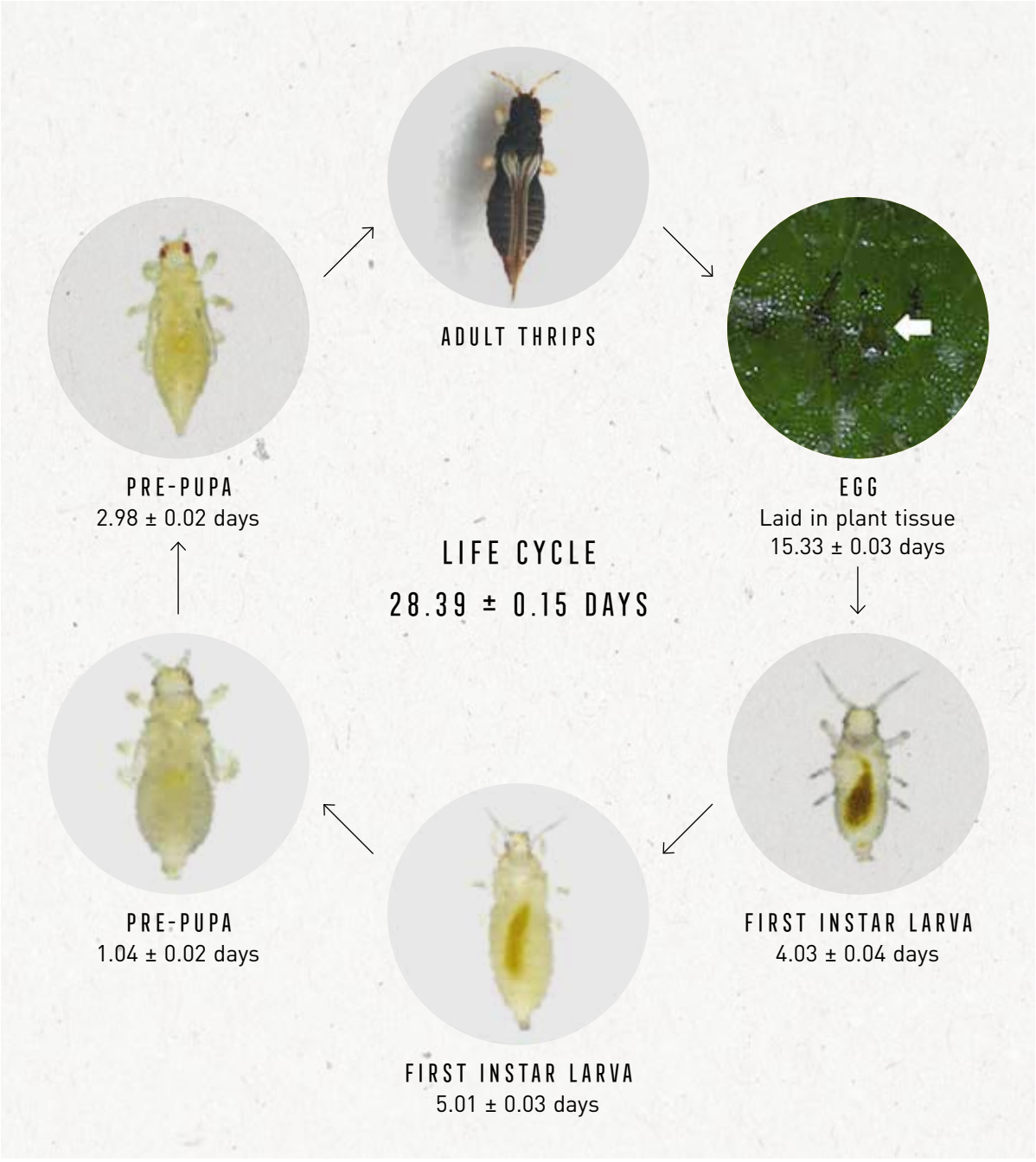


Figure 73 — Life cycle of *Heliothrips haemorrhoidalis*
(Source : de Souza etal., 2021 https://doi.org/10.1007/s12600-021-00943-7)

1. *Heliothrips haemorrhoidalis* (black tea thrips/greenhouse thrips)

STAGE	DESCRIPTION
Egg	No information
Larva	Full grown second-instar larvae are about 1.1 mm long. The body is yellow, with ninth and tenth abdominal segments brown. The antennae, except the first segment, are pale grey; the terminal segment is long, slender and needle-like. The pterothorax and abdomen have many thin and longitudinal plaques. Dorsal body setae are small; three pairs of anal setae are short, about as long as the tenth abdominal segment.
Pupa	No information.
Adult	The body is dark brown with the apex of the abdomen paler, being 1.4–1.7 mm long in the female and 1.1–1.2 mm in the male. The legs are entirely white or yellow. Teneral individuals have the abdomen orange.

Figure 74 — Larvae of *Heliothrips haemorrhoidalis* (black tea thrips/greenhouse thrips) (https://www.nexles.com/articles/greenhouse-thrips-heliothrips-haemorrhoidalis/)

Figure 75 — Adult *Heliothrips haemorrhoidalis* (black tea thrips/greenhouse thrips) (https://www.nexles.com/articles/greenhouse-thrips-heliothrips-haemorrhoidalis/)

2. *Selenothrips rubrocinctus* (red-banded thrips)

STAGE	DESCRIPTION
Egg	No information
Nymphs and Pupae	The female is about 1.2 mm in length and has a dark brown to black body underlain by red pigment chiefly in the first three abdominal segments; the anal segments retain a reddish black color, and the wings are dark. The male is similar, but smaller and is seldom collected.
Adult	The female is about 1.2 mm in length and has a dark brown to black body underlain by red pigment chiefly in the first three abdominal segments; the anal segments retain a reddish black color, and the wings are dark. The male is similar, but smaller and is seldom collected.

Figure 76 — Pupae of redbanded thrips, *Selenothrips rubrocinctus* (Giard)
Photograph by Lyle J. Buss, University of Florida

Figure 77 — Adult of the red banded thrips. Photograph by Lyle J. Buss, University of Florida.

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Economic Impact	*H. haemorrhoidalis* together with *S. rubrocinctus* has potential to cause up to 80%) cull of the fruits by lesions and crack. The larvae and adults feed on the foliage and the fruit by piercing the epidermis with their mouthparts. Redbanded thrips prefer young foliage and their feeding causes leaf silvering, distortion, leaf drop. The thrips destroys the cells on which it feeds, causes injury to the fruit, and leaves unsightly dark-colored droplets or blotches of excrement on the leaf surface. A more serious injury is leaf drop, which may denude trees. Honeydew excretory products from red-banded thrips and other insect infestations fall to leaves, fruits or objects beneath, giving rise to the objectionable fruit-degrading, black sooty mold.
Environmental Impact	When chemical control is used, there is risk to human health, environment and non-target species.
Impact on Biodiversity	Chemical control would harm native insects and species of conservation significance.
Social Impact	Human health and tourism would be affected if plantations treated with insecticides are close to habitat and touristic resorts.

QUARANTINE ORGANISM

H. haemorrhoidalis - Widely distributed in Africa, Oceania and Europe

Selenothrips rubrocinctus - Widespread in Africa, Oceania but absent in Europe (CABI, 2021).

FAVORABLE CONDITIONS TO THE INFESTATION

TYPE	FAVORABLE CONDITION	IMPACT / EXPLANATION
Temperature	21–28°C	At this temperature, The female takes 4–6 days to start oviposition after emergence and produces up to 47 eggs on average. Optimal temperature for larval development is 26–28°C
Rainfall	No published information	Information not available
Relative humidity	Information not available	Information not available

AFFECTED STAGES OF THE CROP

NURSERY	YOUNG, PLANTED TREES	VEGETATIVE STAGE	FLORAL BUDS AND FLOWERING	FRUIT ENLARGEMENT	FRUIT MATURITY / HARVESTING	POST-HARVEST
++	+++	+++	+++	+++	+++	+++

SYMPTOMS AND DAMAGES

Symptoms of attack by *H. haemorrhoidalis* result from feeding by adults and/or larvae on the leaves and fruits; the feeding punctures cause the development of chlorotic spots. Severely infested leaves become papery and wilted, and soon die. If the infestation is serious, defoliation results. Brown patches occur on the surfaces of fruits and, if injured during growing, cracks often appear.

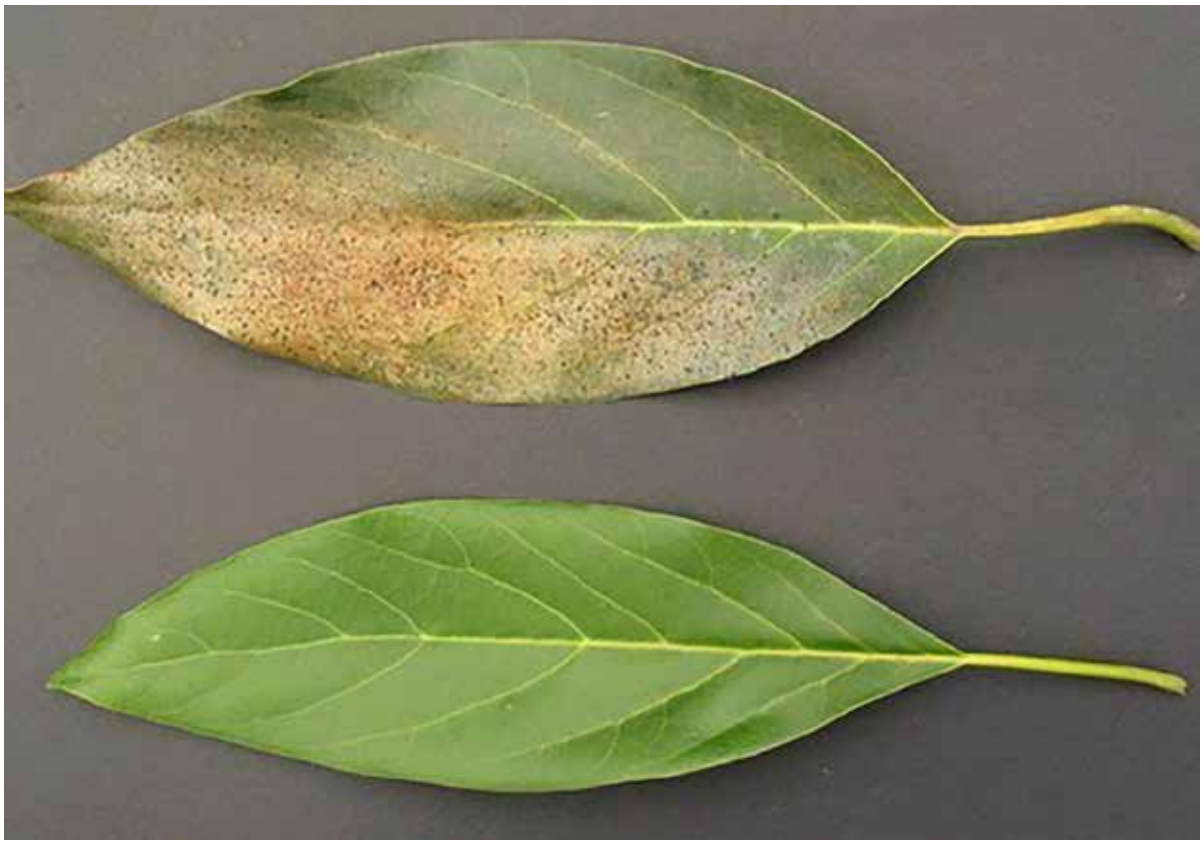


Figure 78 — Damage to leaves of avocado by greenhouse thrips, *Heliothrips haemorrhoidalis* (Funderburk *et al.*, 2008).

Redbanded thrips prefer young foliage and their feeding causes leaf silvering, distortion, leaf drop. The thrips destroys the cells on which it feeds, causes injury to the fruit, and leaves unsightly dark colored droplets or blotches of excrement on the leaf surface. A more serious injury is leaf drop, which may denude trees. Honeydew excretory products from red-banded thrips and other insect infestations fall to leaves, fruits or objects beneath, giving rise to the objectionable fruit-degrading, black sooty mold.

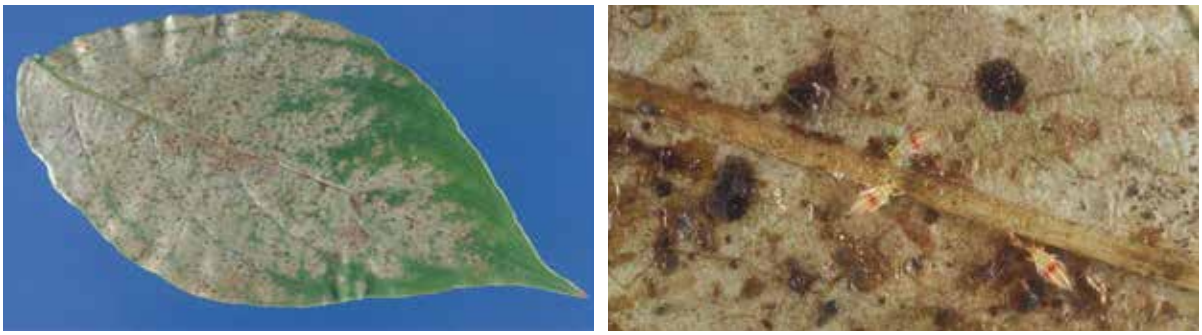


Figure 79 — Typical thrips damage, with immature redbanded thrips, Selenothrips rubrocinctus (Giard). Photograph by Lyle J. Buss, University of Florida.

On fruit, feeding begins near the calyx, gradually producing a scar that can cover the entire fruit. The fruit subsequently develops a leathery, brown skin. Feeding is most common on young fruit; economic damage generally occurs on fruit up to 2 cm in length (2–3 weeks after fruit set). Older fruit with thicker skin is less susceptible to attack.

Figure 80 — Characteristic "Alligator skin" from thrips damage (https://www.planthealthaustralia.com.au/wp-content/uploads/2013/01/Avocado-thrips-FS.pdf)

MONITORING

Both adult and immature stages are detected by examining the under surfaces of leaves and the surfaces of fruits. Chlorotic spots, brown patches and necrotic lesions are apparent. At low population levels, both thrips showed a distinct preference (93%) to feed between clustered fruits, which resulted in damage to 22–33% of the clustered fruits, whereas only 1–3% of single fruits were damaged. Fruits may be used as "traps", as this obviates the use of conventional sticky yellow traps and gives an immediate and more direct assessment of crop loss (Dennill and Erasmus 1992).

CONTROL BY GOOD CULTURAL PRACTICES

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT/IMPACT
PRE-PLANTING CHOICES		
Control pest in the nursery and use resistant varieties where possible	The pest attacks the crop in all the stages	Minimize damage for young crops
PREPARING THE PLOT (ORCHARD)		
PLANTING		
Control the pest during vegetative growth stages	The pest attacks the crop in all growth stages	Minimize build-up of the pest before fruiting
ORCHARD MANAGEMENT		
Sanitation	Removal of branches and leaves and collecting litter (fallen leaves and twigs) reduces infestation	Pruning allows light penetration into the canopy and since thrips don't like light, this reduces infestation. Field sanitation practices including removing old branches and leaves especially on the ground helps in control of thrips.
Pruning	Prune and destroy injured and infested terminals when managing a few small specimen plants	Pruning the interior of trees can increase predaceous mite populations in the exterior canopy, thereby reducing fruit scarring by citrus thrips.

Row covers	Any type of covering that excludes insects but allows light and air penetration can be used. Apply row covers before crops emerge or to pest-free plants during planting	This prevents the trips from burrowing in soil for breeding and reduces population and damage
Reflective Mulch	Mulch or mesh that reflects light interferes with certain flying insects' ability to locate plants	This reduces infestation and damage
HARVESTING AND POST-HARVEST HANDLING		
Fumigation	Use ethyl formate	

BIOLOGICAL CONTROL

Use of predacious *Orius thripoborus*; this anthocorid is potentially useful as a biological control agent of the thrips as demonstrated in South Africa ((Dennill, 1992). The parasite *Thripobius semiluteus* has successfully used to control *H. haemorrhoidalis* in avocado orchards in southern California (McMurtry *et al.*, 1991).

Redbanded thrips are preyed upon by a large assortment of natural predators such as spiders, mites, lacewings, predatory thrips, and predatory bugs, especially minute pirate bugs (Chin and Brown 2008).

Predation can be enhanced by using approved chemical pesticides that do not harm these natural enemies.

CHEMICAL CONTROL

Spinosad is generally more effective against thrips than other chemical products. Spinosad lasts 1 week or more and moves short distances into sprayed tissue (has translaminar activity) to reach thrips feeding in protected plant parts. Adding horticultural oil to the spray mix can increase its persistence within plant tissue. This insecticide is a fermentation product of a naturally occurring bacterium, and certain formulations are organically acceptable.

Active ingredients that could be used against the thrips:

— **Abamectin**

Mode of action: a systemic insecticide that acts as a nerve toxin.

Application: apply when immature thrips are noticed but before exceeding 5 immature thrips per leaf /fruit.

Resistance management*:* only apply, if necessary, a second application 30 days later.

— **Acetamiprid + Pyriproxifen**

Mode of action: a broad spectrum insecticide that provides knockdown and residual control of the pest.

Application: apply as a cover spray post flowering when there are indications of infestation or crawler release. Do not target populations that are well established where mature adults dominate.

— **Deltamethrin**

Mode of action: a broad spectrum insecticide that acts by contact and by ingestion leading to paralysis in the insect.

Application: apply at first sign of infestation and repeat if necessary. Repeat applications may be necessary to control re-infestations, as residual control is limited.

— **Fatty acids of potassium salts**

Mode of action: a broad-spectrum contact insecticide that is formulated using potassium salts combined with fatty acids.

Application: apply as a cover spray when the pests are noticed with no limits on the number of sprays per season.

— **Malathion**

Mode of action: a broad spectrum non-systemic insecticide that combines contact, stomach and respiratory action.

Application: apply as a cover spray when the pests are noticed.

— **Neem oil extract (azadirachtin)**

Mode of action: neem oil extract acts by causing insects to reduce or cease feeding, prevent larvae from maturing, reduces or interrupts mating behavior and, in some cases, the oil coats the breathing holes of insects and kills them.

Application: apply neem oil extract at first sign of insect. This product is most effective in controlling insects when applied on a 7–14 day schedule (check information on the label). For heavy insect populations, apply on a 7-day schedule. Spray to run off. Complete coverage for all plant tissue is necessary for control.

— **Potassium soap**

Mode of action: a broad-spectrum contact insecticide that is formulated using potassium salts combined with fatty acids.

Application: apply as a cover spray when the pests are noticed with no limits on the number of sprays per season. The rate can range from up to 1.5 to 3.0 L per 100 L of water depending on the crop stage and the calibration of the equipment's.

— **Pyrethrin extract**

Mode of action: a broad-spectrum organic insecticide that acts on contact.

Application: apply when pest is first observed on fruit. Repeat applications may be necessary. Treatments per season not limited.

— **Spinetoram**

Mode of action: a broad-spectrum insecticide with both contact and stomach poison activity.

Application: commence spraying at the first signs of thrips presence. Repeat application when necessary. Apply as a light cover spray ensuring thorough coverage of the target area.

— **Spinosad**

Mode of action: it acts by ingestion and contact and causes paralysis in insects.

Application: carefully monitor crops for eggs and immature stages of pest species by regular field scouting. Target sprays against mature eggs and newly-hatched larvae when numbers exceed spray threshold. The rates will vary depending on the product, on the crop stage, the calibration of the equipment's and other parameters such as the temperature.

— **Sulphur**

Mode of action: a broad spectrum insecticide/fungicide that acts on contact and is toxic to spider mites.

Application: apply when pest is noticed. The rates will vary depending on the product, on the crop stage and the calibration of the equipment's.

Note: rotate active ingredients with different modes of action to avoid resistance development.

6.5.4. WHITEFLIES

SCIENTIFIC NAME

Aleurodicus dispersus (Spiraling whitefly/whitefly**)** **–** Major pest

*Trialeurodes vaporariorum (*Westwood *w*hitefly/greenhouse whitefly) - Major pest

LIFE CYCLE AND BIOLOGY

1. *Aleurodicus dispersus* (Spiraling whitefly/whitefly)

Figure 81 — Spiraling whitefly lifecycle (vikaspedia)

STAGE	DESCRIPTION
Egg	The eggs (0.3 mm long) are usually smooth surfaced, yellow and tan elliptical in shape (Reddy, 2015). These are laid at an angle of 90° with Spiralling deposits of white flocculence on underside of the leaves. The eggs have a short pedicel or subterminal stalk, which is inserted into the host plant during oviposition (Waterhouse and Norris, 1989). The eggs are laid, along with deposits of waxy secretions, in a spiraling pattern.
Larvae/ Nymphs	The first instars are mobile and called crawlers. They are usually 0.32 mm long and settle near the spiral pattern of the eggs from which they hatched. The second and third instars are 0.5–0.65 mm long and remains feeding at same place. The distinguishing feature about the third instar larvae is the presence of glass-like rods of wax (usually short and evenly-spaced) lined along the body. The fourth instar or puparium is 1.06 mm long and covered with numerous amounts of white materials and long glass-like rods (~8 mm in length).
Pupae	The final and fourth immature stage is considered the pupa of this species. This stage feeds during the earlier phases then stops feeding and undergoes internal tissue reorganization before molting into the adult (Waterhouse and Norris, 1989).
Adult	Adult *A. dispersus* are white and coated with a fine dust-like waxy secretion. Body length of males 2.28 mm, and females 1.74 mm. Both sexes are winged. Wings are clear soon after emergence, but turn white due to the wax coating after a few hours. Adult female *A. dispersus* lay a few to several elliptical, smooth-surfaced, yellow-to-tan coloured eggs.

Figure 82 — Spirals of eggs and wax from spiraling whitefly (https://www.pestnet.org/fact_sheets/spiralling_whitefly_025.htm)

Figure 83 — Immature stages of the spiralling whitefly
(Source: https://www.b om/bug-database/lawn-pests/spiraling-whitefly/)

2. *Trialeurodes vaporariorum (*Westwood whitefly/greenhouse whitefly)

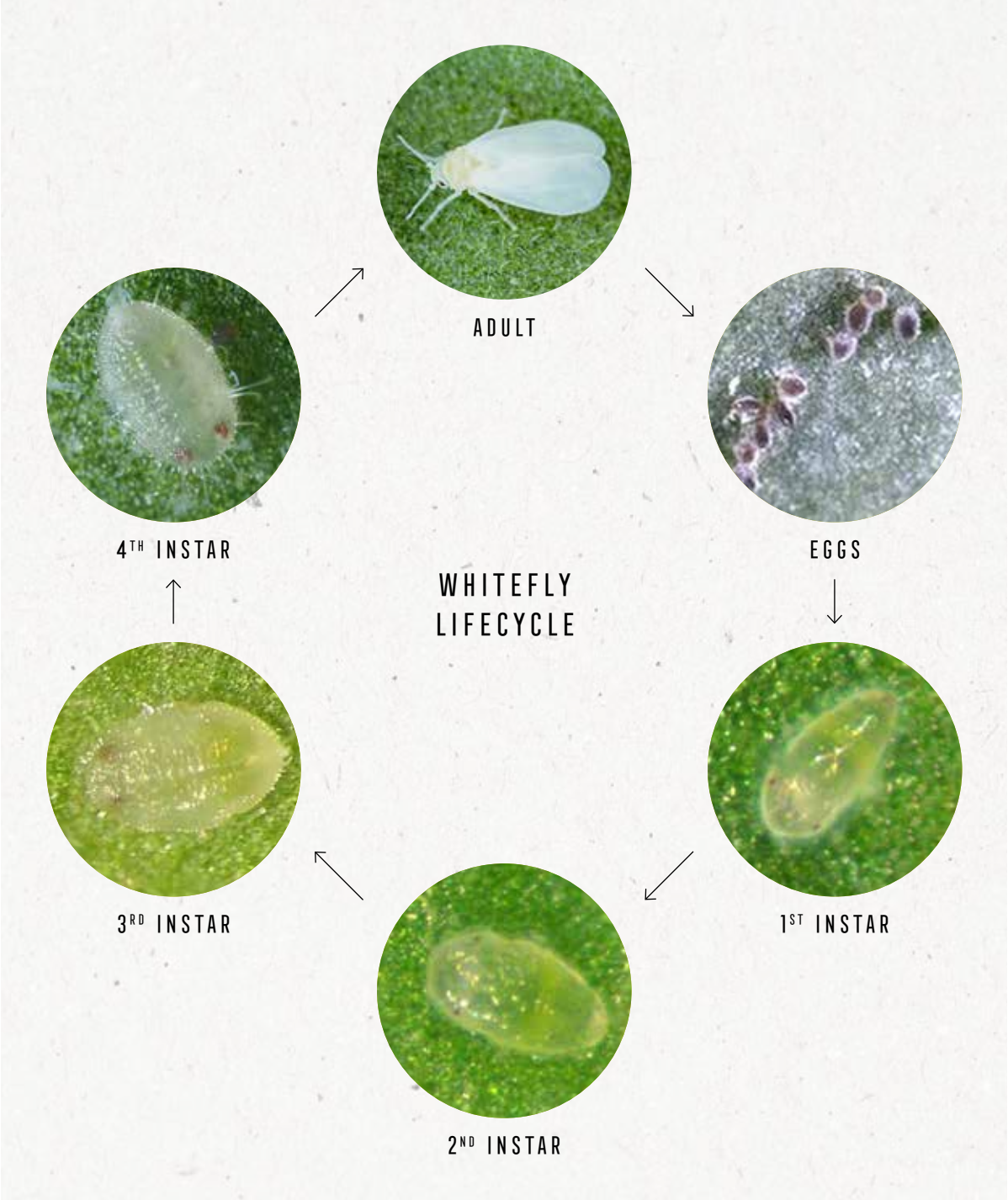


Figure 84 — Whitefly/greenhouse whitefly life cycle (University of California Cooperative Extension)

STAGE	DESCRIPTION
Egg	Eggs are approximately conical in shape, yellowish-white turning to purplish grey after 2 days and 0.25 mm long. They are oviposited on a short pedicel, which is inserted in epidermal cells on the lower leaf surface, often in a circle or a crescent.
Larvae/ Nymphs	Nymphs or "crawlers" are usually pale green, but can also range from yellow to dark brown. They are oval, flat and resemble scale insects. There are four or possibly five leg segments and two to three antennal segments. Small amounts of powdery white wax are usually produced after the crawler settles and begins feeding. The first nymph is mobile, whereas later nymphal stages are immobile.
Pupae	The pupa is the final stage of the fourth nymphal instar and is assumed to be at the point where the nymph stops feeding and apolysis begins. The pupa becomes a milky-yellow colour and, as the adult develops within, red eyes become visible through the cuticle.
Adult	Adults are about 1.5 mm long, white and resemble tiny moths. The wings are pale yellow, held relatively flat when in repose and are coated with a pure white waxy bloom.

Figure 85 — Immature stages of the greenhouse white fly
https://www.apsnet.org/edcenter/apsnetfeatures/Pages/GreenhouseWhitefly.aspx

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Economic Impact	The economic impact of *A. dispersus* infestations is due to a combination of three factors. Direct feeding damage results from the extraction of sap from leaves, mainly by larval stages but with adults also contributing. Direct feeding can cause premature leaf drop, reduces plant vigour and yields, but rarely kills plants outright. Indirect damage is due to excreted honeydew that encourages the development of sooty moulds, which hinder photosynthesis and reduce yields. Finally, cosmetic damage is due both to sooty moulds and to the white flocculence secreted by immature stages, which reduces the market-value of crops.
Environmental Impact	The pest has a wide host range and controlling the pest using chemicals can result in wide scale application which can lead to environmental pollution if not well handled.
Impact on Biodiversity	Use of pesticides in management can harm natural enemies of the pest and other beneficial organisms.
Social Impact	Wind-borne flocculence can be unsightly, and may also contribute to asthma attacks (Waterhouse and Norris, 1989).

QUARANTINE ORGANISM

Aleurodicus dispersus: Wide spread in Africa, and The Oceania. Present in a few countries in Europe (The Netherlands, Spain, Portugal, Madeira and Canary Islands).

Trialeurodes vaporariorum: Wide spread in Africa and Europe but has limited distribution in the Oceania.

FAVORABLE CONDITIONS TO THE INFESTATION

TYPE	FAVORABLE CONDITION	IMPACT / EXPLANATION
Temperature	15–25°C (optimum) - *Aleurodicus dispersus* 19–21°C - *Trialeurodes vaporariorum*	Heavy occasional rains and cool temperatures result in a temporary reduction in *A. dispersus* population (Mani, 2010). The whiefly is also a vector of many viruses. Optimum conditions for breeding outside greenhosue conditions. In cold climates, this whitefly is found only in glasshouses
Rainfall	Tropical rainfall pattern Tropical highland rainfall pattern	Heavy occasional rains and cool temperatures result in a temporary reduction in *A. dispersus* population (Mani, 2010). Favours *Trialeurodes vaporariorum* breeding throughout the year
Relative humidity	No published information for *Aleurodicus dispersus* Tropical highland conditions (19°C, 80% RH) for *Trialeurodes vaporariorum*	No published information *Aleurodicus dispersus* Suitable for establishment, breeding and multiplication

AFFECTED STAGES OF THE CROP

NURSERY	YOUNG, PLANTED TREES	VEGETATIVE STAGE	FLORAL BUDS AND FLOWERING	FRUIT ENLARGEMENT	FRUIT MATURITY / HARVESTING	POST-HARVEST
++	+++	+++	+++	++	++	0

SYMPTOMS AND DAMAGES

Infestation spread from the bottom leaves to the top. Large amount of honeydew is excreted which coats surrounding surfaces and often develops a layer of sooty mould.

MONITORING

Regular field monitoring is important for the detection and management white flies. Visual sampling by leaf examination is the most common and accurate method of monitoring whiteflies. Bright yellow sticky traps are useful for tracking the movement of whiteflies into areas or fields or at the beginning of the season. When used over a large area in a coordinated fashion, they can provide valuable information about population movement to growers in a region.

CONTROL BY GOOD CULTURAL PRACTICES

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT/IMPACT
PRE-PLANTING CHOICES		
/	/	/
PREPARING THE PLOT (ORCHARD)		
PLANTING		
Mixed cropping	Selection of crops for intercropping can be used to manage whitefly populations.	This is only effective for young trees during establishment
ORCHARD MANAGEMENT		
Field sanitation	Removal of alternate hosts that provide breeding habitats	Reduce whitefly population/infestation. Weeds play an important role in harboring whiteflies between crop plantings. They also often harbor whitefly-transmitted viruses. Therefore, weeds should be removed in advance of planting. Fields should also be kept weed free.
HARVESTING AND POST-HARVEST HANDLING		
/	/	/

BIOLOGICAL CONTROL

Whiteflies are attacked by a large number of natural enemies: parasitic wasps (*e.g. Eretmocerus* spp., *Encarsia* spp.), predatory mites (*Amblyseius spp.* and *Typhlodromus* spp.), predatory thrips, lacewings, rove beetles and ladybird beetles (https://infonet-biovision.org/PlantHealth/Pests/Whiteflies).

Use of natural enemies (predators) like coccinellid beetles. The parasitoid *Encarsia haitiensis* and *E. Formosa* can successfully control *A. dispersus and T. vaporiorum* respectively.

USE OF BIOPESTICIDES AND BOTANICALS

Neem-based pesticides are reported to control young nymphs, inhibit growth and development of older nymphs, and reduce egg laying by adult whiteflies. They also reduce significantly the risk of Tomato Yellow Leaf Curl Virus transmission. Efficacy of neem-based pesticides can be enhanced by adding 0.1 to 0.5% of soft soap.

Several fungi (*e.g. Verticillium lecanii*, *Beauveria bassiana*, *Paecilomyces fumosoroseus*) attack whiteflies and can be useful control agents in situations where the crop is grown in high humidity conditions. Commercial preparations are available.

CHEMICAL CONTROL

A number of chemical pesticides are effective against whitefly. However, the pest has a wide host range and is known to develop resistance very pretty fast. Management of resistance development is achieved through alternating active substances.

However, no pesticide applications are recommended for whiteflies in avocado. Chemical treatment of whiteflies often is not effective; temporary suppression may be achieved only to be followed by a resurgence of the pest, especially after applying certain broad-spectrum insecticides.

Active ingredients that could be used against the whiteflies:

— **Acetamiprid + Pyriproxifen**

Mode of action: broad spectrum insecticide that provides knockdown and residual control of the pest.

Application: foliar spray.

— **Buprofezin**

Mode of action: It is insect growth regulator that acts by contact and it inhibits moulting leading to death.

Application: apply it when pest is noticed or just before active first-generation crawlers start moving as full cover spray.

— **Fatty acids of potassium salts**

Mode of action: a broad-spectrum contact insecticide that is formulated using potassium salts combined with fatty acids

Application: apply it as a cover spray when the pests are noticed with no limits on the number of sprays per season.

— **Malathion**

Mode of action: a broad-spectrum insecticide which acts on contact, ingestion and inhalation exposures.

Application: apply it as a cover spray or spot treatments where pests are noticed on the crop.

— **Neem oil extract (azadirachtin)**

Mode of action: neem oil extract acts by causing insects to reduce or cease feeding, prevent larvae from maturing, reduces or interrupts mating behavior and, in some cases, the oil coats the breathing holes of insects and kills them.

Application: apply neem oil extract at first sign of insect. This product is most effective in controlling insects when applied on a 7–14 day schedule but always refer to label instruction before use. Complete spray coverage for all plant tissue is necessary for control.

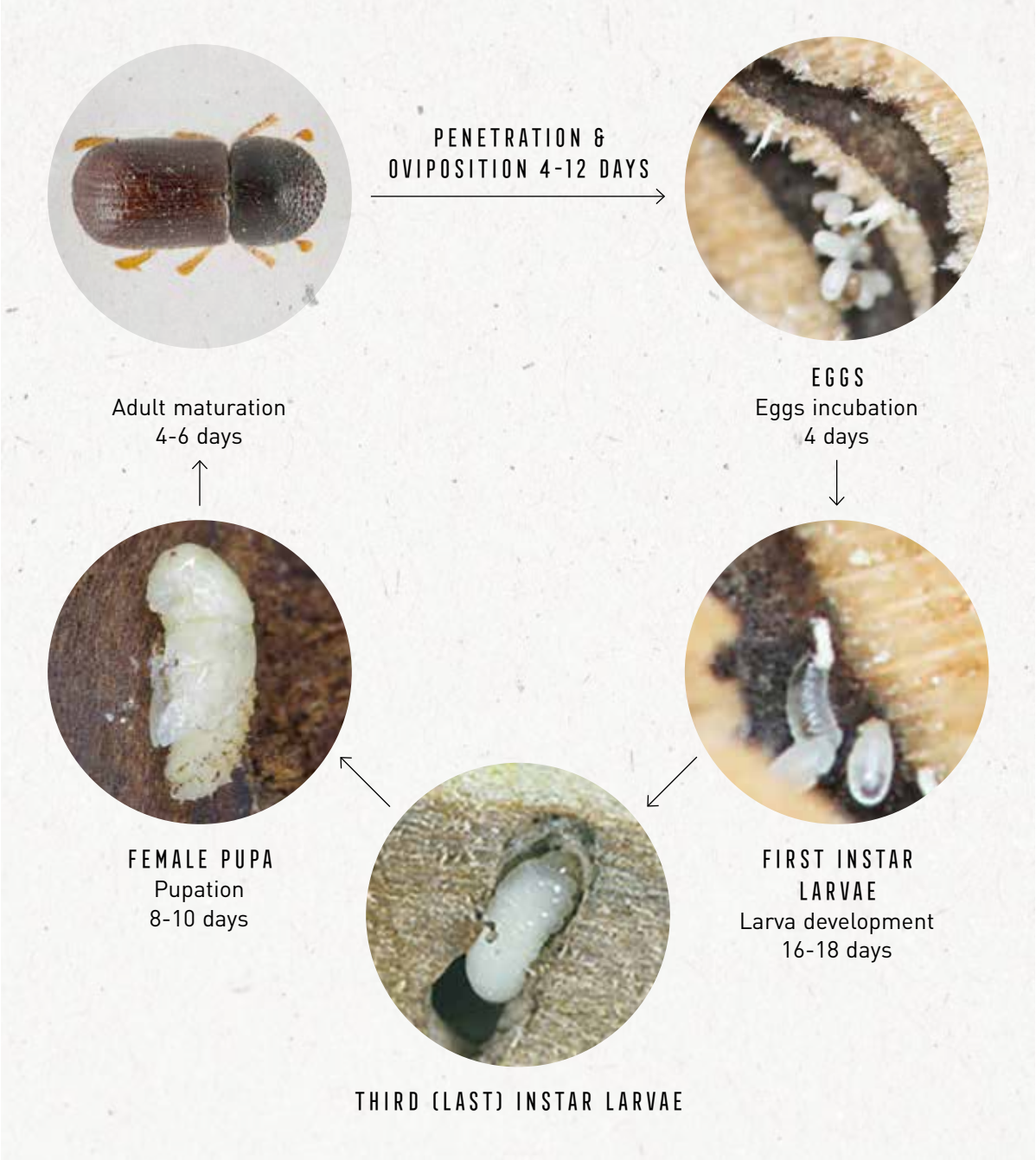
Note: rotate active ingredients with different modes of action to avoid resistance development.

6.5.5. THE AVOCADO SHOT-HOLE BORER

SCIENTIFIC NAME

1. *Euwallacea fornicatus Eichhoff (*Polyphagous shot-hole borer) - Major pest
2. *Euwallacea perbrevis* (tea shot-hole borer) – Minor pest
3. *Xylosandrus compactus (Shot-hole borer*) – Minor pest

LIFE CYCLE AND BIOLOGY



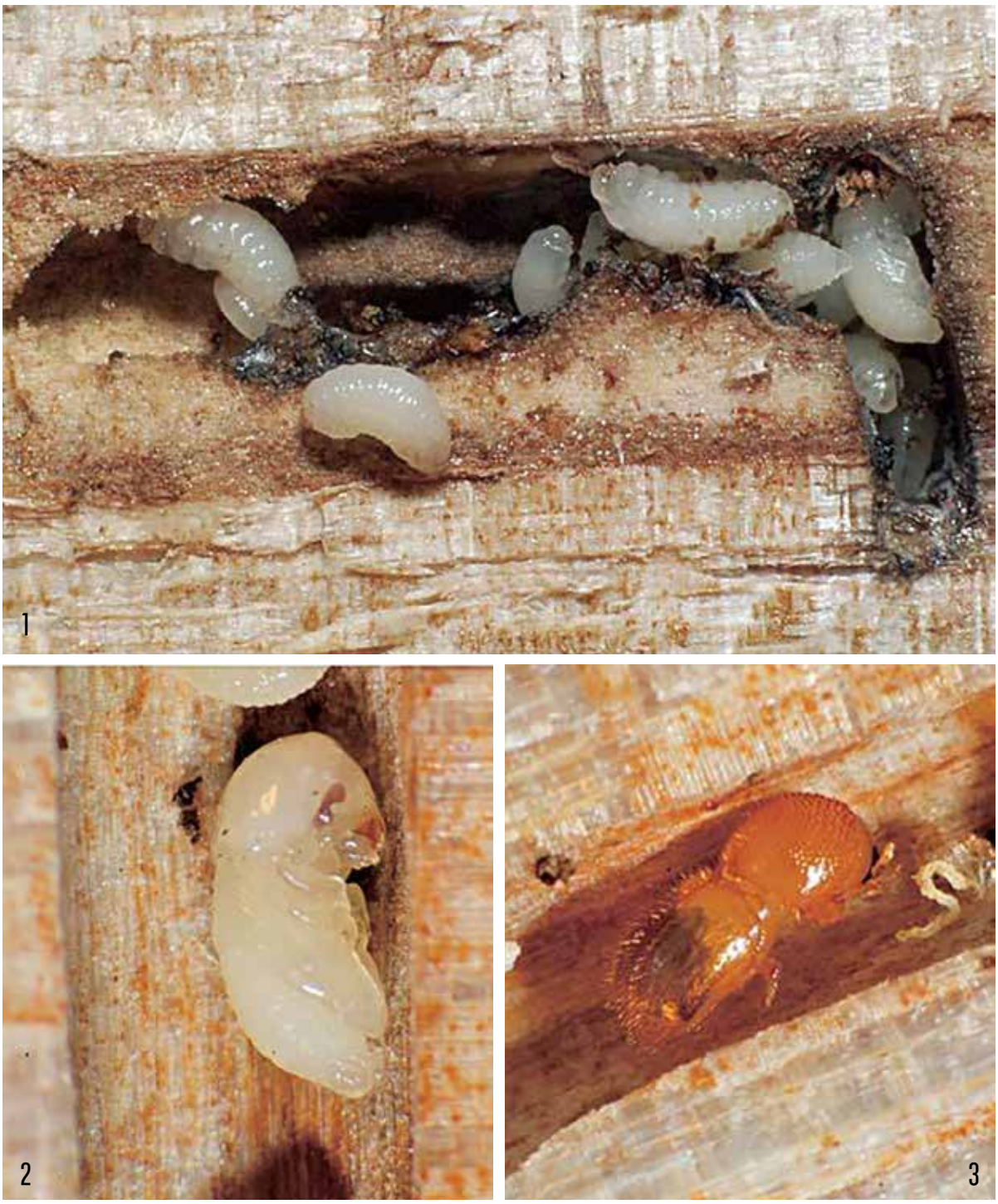


Figure 86 — Polyphagous shot-hole borer life cycle (Phytoparasitica) (Left), Xylosandrus compactus (Eichhoff). 1. Group of larvae and pupae in the maternal gallery. 2. Pupa. 3. Newly emerged adult (photo P. Giannotti) (Right) (https://www.researchgate.net/publication/287254381_Bioecological_notes_on_Xylosandrus_compactus_Eichhoff_Coleoptera_Curculionidae_Scolytinae_a_species_recently_recorded_into_Italy/figures)

1. *Euwallacea fornicatus Eichhoff (*Polyphagous shot-hole borer)

STAGE	DESCRIPTION
Egg	Eggs are off-white, partly translucent, approximately 0.3 mm long. Eggs hatch in four to six days. Fertilized, diploid eggs (those with both maternal and paternal genetic information) hatch into females, while the unfertilized, haploid eggs (those with only maternal genetic information) hatch into males. There is usually only a single male egg per family.
Larvae	Larvae are typical weevil larvae: white, C-shaped, legless, with an orange head capsule. Tea shot-hole borer larvae have three instars, as almost all weevils do. The larvae feed entirely on the symbiotic ambrosia fungus. The larval stage is complete in 16–18 days and the third-instar larvae reach about 3.0 mm in length.
Pupae	Pupae are white, the same size as adult beetles. The haploid pupa of the male is distinctly smaller than the pupa of the female. Pupation takes place inside the same communal gallery as larval development. Adults emerge within seven to nine days (Kumar *et al.* 2011, James 2007).
Adult	Adult females are 1.9–2.5 mm long, 2.3 times as long as wide. They are black or nearly black, but recently eclosed adults may be brown. Males are noticeably smaller, 1.5 mm, 2.0 times as long as wide. Their elytra are fused, eyes are minute, and wings are atrophied and non-functional (https://entnemdept.ufl.edu/creatures/trees/beetles/tea_shot_hole_borer.htm)

Figure 87 — Adult Polyphagous shot-hole borer (https://www.plantwise.org/KnowledgeBank/datasheet/57163)

2. *Euwallacea perbrevis* (tea shot-hole borer)

STAGE	DESCRIPTION
Egg	The eggs of *E. perbrevis* have not been described. However, the eggs of the related genus *Xyleborus* are very small (0.3 mm long), round and partly translucent, with a smooth surface. They are laid singly or in groups. Freshly laid eggs are pale, but they gradually darken before eclosion, hatching in 4 to 6 days.
Larvae	The mature larva is about 3.5 mm long and 1.1 mm wide. Larvae are white, legless, C-shaped, with a reddish head, taking 16–18 days to pupate. The head is colourless, about 0.5 mm wide, with the anterior margin nearly straight.
Pupae	Pupae are a similar size to adults and are white. Pupae eclose after 7–9 days.
Adult	Adult females are dark brown to almost black, with a body length of 2.2–2.6 mm. The males are wingless and smaller than the females, 1.50–1.67 mm long (CABI, 2021).

3. *Xylosandrus compactus* (Shot-hole borer)

STAGE	DESCRIPTION
Egg	The egg of *X. compactus* is about 0.3 mm wide and 0.5 mm long. It is white and ovoid with a smooth surface (Hara and Beardsley, 1979). The incubation period varies from 3 to 5 days with over 80% of eggs hatching after 4 days (Hara and Beardsley, 1979).
Larvae	The mature larva is about 2.0 mm long. The body is creamy white with a pale-brown head. It has no legs. The mean head width of final-instar larvae is about 0.36 mm (Ngoan *et al.*, 1976).
Pupae	The body of the pupa is creamy white and exarate. It is about the same length as the adult.
Adult	The adult females are dark brown to almost black, 1.4–1.9 mm long and about two times longer than wide. The front of the head is convex, with a weak transverse impression just above the mouthparts. The antennal funicle is five-segmented, and the antennal club is obliquely truncate, about 1.2 times longer than wide. The small, wingless males are about 0.8–1.1 mm long and two times longer than wide.

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Economic Impact	*E. fornicatus* severely impacts natural forests, urban trees and commercial plantations of avocado in its native and introduced distribution., it was also reported in South Africa, causing significant damage to trees in urban and natural areas, including avocado orchards (Paap *et al.*, 2018). *X. compactus* is a serious pest of shrubs and trees. It causes extensive damage but no data to show level and impact of this damage.
Environmental Impact	Minimal
Impact on Biodiversity	Since the pest has forest tree species as hosts, it can lead to death of trees thus impacting on the biodiversity.
Social Impact	Not known

QUARANTINE ORGANISM

Euwallacea fornicatus Eichhoff is present in Samoa and South Africa.

Euwallacea perbrevis: In Africa present in Reunion. In The Oceania it is present in a few countries (American Samoa, Australia, Fiji, Palau, Papua New Guinea, Samoa and Timor-Leste).

Xylosandrus compactus is wide spread in all the continents.

FAVORABLE CONDITIONS TO THE INFESTATION

TYPE	FAVORABLE CONDITION	IMPACT / EXPLANATION
Temperature	26–35°C	Optimum for growth and development
Relative humidity	75–95%)	Optimum for growth and development

AFFECTED STAGES OF THE CROP

NURSERY	YOUNG, PLANTED TREES	VEGETATIVE STAGE	FLORAL BUDS AND FLOWERING	FRUIT ENLARGEMENT	FRUIT MATURITY / HARVESTING	POST-HARVEST
0	++	+++	0	0	0	0

SYMPTOMS AND DAMAGES

E. fornicatus bores and tunnels into stems and branches of healthy trees and causes damage through mass accumulation. Females usually colonize the base of secondary branches, resulting in localized branch dieback. In tea, bushes become debilitated. In avocado, the initial infestation is characterized by white exudates from the beetle entrance holes (Owens *et al.*, 2019).

E. perbrevis bores into the stems and branches of suitable hosts, initially visible as circular, 1.5 mm holes with white frass in addition to resin, latex or other plant host defences depending on the species attacked. In avocado growing in dry conditions, a white exudate forms, known as a "sugar volcano" (Eskalen *et al.*, 2013). Following attack, branches become weak, unproductive, wilted, susceptible to further attack, and usually eventually dieback of the branch. The physical damage to the branch may result in it breaking and falling. Trees and shrubs become weakened and disfigured from losing branches.

X. compactus bores into the current year's twigs, killing them in a few weeks or causing them to break from the weight of the crop. The pest weakens and retards the fruiting of young plants and makes the replacement of trees very difficult. The typical host symptoms that characterize X. compactus infestation are necrosis of the leaves and stem extending from the entrance hole distally to the end of the branch. Flagging of branches occurs about 5–7 days after initial tunnelling and gallery formation. Wilting of twigs and branches usually becomes evident within weeks of infestation. The entrance holes are small (0.8 mm diameter) and are located on the underside of branches. Cankers, 10–210 mm long, are commonly seen around the attacked areas of larger twigs and branches (Dixon and Woodruff, 1982). A whitish pile of dust from boring may be seen at each hole.

Figure 88 — Damage caused by Polyphagous shot hole borer (https://sustainability.uci.edu/pshb-uci/)

MONITORING

Potential hosts, such as avocado, should be surveyed periodically for trees showing branch dieback and signs of beetle attack at junctions of small and mid-size shaded branches showing the presence white "sugar volcanoes". Compacted frass and sawdust will also show the presence of colonization. External symptoms are shared with other ambrosia beetles. Quercivorol and α-copaene as attractants in white sticky traps or bottle traps can be used for monitoring and survey purposes (Kendra *et al.*, 2017; Owens *et al.*, 2019).

CONTROL BY GOOD CULTURAL PRACTICES

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT/IMPACT
PRE-PLANTING CHOICES		
/	/	/
PREPARING THE PLOT (ORCHARD)		
/	/	/
PLANTING		
/	/	/

ORCHARD MANAGEMENT		
Surveillance and monitoring	Periodic surveys for trees with branch dieback and signs of beetle colonization are recommended.	This enhances early detection. In avocado plantations, small and mid-size branches will show the presence of "sugar volcanos" (sugar exudates) as a clear sign of infestation.
Field sanitation (pruning)	Remove infested branches an either burn or burying or wrapped with tarpaulin or polythene bags and exposed to sunlight.	Kills adults and larvae thus reducing population.
Harvesting and post-harvest handling		
/	/	/

BIOLOGICAL CONTROL

— **Conservation of natural enemies**

No information for *E. fornicatus* and E. *perbrevis* but for *X. compactus* a number of natural enemies including predator-*Callimerus* sp, and parasites (*Dendrosoter enervatus*, *D. protuberans* and *Tetrastichus* sp. nr. *Xyleborорum* are known to attack the pest and can be conserved through promotion of pest control strategies that do not harm them.

— **Release of natural enemies**

No information for *E. fornicatus* and E. *perbrevis* but for *X. compactus* the known natural enemies can be reared in the lab and released.

USE OF PLANT PROTECTION PRODUCTS

The decision to use chemical control is influenced by the difficulties of application (*E. fornicatus* feeds deep in the wood of infested branches), the cost and environmental concerns.

BIOPESTICIDE

Entomopathogenic fungus, *Beauveria bassiana* is known to attack the pests under natural environment and the strain of the fungus has been developed as a means of biological control. It significantly reduces the beetle population, and is now available commercially as a wettable powder ((UPASI Tea Research Foundation, 2003).

CHEMICAL CONTROL

For *E. fornicates*, recommended chemicals include substances like **emamectin benzoate**. For *X. compactus* it is recommended to spray with **cypermethrin** but cost benefit analysis should be carried out to establish if it is economically viable.

6.5.6. THE AVOCADO LACE BUG

SCIENTIFIC NAME

Pseudacysta perseae (The avocado lace bug)

Pest status in avocado: Major pest

LIFE CYCLE AND BIOLOGY

STAGE	DESCRIPTION
Egg	Females lay tiny eggs, often hidden under black, tar-like globs of excrement. After about 5 molts, nymphs mature into adults. Egg to adult development ranges from about 3 weeks during warm weather to several months when temperatures are cool. Avocado lace bug has several generations a year. All stages can be present throughout the year. Eggs occur on the lower leaf surface, covered with black, sticky excrement. To the naked eye, eggs may resemble grains of black pepper. Beneath the excrement, eggs are oblong, yellowish, and have a white rim around the cap from which nymphs emerge.
Nymphs	Nymphs are mostly black or dark brown with elaborate spiny projections, pale appendages, and (on the back of older nymphs) pale areas where wings are developing (Bender *et al.* 2007).
Adult	Adults are 2 mm long and oblong-oval shaped. The body beneath, head, pronotum (except for the front edge and tips of posterior third), and a bar crossing the basal third of elytra, but reaching only slightly outside of the discoidal area, are piceous-brown or blackish; the remainder of the upper surface is yellowish white; legs and antennae are pale yellow, the claws and apical half of fourth antennal segment are blackish. Elytra are much surpassing the abdomen, their tips broadly rounded; and the discoidal area is long, narrow, and not closed behind (Mead, 1998).

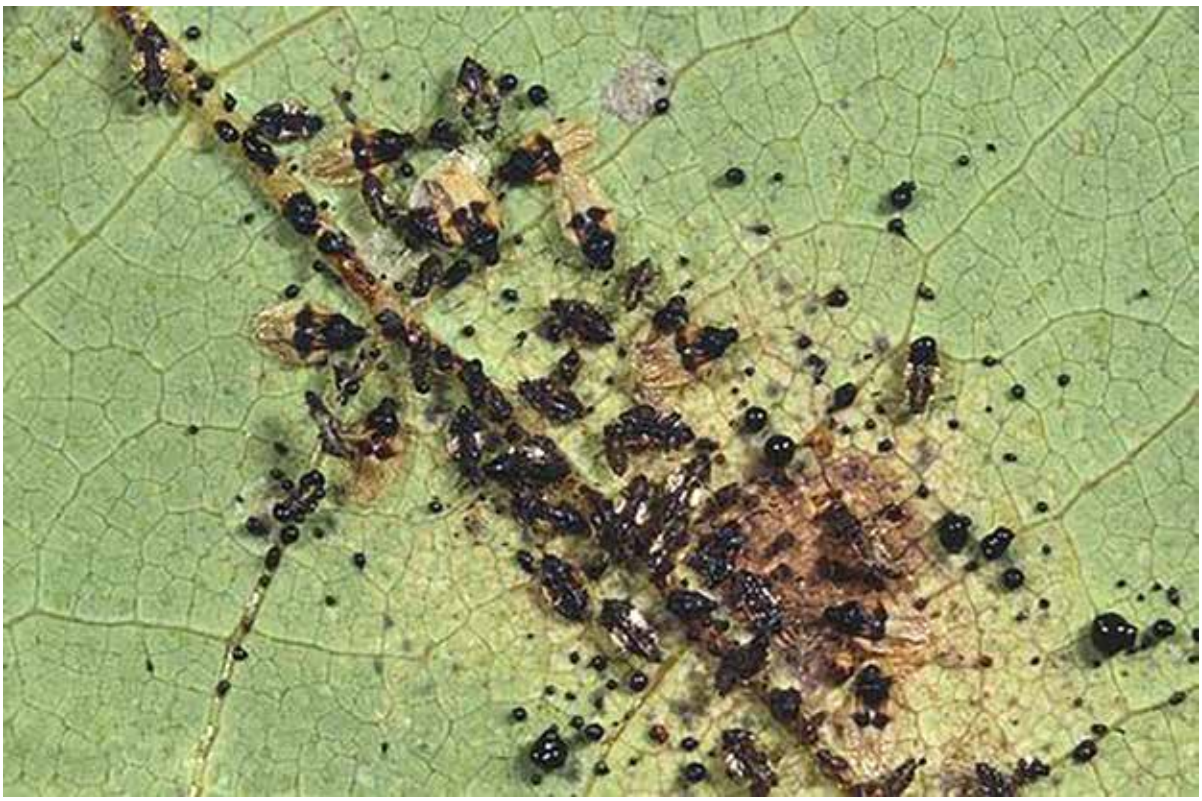


Figure 89 — Adults, eggs and nymphs of avocado lace bug (http://ipm.ucanr.edu/PMG/P/I-HM-PPER-CO.008.html)

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Economic Impact	Lace bugs do not feed on fruit. They suck leaf sap, feeding in groups on the underside of leaves. A colony of lace bugs feeding causes faint pale green to yellowish blotches visible on both the lower and upper leaf surfaces. There is no information on the economic impact. But feeding and destroying leaves can interfere with photosynthesis thus reducing yield
Environmental Impact	Minimal

FAVOURABLE CONDITIONS TO THE INFESTATION

TYPE	FAVORABLE CONDITION	IMPACT / EXPLANATION
Temperature	25–30°C	High temperature of up to 25–30°C favour development and multiplication. The pest takes 21 days to complete life cycle at 30°C and 28 days at 25°C (Morales *et al.*, 2000).

AFFECTED STAGES OF THE CROP

NURSERY	YOUNG, PLANTED TREES	VEGETATIVE STAGE	FLORAL BUDS AND FLOWERING	FRUIT ENLARGEMENT	FRUIT MATURITY / HARVESTING	POST-HARVEST
0	++	+++	0	0	0	0

QUARANTINE ORGANISM

Absent in Africa, in Europe only present in Portugal and Madeira, widespread in North America, absent in Oceania (CABI, 2021; CISR, 2021).

SYMPTOMS AND DAMAGES

Lace bugs do not feed on fruit. They suck leaf sap, feeding in groups on the underside of leaves. A colony of lace bugs feeding causes faint pale green to yellowish blotches visible on both the lower and upper leaf surfaces. Black, shiny specks of excrement appear on the under leaf surface where lace bugs occur. As lace bugs continue feeding, large brown or tan dead blotches develop on leaves. Heavily damaged leaves become dry, may curl, and drop prematurely (UC-IPM, 2019).

CONTROL BY GOOD CULTURAL PRACTICES

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT/IMPACT
PRE-PLANTING CHOICES		
/	/	/
PREPARING THE PLOT (ORCHARD)		
/	/	/
PLANTING		
/	/	/
ORCHARD MANAGEMENT		
Mulching and proper drainage	Avocado do not do well in poor drained, water logged soils	Improves health of plants and make them less susceptible to pests
Water and fertility management	Applying appropriate amounts and frequency of irrigation and fertilizer	Healthy plants are less susceptible to pests
HARVESTING AND POST-HARVEST HANDLING		
/	/	/

BIOLOGICAL CONTROL

— By conservation of natural enemies

Predators of lace bugs include lacewing larvae, lady beetles, jumping spiders, predatory thrips, and predaceous mites. Two species of tiny parasitic wasps kill avocado lace bug eggs i.e., *Oligosita* sp. (*Trichogrammatidae*). Predatory thrips attack avocado lace bug.

Use of "soft chemicals" that do not kill natural enemies of FCM. Biopesticides and botanicals can also be used where applicable.

Use of cut stems of *Montanoa bipinnatifida* (Asteraceae) placed in infested plantations to attract the beetles, which may later be killed by burning the stems.

— By release of natural enemies

No information on mass rearing and release of natural enemies to control this pest.

CONTROL WITH PLANT PROTECTION PRODUCTS

Do not apply any pesticide when plants are drought-stressed, when it is windy, or when temperatures are below freezing point. Insecticidal soap, narrow-range oil temporarily control lace bugs if thoroughly sprayed to cover the underside of infested leaves. These IPM-compatible products have very low toxicity to humans and relatively low adverse impact on naturally occurring parasites and predators. Avoid broad-spectrum, persistent insecticides, which kill many natural enemies (UC-IPM, 2019).

USE OF BIOPESTICIDES

The beneficial fungus *Beauveria bassiana* is known to control avocado lace bug. Apply as per manufacturer's recommendation.

OTHER CONTROL STRATEGIES

Push-pull strategies using quercivorol and α-copaene as attractants in white sticky traps and verbenone as deterrents are effective control strategy.

6.5.7. STINK BUGS

A large number of stink bug species feed on tropical and subtropical crops, including avocados.

SCIENTIFIC NAME

Nezara viridula Green stink bug

Pest status in avocado: Minor pest

LIFE CYCLE AND BIOLOGY

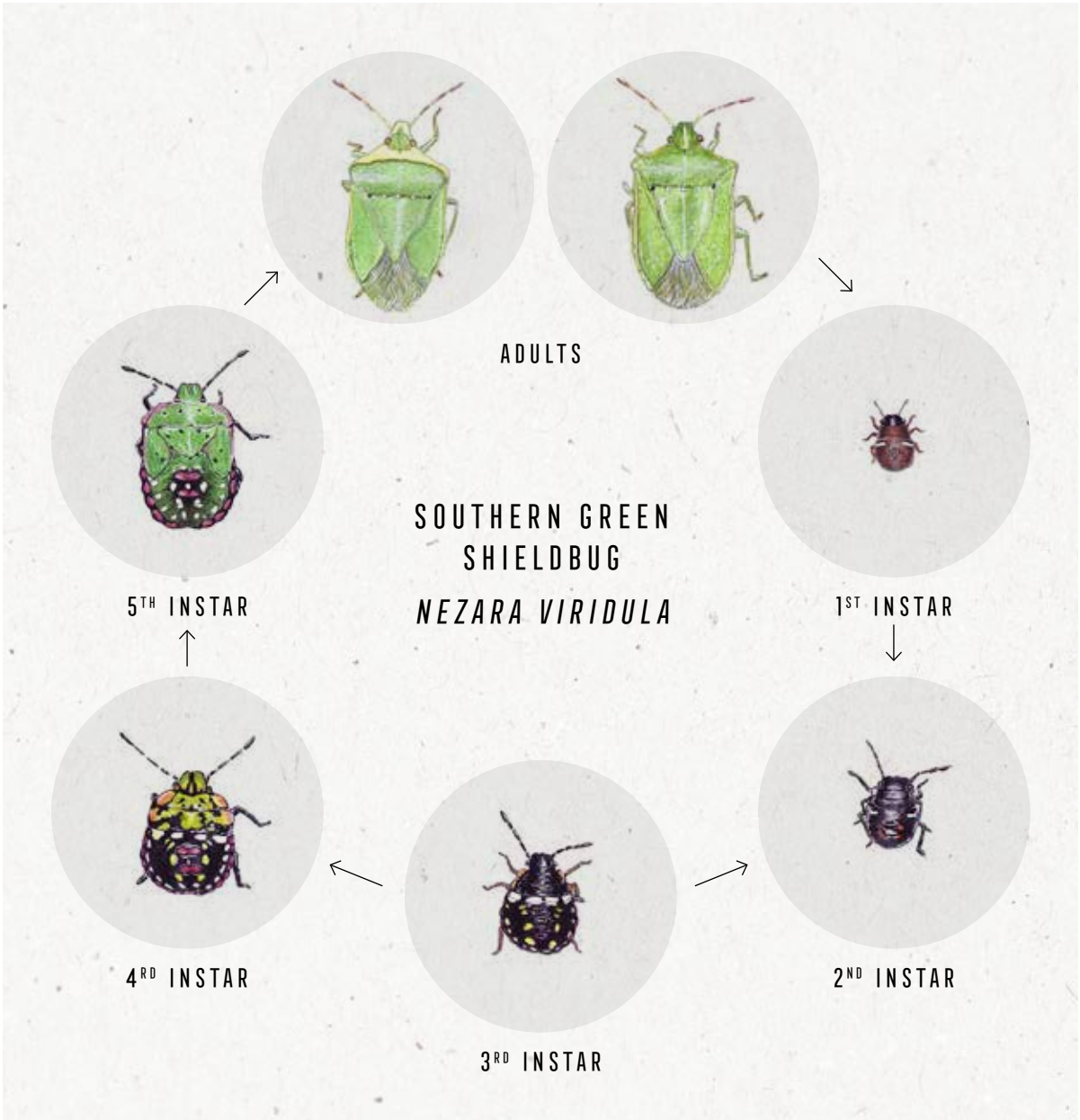


Figure 90 — Lifecycle of the green stink bug (University of California)

STAGE	DESCRIPTION
Egg	Eggs are deposited in tightly packed, single-layered rafts of about 60 (range of 30–130) eggs. Each egg is tightly glued against other eggs and to the substrate, with no intervening gaps. Eggs are cream to yellow, slightly elongate, and circular from above. As they develop, they become deep yellow, then pinkish, and finally bright orange. The head of the developing embryo becomes visible 3 days after oviposition, as a red crescent.
Nymphs	The antennae of nymphs have four segments. Nymphs have no wings, but wing pads are visible on fifth-instar nymphs. Nymphal colour changes progressively in successive instars. On hatching, the nymphs are mostly black. By the fifth instar, a considerable proportion of each is green. The instars can be differentiated from one another by colour and size variation (Kobayashi, 1959).
Pupae	No information.
Adult	*N. viridula* adults are large green shield bugs, approximately 15 × 8 mm in size. They are uniform apple-green above and a paler shade of green below. The green colour may be replaced by a red-brown. Three small white dots are usually evident on the front edge of the scutellum, where it joins the prothorax.

Figure 91 — Eggs of Nezara viridula (https://entnemdept.ufl.edu/creatures/veg/bean/southern_green_stink_bug.htm)

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Economic Impact	Stink bugs cause significant loses in avocado. In south Africa, for example, it was the leading cause of damage to avocado in 1991 with up to 24.57% fruit damage (Erichsen and Schoeman, 1992).

FAVORABLE CONDITIONS TO THE INFESTATION

TYPE	FAVORABLE CONDITION	IMPACT / EXPLANATION
Temperature	25°C	Provides the optimum temperature for the greatest rate of development and survival of immature stages (Ali and Ewiess 1977).
Relative humidity	40 ± 10%	Shortens the development time and increases the longevity of adults (Chanthy et. al., 2015).

AFFECTED STAGES OF THE CROP

NURSERY	YOUNG, PLANTED TREES	VEGETATIVE STAGE	FLORAL BUDS AND FLOWERING	FRUIT ENLARGMENT	FRUIT MATURITY / HARVESTING	POST-HARVEST
0	0	0	++	+++	+++	++

QUARANTINE ORGANISM

Widely distributed throughout the world.

SYMPTOMS AND DAMAGES

N. viridula may attack all parts of a plant, including the stems and leaf veins, but the bugs feed mostly on fruiting structures and growing shoots. their piercing and sucking mouthparts puncture the plant tissues and form minute, hard, brownish or blackish spots. Feeding retards the growth of immature fruits, which the bugs prefer to over-ripe fruit, and distorts them and causes premature drop.

CONTROL BY GOOD CULTURAL PRACTICES

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT/IMPACT
PRE-PLANTING CHOICES		
/	/	/
PREPARING THE PLOT (ORCHARD)		
/	/	/
PLANTING		
/	/	/
ORCHARD MANAGEMENT		
Sanitation	Weeding, pruning, removal of dead plant materials. However, no details on avocado. This information is adapted from other host plants mainly soybean	Reduce population and by removing infested materials
HARVESTING AND POST-HARVEST HANDLING		
/	/	/

BIOLOGICAL CONTROL

— **Conservation of natural enemies**

This can be achieved through integrated approach in management by adopting practices that do not harm the beneficial organisms.

— **Introduction and or mass release**

There are several natural enemies *e.g.* egg parasitoids (*Trissolcus basalis*, *Telenomus podisi*, *Ooencyrtus johnsoni*, *O. californicus*, *Trissolcus brochymenae* and *T. urichi*).

There are also predators that prey on *N. viridula* such as ants, spiders but no information on studies on rearing and mass release.

USE OF PLANT PROTECTION PRODUCTS

CHEMICAL CONTROL

— **Lambda-cyhalothrin (synthetic pyrethroid)**

Mode of action: non-systemic insecticide with contact and stomach action, and repellent properties. Gives rapid knockdown and long residual activity.

Application: apply it early in the morning or late evening and avoid spraying against the wind.

— **Acetamiprid + Pyriproxifen**

Mode of action: broad spectrum insecticide that provides knockdown and residual control of the pest.

Application: apply it as a cover spray post flowering when there are indications of infestation.

Note: rotate active ingredients with different modes of action to avoid resistance development.

BIOPESTICIDES AND BOTANICALS

Even though insecticidal plant extracts such as azadirachtin efficacy is lower than insecticides, they can be incorporated into IPM programmes.

PHEROMONES

To date, no practical use has been made of *N. viridula* pheromones, either for monitoring or control purposes.

OTHER CONTROL METHODS

Utilization of trap-borders of preferred hosts such as Crotalaria (rattlepod) to attract and hold stink bug populations. Stink bugs will usually remain on the plants where parasites can readily find them. It is important that these borders not be allowed to dry before control occurs.

6.5.8. SCALE INSECTS

SCIENTIFIC NAME

Hemiberlesia lataniae (Signoret) (Latania scale) – Major pest

Coccus hesperidum (brown soft scale) - Minor pest

LIFE CYCLE AND BIOLOGY

1. *Hemiberlesia lataniae* (Signoret) (Latania scale)

STAGE	DESCRIPTION
Egg	The eggs are yellow in colour, elongate and 0.15 mm long.
Larvae	The first instar, or crawler, is yellowish in colour and is 0.15 mm long. It moults after approximately 14 days. The second instar exhibits the same colour as the adult female.
Adult	Adult females are variable in colour and shape, measuring 1–2 mm in diameter. On leaves they are grey to white in colour, circular and convex; on stems, they are brown and slightly convex. Exuviae are subcentral and yellow-brown (Davidson and Miller, 1990). Male scale covers are oval-shaped and elongate, similar in colour to those of the females, but are not always present. Exuviae are subterminal and yellow. The adult male is a tiny insect with one pair of wings and no mouthparts, and which lives for 24 to 48 hours.

Figure 92 — Latania scale (Invasive.org)

2. *Coccus hesperidum* (brown soft scale)

STAGE	DESCRIPTION
Egg	Soft brown scales are ovoviviparous in that they produce small larvae that hatch from eggs within the mother. Five to 19 eggs are laid per day over a series of 30–65 days by the adult female. Each female lays between 80 to 250 eggs.
Nymphs	The young nymphs, born within the adult female, remain in her brood chamber for a few hours before leaving. The first stage nymphs are dispersive crawlers. The crawlers search until they find a suitable spot to feed from on the plant and then settles. Movement is sluggish and they usually settle near the female. Dispersal by wind may occur during this period. There are three molts, making three nymphal stages, before the scale reaches adulthood.
Adult	The adult females are characterized by a large brood chamber containing white eggs or first stage larvae. The overall body shape is symmetrically oval, dome-like, and 1/8 to 1/6 inch long. They are pale yellowish brown to greenish and flecked with irregular brown spots. Overall color darkens as the insect ages. Males have not been recorded for this species.

Figure 93 — Brown soft scale, Coccus hesperidum Linnaeus (Homoptera: Coccidae), on satsuma. Photo by Drees. (http://www.extento.hawaii.edu/kbase/crop/Type/c_hesper.htm)

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Economic Impact	Even though there is no data on yield loss in avocado attributed to *H. lataniae*, the pest attacks the branches, leaves and fruit of avocado, and infested fruit are downgraded to a lower quality class and may not be accepted for export.
Environmental Impact	When pesticides are used to control the pests, there is risk of contamination of environment when not used appropriately.

FAVORABLE CONDITIONS TO THE INFESTATION

TYPE	FAVORABLE CONDITION	IMPACT / EXPLANATION
Temperature	21–24°C	Support full development of the pest
Relative humidity	79%	Suitable for reproduction and full development (McLean, 2014)

AFFECTED STAGES OF THE CROP

NURSERY	YOUNG, PLANTED TREES	VEGETATIVE STAGE	FLORAL BUDS AND FLOWERING	FRUIT ENLARGEMENT	FRUIT MATURITY / HARVESTING	POST-HARVEST
0	++	+++	+++	+++	0	0

QUARANTINE ORGANISM

The two pests are widely distributed throughout the world.

SYMPTOMS AND DAMAGES

The presence of latania scale can be detected on leaves, twigs, fruit and as pitting on the bark of stems. It irritates the flesh of avocado cultivar. This is indicated by nodules adhering to the inside of the peel with corresponding depressions in the flesh of ripe fruit.

Heavy feeding by the soft brown scale reduces tree vigor, kills twigs, and reduces yields. Sooty mold grows on excreted honeydew and may affect fruit grade. The honeydew also attracts ants, which interfere with the biological control of a number of pests (https://texasinsects.tamu.edu/homoptera/brown-soft-scale/).

CONTROL BY GOOD CULTURAL PRACTICES

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT/IMPACT
PRE-PLANTING CHOICES		
Use clean un infested planting materials	Prevent introduction of the pest in areas where it does not exist.	Effective in excluding and preventing pest build up.
PREPARING THE PLOT (ORCHARD)		
/	/	/
Planting	Use resistant varieties where they are available.	Plant resistance is cheap, environmentally pest management strategy.
	Adequate spacing.	scales seldom spread from plant to plant unless the crowns of the plants are in contact with each other (Beardsley and Gonzalez, 1975).
ORCHARD MANAGEMENT		
Pruning	Maintain clear plant canopy and avoid overlapping canopies that allows spread of the pest.	As plants grow, pruning maintains spacing and allows maximum coverage when using insecticides Link.
HARVESTING AND POST-HARVEST HANDLING		
Use of insecticidal soaps	Dipping without scrubbing in a soap-pyrethroid solution for five minutes is only 70% effective against adults and nymphs (Hansen et. al., 1992).	This is sustainable and environment friendly approach that ensures control of the pest. NB: This is only applicable for planting materials.

BIOLOGICAL CONTROL

— Conservation of natural enemies

Good agricultural practices that include IPM should be utilized to promote multiplication of natural enemies that suppress the pest.

— Introduction and/or mass release

In New Zealand *H. coccophagus* was introduced and become established and used successfully to control the latania scales. *Chilocorus* spp. was also introduced to enable the predatory Hemisarcoptes mites to be dispersed by phoresy.

Ladybird beetles, were also introduced to control scales in Hawaii. Some of these, such as *Telsimia nitida* Chapin, (Coleoptera: Coccinellidae) were able to establish. These beetle adults and larvae are carnivorous; they eat soft-bodied insects. Scale covers that look chewed and have no insect underneath are signs that predators have been feeding on the scales.

Larval parasitoids such as *Aphytis chrysomphali* parasitizes latania scales (Zimmerman, 1948).

There are over 30 known natural enemies of the soft brown scale worldwide. Parasites and hyperparasites (parasites of the parasites) are generally small flies and wasps that deposit their eggs into the scale. Parasites are known for all scale developmental stages. In some species, several parasites may emerge from one scale. Some of these include: *Aphycus alberti* Howard and *Anicetus annulatus*. Populations of soft brown scale are normally controlled by natural enemies. In some cases, these scales are controlled by indigenous parasite populations. When needed, release of reared parasites has been highly effective. Hart (1972) reported that releases of *Microterys flavus* (Howard) in Texas citrus groves gave longer periods of control than chemically treated areas.

USE OF PLANT PROTECTION PRODUCTS

— Acetamiprid + Pyriproxifen

Mode of action: broad spectrum insecticide that provides knockdown and residual control of the pest.

Application: apply as a cover spray post flowering when there are indications of infestation or crawler release. Do not target populations that are well established where mature adults dominate.

— Buprofezin

Mode of action: growth regulator that acts by contact and it inhibits moulting leading to death.

Application: apply it as a full cover spray when pest is noticed or just before active first generation crawlers start moving.

— **Pyriproxyfen**

Mode of action: It is a broad spectrum insect growth regulator that inhibits the development of young insects to maturity and acts by contact or through stomach action.

Application: apply it as a cover spray post flowering when there are indications of infestation or crawler release. Do not target populations that are well established where mature adults dominate.

Although there are systemic and contact insecticides that can control *H. lataniae* and *C. hesperidum*, it is mostly not necessary to apply chemical control.

OTHER CONTROL METHODS

MECHANICAL CONTROL

Scraping and scrubbing to remove scales from plants is an effective mechanical control tactic. Removing scales is especially important on exported plant materials, since intact armor is a sign of scale infestation; plants with armor may not pass quarantine inspection (http://www.extento.hawaii.edu/kbase/crop/Type/h_latani.htm).

6.5.9. MITES

SCIENTIFIC NAME

Polyphagotarsonemus latus (Broad Mite)

Pest status: Minor pest

LIFE CYCLE AND BIOLOGY

STAGE	DESCRIPTION
Egg	The eggs are colorless, translucent and elliptical in shape. They are about 0.08 mm long and are covered with 29 to 37 scattered white tufts on the upper surface (Denmark 1980, Peña and Campbell 2005, Baker 1997).
Larvae	Young broad mites have only three pairs of legs. They are slow moving and appear whitish due to minute ridges on the body (Peña and Campbell 2005). As they grow they range in size from 0.1 to 0.2 mm long (Anonymous a). The quiescent stage appears as an immobile, engorged larva (Baker 1997).
Nymph	After one day, the larva becomes a quiescent nymph that is clear and pointed at both ends. The nymphal stage lasts about a day. Nymphs are usually found in depressions on the fruit, although female nymphs are often carried about by males (Peña and Campbell 2005).
Adult	Adults: Female mites are about 0.2 mm long and oval in outline. Their bodies are swollen in profile and a light yellow to amber or green in color with an indistinct, light, median stripe that forks near the back end of the body. Males are similar in color but lack the stripe. The two hind legs of the adult females are reduced to whip-like appendages. The male is smaller (0.11 mm) and faster moving than the female. The male's enlarged hind legs are used to pick up the female nymph and place her at right angles to the male's body for later mating (Peña and Campbell 2005) (https://entnemdept.ufl.edu/creatures/orn/broad_mite.htm).

Figure 94 — Broad Mite (alchetron.com)

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Economic Impact	The mite's toxic saliva causes twisted, hardened and distorted growth in the terminal of the plant. Leaves turn downward and turn coppery or purplish. Internodes shorten and the lateral buds break more than normal. The blooms abort and plant growth is stunted when large populations are present (Denmark 1980). On fruit trees the damage is usually seen on the shaded side of the fruit, so it is not readily apparent. Fruit is discoloured by feeding and in severe cases premature fruit drop may occur. Severely damage fruit is not sellable in the fresh market but may be used for processing.

FAVORABLE CONDITIONS TO THE INFESTATION

TYPE	FAVORABLE CONDITION	IMPACT / EXPLANATION
Temperature	25°C	Optimum temperature. the developmental period from egg to adult at 25°C averages 4.1 days for both males and females (CABI, 2021).

AFFECTED STAGES OF THE CROP

NURSERY	YOUNG, PLANTED TREES	VEGETATIVE STAGE	FLORAL BUDS AND FLOWERING	FRUIT ENLARGEMENT	FRUIT MATURITY / HARVESTING	POST-HARVEST
++	++	++	+++	++	0	0

QUARANTINE ORGANISM

Widely distributed throughout the world

SYMPTOMS AND DAMAGES

They may damage the young stems of terminal leaves or shoots. The damaged tender leaves get twisted, fail to grow longer and die in the long run. Their feeding leads to death of tissues, discolouration (bronzing), deformation and swelling. Severely affected fruits that set may fall off the plant. The fruits that don't fall may be deformed and develop everlasting tan marks on the skin.

CONTROL BY GOOD CULTURAL PRACTICES

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT/IMPACT
PRE-PLANTING CHOICES		
/	/	/
PREPARING THE PLOT (ORCHARD)		
/	/	/
PLANTING		
/	/	/
ORCHARD MANAGEMENT		
Pruning	Allow light penetration into orchard	Broad mites are very sensitive to heat and this supresses the population especially in areas receiving adequate sunshine Link
HARVESTING AND POST-HARVEST HANDLING		
/	/	/

BIOLOGICAL CONTROL

— **Conservation of natural enemies**

Some of the natural enemies including *Amblyseius ovalis and Neoseiulus barkeri* (predators), have been successfully used to control the pest.

Good agricultural practices that include IPM should be utilized to promote multiplication of natural enemies that suppress the pest.

— **Introduction and or mass release**

In China *Neoseiulus cucumeris* was used to control broad mite but not on avocado.

— **Fenpyroximate (pyrazole acaricide and a tert-butyl ester)**

Mode of action: Contact miticide/insecticide with no systemic activity. It acts by inhibiting mitochondrial complex I electron transport.

Application: apply as a foliar spray early morning or late evening.

— **Pyridaben 20% WP (Pyridazinone (A.I)**

Mode of action: non-systemic with rapid knock down action and long residual activity. Inhibitor of mitochondrial electron transport at complex I.

Application: apply it as a foliar spray.

— **Spiromesifen (Tetronic acid)-EC**

Mode of action: non-systemic inhibitors of lipid synthesis.

Application: the apply it as a foliar spray.

— **Spirotetramat (Tetramic acid)-SC**

Mode of action: stomach acting, broad spectrum, long acting insecticide that is rapidly translocated, inhibition of lipogenesis in treated insects.

Application: apply it as a foliar spray.

— **Abamectin**

Mode of action: it is a systemic insecticide that acts as a nerve toxin.

Application: apply it as a foliar spray at the first signs of infection and before severe infestation.

Resistance management: Only apply, if necessary, a second application 30 days later.

— **Potassium soap**

Mode of action: broad-spectrum contact insecticide

Application: apply it as a cover spray when the pests are noticed with no limits on the number of sprays per season.

— **Sulphur**

Mode of action: broad spectrum insecticide/fungicide that acts on contact and is toxic to spider mites.

Application: the application rates varies depending on the product.

6.5.10. NEMATODES

SCIENTIFIC NAME

Pratylenchus vulnus (walnut root lesion nematode) - Major pest

LIFE CYCLE AND BIOLOGY

STAGE	DESCRIPTION
Adult female	The adult female can be recognized by an opening in the cuticle on the ventral side (the vulva) that is about 70–85% of the body length down from the head. The female tail tapers like a cone but it is rounded at the end (termed "conoid" in shape).
Adult male	Pratylenchus males are generally slightly smaller and more slender than females, with the absence of the gonad and vulva. The males have a row of cells that form the testis. The testes look like the gonads in the female, but they empty at the anal opening.

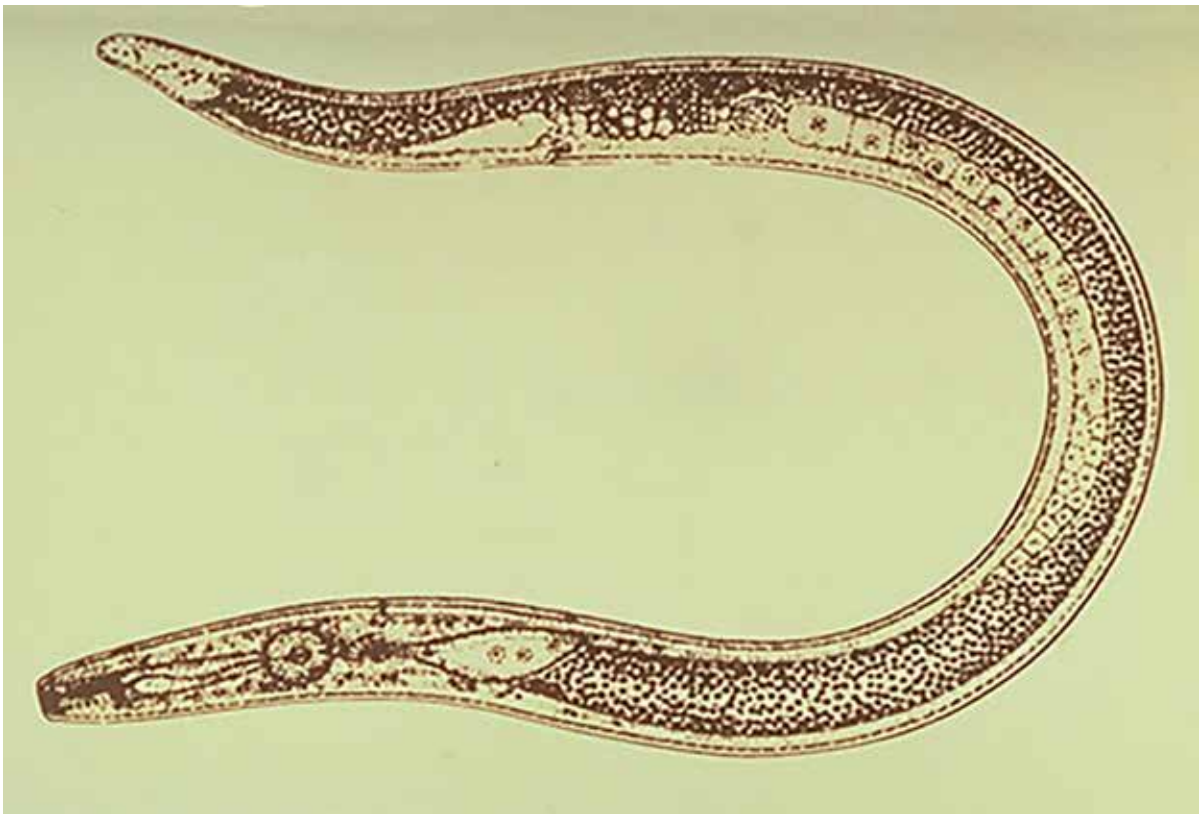


Figure 95 — walnut root lesion nematode
(https://www.apsnet.org/edcenter/disandpath/nematode/pdlessons/Pages/LesionNematode.aspx)

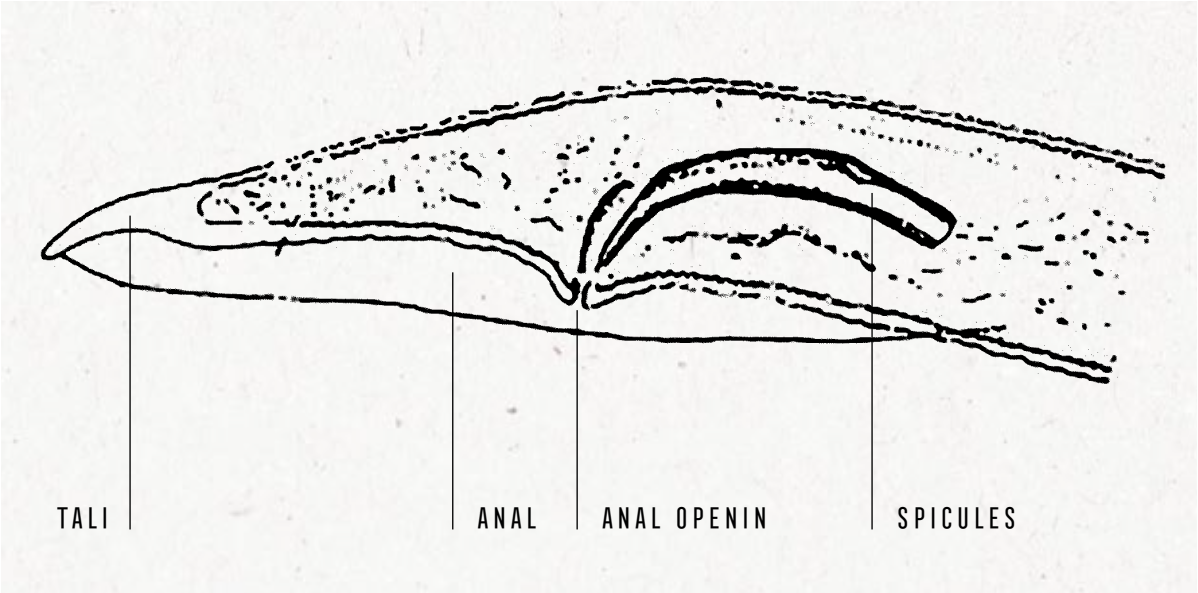


Figure 96 — Illustration of the tail region of an adult male lesion nematode (Courtesy R. Fortuner)

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Economic Impact	Although there is no data on the impact of the pest in avocado, *P. vulnus* can suppress plant growth by 50% (https://www.plantwise.org/knowledgebank/datasheet/43904)
Environmental Impact	Nematicides use in control nematodes are usually persistent in soil and can contaminate ground and surface water.
Impact on Biodiversity	Nematicides when used can kill beneficial non-target soil microbes and organisms thus altering the ecosystem.
Social Impact	When nematicides are not handled properly, the users are exposed to health risks.

FAVORABLE CONDITIONS TO THE INFESTATION

TYPE	FAVORABLE CONDITION	IMPACT / EXPLANATION
Temperature	26°C	Optimum temperature for reproduction and development.
Rainfall	No published information.	Heavy rainfall suppresses the nematodes by reducing oxygen levels in soil through filing of air pores with water.

AFFECTED STAGES OF THE CROP

NURSERY	YOUNG, PLANTED TREES	VEGETATIVE STAGE	FLORAL BUDS AND FLOWERING	FRUIT ENLARGEMENT	FRUIT MATURITY / HARVESTING	POST-HARVEST
+++	+++	+++	0	0	0	0

QUARANTINE ORGANISM

Present in a number of countries in Africa, Europe and Oceania.

SYMPTOMS AND DAMAGES

Being an endoparasite of roots, *P. vulnus forms* dark-coloured lesions on root surfaces, first as small cracks in the bark, later extending parallel to the long axis of the root and around the root to affect large areas, sometimes girdling and killing the root (Corbett, 1974).

CONTROL BY GOOD CULTURAL PRACTICES

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT/IMPACT
PRE-PLANTING CHOICES		
Use of clean planting materials	Exclude nematodes from planting materials.	This is one of the most effective management strategies.
Planting in uninfested soils (nursery)	Avoidance of introduction in clean soils.	Effective in management of nematodes.
PRE-PLANTING CHOICES		
/		
PLANTING		
Scouting	Inspect seedling for nematodes present and carry out soil testing.	Provides effective long-term control of nematodes.
Use of resistant varieties where available	Resistant varieties are less damaged and yield not significantly reduced.	It is effective, require no skills to use and is environmentally sustainable.

ORCHARD MANAGEMENT		
Fertility and water management	Apply organic soil amendments like farm yard or organic manure as opposed to organic fertilizers.	Health crops are able to tolerate nematode infestation without drop in yield. Some of the organic soil amendments are known to have compounds that are antagonistic to nematodes.
HARVESTING AND POST-HARVEST HANDLING		
/		

USE OF PLANT PROTECTION PRODUCTS

CHEMICAL CONTROL

— **Dazomet**

Mode of action: dazomet is transformed into Methyl isothiocyanate (MITC) gas which diffuses through the soil pores to sterilize the soil.

Application: apply it as a pre-planting soil fumigation. The rate can range around 500Kg/ha in soil depth of 20–30 cm depending on the crop stage and calibration of the equipment. Follow label instructions for use.

BIOPESTICIDES

— ***Verticillium* fungus**

Apply it as a drench (solution) against nematodes.

6.6. FUNGAL DISEASES OF AVOCADO

6.6.1. ANTHRACNOSE

SCIENTIFIC NAME

The fungus *Colletotrichum gleosporioides* is the disease-causing agent.

LIFE CYCLE AND BIOLOGY

STAGE	DESCRIPTION
Inoculum sources	Infected plant materials and debris.
Infection	Infection takes place when fruit is still very young and the fungus stays dormant till the fruit ripens.
Development, sporulation	Cool wet weather promotes its development, and the optimum temperature for continued growth of the spores is between 23–29˚C but the fungus can survive at temperatures as low as 4˚C. Spore germination, dispersal and infection require relative humidities near 100%.
Dissemination	The fungus is spread by water splash. Rainfall, wind.

DESCRIPTION/IDENTIFICATION

The disease primarily a post-harvest problem when fruit is at maturity stage. Infection takes place when fruit is still very young and the fungus stays dormant till the fruit ripens. The disease appears as depressed spots on the fruit and the spots are manifested as a rot, which can penetrate deep into the flesh. In wet weather, the spots may be covered with mass of slimy, salmon pink fungal spore mass. The disease may develop very rapidly in storage if conditions in storage are humid and warm.

OTHER HOST PLANTS

Bananas, Beans, Cashew, Cassava, Citrus plants, Cotton, Cowpea, Cucumber, Eggplant, Green gram, Mango, Onion, Peas, Peppers, Pumpkin, Sorghum, Soybean, Spinach, Sugarcane, Tomato, Watermelon, Wheat, Yam, Zucchini/Courgette.

AFFECTED STAGES OF THE CROP

NURSERY	YOUNG, PLANTED TREES	VEGETATIVE STAGE	FLORAL BUDS AND FLOWERING	FRUIT ENLARGEMENT	FRUIT MATURITY / HARVESTING	POST-HARVEST
+	+	++	+++	++	+++	+++

SYMPTOMS AND DAMAGES

BRANCH/STEM	CANKERS
Leave	small and irregular yellow, brown, dark-brown or black spots. The spots can expand and merge to cover the whole affected area. The colour of the infected part darkens as it ages.
Fruit	small, water-soaked, sunken, circular spots that may increase in size up to 1 cm in diameter. As it ages, the center of an older spot becomes blackish and emits gelatinous pink spore masses (https://infonet-biovision.org/PlantHealth/Pests/Anthracnose).

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Economic	It causes severe losses of avocado fruits both in the field and after harvest. Losses of up to 60% have been recorded (Wasilwa, Njuguna, and Okoko, 2004).

QUARANTINE ORGANISM

Wide spread throughout the world.

FAVORABLE CONDITIONS TO THE INFESTATION

TYPE	FAVORABLE CONDITION	IMPACT / EXPLANATION
Temperature	23–29°C but the fungus can survive at temperatures as low as 4°C.	Suitable for sporulation and disease development.
Relative humidity	100%	Suitable for spore germination, dispersal and infection.

MONITORING

Monitor trees weekly throughout the rainy season for symptoms the disease. The disease prefers humid conditions and symptoms can develop on flowers, fruit, leaves, twigs or branches. Anthracnose is most serious on mature fruits and can develop after harvest. When young fruit become infected fruit drop can occur. Check fruits for small, light-brown circular spots. These enlarge and turn brown/black in colour. The lesions are sunken and in humid conditions produces a pink/orange mass of spores. Symptoms are difficult to see on ripe "Haas" fruit because of their dark skin colour. On leaves symptoms do not occur commonly but lookout for small black spots (CABI, 2021).

CONTROL BY GOOD CULTURAL PRACTICES

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT/IMPACT
PRE-PLANTING CHOICES		
Collect and destroy plant debris	They are sources of inoculum	Can reduce levels of infection
Use certified seedlings	This helps in disease avoidance	
PREPARING THE PLOT (ORCHARD)		
Field sanitation	Removal of plant debris, fruits and other dead plant materials and weeding	Reduce fungal inoculum
PLANTING		
Use of resistant varieties where available	They are less susceptible to infection	Reduce cost of production since less chemicals will be used. Increases profit margin for farmers. Dose not require special training/ skills
ORCHARD MANAGEMENT		
Field sanitation	Removal of plant debris, fruits and other dead plant materials	Reduce fungal inoculum
HARVESTING AND POST-HARVEST HANDLING		
/	/	/

CHEMICAL CONTROL

A number of fungicides are sued in control of the disease and they include:

— **Prochloraz (active substance - imidazole)**

Mode of action: broad-spectrum with protectant and eradicant properties that disrupts membrane function.

Application: apply it as foliar spray early morning or late evening and/or as a post-harvest treatment (generally dipping).

— **Copper (II) hydroxide (also known as: cupric hydroxide; copper dihydroxide)**

Mode of action: absorbed copper disrupts the enzyme systems of the pathogens. It has multi-site activity.

Application: apply it as foliar cover early morning or late evening at a rate that can range around 1.2 kg/ha depending on the crop stage and calibration of the equipment.

— **Metiram (Carbamate)**

Mode of action: broad spectrum, non-systemic with protective action and multi-site activity.

Application: apply it as a foliar cover.

— **Azadirachtine**

Mode of action: broad spectrum fungicide that has both preventive and curative action.

Application: for disease prevention, neem oil extract should be applied on a 7 to 14 day schedule until the potential for disease development is eliminated. Complete coverage of plant tissue is necessary for control. In any case, follow instructions on the label, but a common application scheme may be as follow: to control disease that is already present, apply on a 7 day schedule until disease pressure is eliminated then continue on a 14 day schedule to prevent the disease from recurring.

— **Azoxystrobin**

Mode of action: broad-spectrum systemic fungicide which has curative, translaminar and preventative action.

Application: first application should be made when the fruits are approximately pigeon-egg size (early fruit set). Follow with applications of an approved fungicide from a different chemical group. Apply it as a foliar spray.

Resistance management: You should not exceed 3 applications in 1 season. Do not use curatively and do not start disease control program with azoxystrobin. Use

as part of an integrated crop management strategy incorporating other methods of control including where appropriate other fungicides with different mode of action (ex: fludioxonil, triazoles, etc.).

— **Fludioxonil**

Mode of action: fludioxonil is a broad-spectrum fungicide which is non-systemic with a long residual activity. In combination with azoxystrobin, it can be used as protectant and post-harvest treatment.

Application: apply as a dip, drench or flood spray at post-harvest. Ensure fruit is immersed in dip or exposed to solution for a minimum of 30 seconds and up to 60 seconds.

Resistance management: Do not apply in combination to azoxystrobin to avocados if a Group 11 fungicide was the final pre-harvest application.

— **Cyprodinil-fludioxonil**

Mode of action: broad-spectrum fungicide

Application: first application during early bloom and repeat on 7–10 day intervals if conditions remain favourable for disease development. Always, follow label instruction for use.

Resistance management: alternate after two applications with another fungicide with different mode of action for two applications. Do not exceed 4 applications per year.

— **Fluopyram + trifloxystrobin**

Mode of action: flupyram is a broad-spectrum fungicide with preventive systemic and curative properties. Trifloxystrobin is also a broad-spectrum systemic fungicide with protective and curative properties.

Application: begin applications as soon as crop development has reached susceptible stages for disease infections to occur.

Resistance management: Apply in a preventative fungicide program, incorporating fungicides from different mode of action groups. Intervals between fungicide applications generally should be 14–21 days, but should be adapted to local, disease and weather conditions and according to label instructions.

— **Fluopyram + tebuconazole**

Mode of action: flupyram is a broad-spectrum systemic fungicide with preventive and curative properties and acts by blocking energy production. Tebuconazole is also a broad-spectrum fungicide that acts by interfering with the fungal cell wall hence inhibiting reproduction.

Application: apply it as part of a regular fungicide program, in alternation with fungicides from a different chemical mode of action group. Intervals between applications should be 14–21 days. Always follow label instruction for use.

Note: rotate active ingredients with different modes of action to avoid resistance development

Biocontrol agents

- *Trichoderma longibrachiatum*, *T. harzianum* and *T. viride* are known to control anthracnose. They act through mycoparasitism. They have no phytotoxicity on crops when applied.
- *Bacillus amyloliquefaciens* (strain QST 713) can be used preventively for the management of anthracnose. Application should begin as soon as the susceptible stages for anthracnose infections to occur have been reached. Applications of *Bacillus amyloliquefaciens* (strain QST 713) can be rotated with other registered fungicides and repeat applications can be done every 7–21 days. Use the shorter interval when conditions are very favourable for infection. Always refer to label instructions before use.
- *Bacillus subtilis*

6.6.2. FRUIT ROT

SCIENTIFIC NAME

The fungus *(Dothiorella)* is the disease-causing agent.

LIFE CYCLE AND BIOLOGY

STAGE	DESCRIPTION
Inoculum sources	Infected plant materials.
Infection	Occurs post-harvest
Development, sporulation	Dothiorella fruit rot does not appear when the fruit is still on the tree but develops after the fruit is picked and starts to soften.
Dissemination	These pathogens spread by wind-blown or water-splashed spores produced in or on cankers, dead twigs and branches, and dying fruit and leaves. Spores infect through wounds and lenticels (tiny natural openings) on fruit.

DESCRIPTION/IDENTIFICATION

Damage from avocado fruit rot closely resembles that from Anthracnose and fruit damaged by these pathogens are usually culled and lumped together in the packing house. Anthracnose produces pink sporulation on the fruit surface, in contrast with the grayish mycelium from avocado fruit rot.

AFFECTED STAGES OF THE CROP

NURSERY	YOUNG, PLANTED TREES	VEGETATIVE STAGE	FLORAL BUDS AND FLOWERING	FRUIT ENLARGEMENT	FRUIT MATURITY / HARVESTING	POST-HARVEST
0	0	0	++	++	+++	+++

SYMPTOMS AND DAMAGES

SHOOT	DEAD TWIGS
Branch/stem	Dead branches.
Leave	Dead leaves.
Fruit	Small purplish brown spots appear on any part of the fruit, but more often at the stem end. These spots gradually enlarge and may involve the entire fruit surface. The flesh is invaded by the fungus, becomes discoloured, and develops an offensive odour. This disease is an occasional but minor postharvest problem of avocados.

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Economic	It is a minor disease in avocado and has minimal economic impact.

QUARANTINE ORGANISM

Wide spread throughout the world.

FAVORABLE CONDITIONS TO THE INFESTATION

TYPE	FAVORABLE CONDITION	IMPACT / EXPLANATION
Temperature	Cool temperatures.	This disease is less important in dry climates.
Relative humidity	High humidity conditions.	Fungi usually prefer moisture.

MONITORING

Scout for small, irregular brown to reddish discolorations / lesions on the peel. Under the peel, brown streaks running lengthwise in the flesh may be observed because decay initially spreads along vascular bundles in the fruit.

CONTROL BY GOOD CULTURAL PRACTICES

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT/IMPACT
PRE-PLANTING CHOICES		
Collect and destroy plant debris	They are sources of inoculum.	Can reduce levels of infection.
PREPARING THE PLOT (ORCHARD)		
Field sanitation	Removal of plant debris, fruits and other dead plant materials and weeding.	Reduce fungal inoculum.
PLANTING		
/	/	/
ORCHARD MANAGEMENT		
Field sanitation	Removal of plant debris, fruits and other dead plant materials.	Reduce fungal inoculum.
Pruning		
HARVESTING AND POST-HARVEST HANDLING		
/	/	/

NB: Apply same management strategies as Anthracnose (UC IPM, 2016)

6.6.3. *PHYTOPHTHORA* ROOT ROT

SCIENTIFIC NAME

The fungus *Phytophthora cinnamomi* is the disease-causing agent.

LIFE CYCLE AND BIOLOGY

STAGE	DESCRIPTION
Inoculum sources	Sources of inoculum are infested plant materials.
Infection	*P. cinnamomi* is a soilborne pathogen.
Development, sporulation	Infective spores move via water and soil and reach root tissues where infection occurs.
Dissemination	Initial long-range spread is likely to have been on infected nursery plants. Long-range spread is by movement of soil. Short-range spread is also by zoospores in drainage, seepage and irrigation water.

DESCRIPTION/IDENTIFICATION

Major disease in avocado. *Phytophthora cinnamomi* is a soil-borne water mould that produces an infection which causes a condition in plants variously called "root rot", "dieback", or (in certain Castanea species), "ink disease". The plant pathogen is one of the world's most invasive species.

OTHER HOST PLANTS

There are more than 1,000 host species.

AFFECTED STAGES OF THE CROP

NURSERY	YOUNG, PLANTED TREES	VEGETATIVE STAGE	FLORAL BUDS AND FLOWERING	FRUIT ENLARGEMENT	FRUIT MATURITY / HARVESTING	POST-HARVEST
+++	+++	++	0	0	0	0

SYMPTOMS AND DAMAGES

Root	*Phytophthora cinnamomi* causes a rot of fine feeder roots, and root cankers in some species, leading to dieback and death of host plants.
Branch/stem	Stem canker.
Fruit	Decline in yield, decreased fruit size, gum exudation.

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Economic	High. Causes serious yield losses in avocado.
Environmental	*Phytophthora cinnamomic* is associated with the widespread death of native plants. This results in changes of vegetation structure.
Social	In addition to the social value of native flora and fauna threatened by *P. cinnamomi* for landscape and tourism, access to areas of infection or at risk may be restricted and hygiene measures imposed to reduce the spread of the pathogen by humans.

QUARANTINE ORGANISM

Wide spread throughout the world.

FAVORABLE CONDITIONS TO THE INFESTATION

TYPE	FAVORABLE CONDITION	IMPACT / EXPLANATION
Temperature	Optimum 20–32.5°C; maximum 30–36°C.	Originally mainly reported in tropical and subtropical countries, it can apparently survive and develop in cooler countries, and does not seem to be obviously restricted by growing season or winter temperatures.
pH	5.5	Optimum soil pH for growth and survival of the pathogen.

MONITORING

Phytophthora cinnamomi is primarily a root pathogen of woody species and causes rot of fine feeder roots leading to death of host plants. Larger roots are only occasionally attacked. Rot may extend into the base of the stem with brown lesions forming in the wood, a symptom that can be seen by peeling off the bark. Foliage becomes chlorotic and wilted and, depending on the severity of the root rot, dies back. *P. cinnamomi* causes also stem cankers which often result in sudden death of trees (CABI, 2021).

CONTROL BY GOOD CULTURAL PRACTICES

ACTION	JUSTIFICATION AND/OR DESCRIPTION	EFFECT/IMPACT
PRE-PLANTING CHOICES		
Use of clean and certified seedlings	Prevents introduction of pathogen.	Avoidance of pathogen in areas where is it not present is an effective management strategy.
Soil solarization	Soil solarization also controls *P. cinnamomi* on young avocado plants.	Reduces pathogen inoculum.
PREPARING THE PLOT (ORCHARD)		
/	/	/
PLANTING		
Utilizing well-drained sandy soils with a low pH (4)	Suppression of pathogen.	Slows down multiplication and spread.
ORCHARD MANAGEMENT		
Field sanitation including rogueing and destruction of infected plants		
HARVESTING AND POST-HARVEST HANDLING		
/	/	/

BIOLOGICAL CONTROL

There are numerous microorganisms which inhibit *P. cinnamomi* via parasitism, antibiosis and competition. Although none of these microorganisms has yet provided economical control, there is increasing evidence that these organisms play an important role in the natural suppression of *P. cinnamomi* in certain soils. For example, Bio enhanced mulches (Costa *et al.*, 1996) and repeated applications of the bacterium Pseudomonas putida (Yang *et al.*, 2001) suppressed *P. cinnamomi* infection on avocado roots.

CONTROL WITH PLANT PROTECTION PRODUCTS

— **Fosetyl (Organophosphate)**

Mode of action: Group U fungicide: systemic, absorbed through leaves and roots.

Application: apply it as a soil drench, foliar spray or trunk injection.

Resistance management: Any fungal population may contain individuals naturally resistant to fosetyl-aluminum and other Group U fungicides. A gradual or total loss of pest control may occur if these fungicides are used repeatedly. To delay fungicide resistance, rotate the use of fosetyl-Aluminuim or other U fungicides with different groups that control the same pathogens.

— **Metalaxyl (Phenylamide-active substance)**

Mode of action: systemic with curative and protective action, acts by suppressing sporangial formation, mycelial growth and the establishment of new infections. Disrupts fungal nucleic acid synthesis - RNA ploymerase 1.

Application: apply it as a systemic granular fungicide at planting and repeat 8 to 12 weeks later. Incorporate in the soil by cultivation or watering. Always refer to label instructions before use.

— **Mefenoxam**

Mode of action: broad-spectrum systemic fungicide with protective and curative properties and is absorbed through the roots, stems and leaves.

Application: it should be applied evenly as a soil drench within the drip area of the tree. Light irrigation. Applications should be made twice per season. The first application should coincide with new growth, usually shortly before the onset of the rainy season, and the second 16–20 weeks later. Always refer to label instructions before use.

Note: rotate active ingredients with different modes of action to avoid resistance development.

OTHER CONTROL MEASURES

Host plant resistance: Use of host plant resistance where resistant cultivars exist is cheap, environment friendly and does not require skills. Some rootstocks of avocado also show tolerance (Kotze and Darvas, 1983).

6.6.4. VERTICILLIUM WILT OF LUCERNE

SCIENTIFIC NAME

The fungus *(Verticillium albo-atrum*) is the disease-causing agent.

LIFE CYCLE AND BIOLOGY

STAGE	DESCRIPTION
Inoculum sources	Infected plant materials and debris.
Infection	The fungus penetrates the tissue of a susceptible host and in some cases the infection becomes systemic whereas others appear to be localized infections. The fungus can survive in soil for several years by producing resting structures.
Development, sporulation	The conidia that do become systemic penetrate the plant tissue and occupy the xylem vessels where conidia are produced. Vascular colonization then occurs as the conidia move up the plant xylem vessels along with water.
Dissemination	Conidia of *V. albo-atrum* form abundantly on senescent or necrotic plant parts and are able to travel large distances through the air (link) Spread of disease generally results from dissemination of infected plant debris by natural agencies or in the processes of cultivation, harvesting, etc. The pathogen may be transferred in cuttings, etc. propagated in infested soils (link).

DESCRIPTION/IDENTIFICATION

Verticillium albo-atrum is a soil-borne pathogen belonging to the class *Deuteromycota* (Fungi Imperfecti; no known sexual stage).

OTHER HOST PLANTS

V. albo-atrum has a limited host range.

AFFECTED STAGES OF THE CROP

NURSERY	YOUNG, PLANTED TREES	VEGETATIVE STAGE	FLORAL BUDS AND FLOWERING	FRUIT ENLARGEMENT	FRUIT MATURITY / HARVESTING	POST-HARVEST
+	+++	+++	+++	0	0	0

QUARANTINE ORGANISM

Wide spread throughout the world.

SYMPTOMS AND DAMAGES

Branch/stem	Cutting the stalk horizontally reveals a slight discolouration of the vessels, brown or greenish, but much less distinct than the discolouration caused by Fusarium.
Leaves	The wilting starts at the lower leaves. These leaves are pale-green, then orange-yellow.

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Economic	On younger seedlings and plants, it can cause serious damage.

FAVORABLE CONDITIONS TO THE INFESTATION

TYPE	FAVORABLE CONDITION	IMPACT / EXPLANATION
Temperature	21°C (optimum temperature).	Optimum temperature for growth, Growth stops above 30°C.

MONITORING

V. albo-atrum can easily be identified after isolation from suspect plant tissue. It can easily be isolated from infected hosts by isolation from xylem of roots, stems, branches, twigs and even leaves and seeds.

CONTROL BY GOOD CULTURAL PRACTICES

ACTION	JUSTIFICATION) AND/OR DESCRIPTION	EFFECT/IMPACT
PRE-PLANTING CHOICES		
Sanitation	Clearing vegetation and removal of plant debris.	Reduce inoculum.
PREPARING THE PLOT (ORCHARD)		
/	/	/
PLANTING		
Resistant cultivars where available	Reduce disease severity.	Effective and environmentally sustainable.
ORCHARD MANAGEMENT		
Crop rotation	Avoid planting fruit trees on an area previously planted with host crops.	Reduce inoculum.
HARVESTING AND POST-HARVEST HANDLING		
/	/	/

CONTROL WITH PLANT PROTECTION PRODUCTS

Chemicals recommended for use as methyl bromide (ban globally, under Montreal Convention), chloropicrin and benomyl are not approved in EU.

USE OF BIOPESTICIDES

— **Microparasitic fungi** (*Pythium oligandrum*)

This biofungicide is used to control *Verticillium* species and other fungal pathogens like *Fusarium* species in different fruits and vegetables but it does not include avocado.

6.6.5. CERCOSPORA SPOT /SPOT BLOTCH

SCIENTIFIC NAME

The fungus (*Pseudocercospora purpurea*) is the disease-causing agent.

LIFE CYCLE AND BIOLOGY

STAGE	DESCRIPTION
Inoculum sources	Initial inoculum of conidia (asexual spores) mostly comes from infected leaves. New shoot tissues are infected wherever this disease occurs.
Infection	The pathogen penetrates host tissue either directly or through wounds.
Development, sporulation	On landing on surfaces of a plant host, conidia require water or heavy dew to germinate and penetrate the host. The pathogen remains latent for about 3 months after penetration. Infected plants produce conidiophores (specialized hypha) that arise from the plant surface in clusters through stomata and form conidia successively. Fruit are susceptible when developed to a quarter to three-quarter of their full size. (https://blogs.cdfa.ca.gov/Section3162/?tag=pseudocercospora-purpurea).
Dissemination	Conidia are easily detached and blown by wind often over long distances. Wind, rain, irrigation water, infected nursery plants, infected leaves, insects (Menge & Ploetz, 2003).

DESCRIPTION/IDENTIFICATION

Individual spots on leaves are very small, less than 2.5 mm in diameter, and brown to purple in colour. On the fruit, damage begins as small, irregular, brown spots that enlarge and coalesce. Cracks often appear in these spots and are very commonly entry points for the anthracnose fungus.

OTHER HOST PLANTS

Avocado is the main host; *Persea* spp. in the family Lauraceae, namely, *P. americana* (syn. *P. gratissima*, avocado), *P. borbonia* (redbay), *P. drymifolia* (Mexican avocado), *P. palustris* (swamp bay), and *Persea* sp. (Farr & Rossman, 2016; (Silva et a., 2016).

AFFECTED STAGES OF THE CROP

NURSERY	YOUNG, PLANTED TREES	VEGETATIVE STAGE	FLORAL BUDS AND FLOWERING	FRUIT ENLARGEMENT	FRUIT MATURITY / HARVESTING	POST-HARVEST
+++	+++	++	+	+++	0	+++

QUARANTINE ORGANISM

Wide spread throughout the world.

SYMPTOMS AND DAMAGES

Branch/stem	Twigs and fruit pedicels may appear dark brown to black irregular lesions), causing premature fruit fall.
Leaves	The lesions appear as small light-yellow spots on fruits and leaves. They later become reddish brown and eventually become hard and crack.

Figure 97 — A "Fuerte" avocado fruit with Cercospora spot (http://www.avocadosource.com)

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Economic	The disease is primarily a problem to quality of fruits. The severity of infection varies from season to season and can cause losses of 60- 69% (https://infonet-biovision.org/PlantHealth/MinorPests/Cercospora-fruit-spot; https://blogs.cdfa.ca.gov/Section3162/?tag=pseudocercospora-purpurea).

FAVORABLE CONDITIONS TO THE INFESTATION

TYPE	FAVORABLE CONDITION	IMPACT / EXPLANATION
Temperature and rainfall	Warm temperatures (25°C).	The disease development is favoured by humid conditions and high temperatures.

MONITORING

Look for small irregular light-yellow spots (less than 2.5 mm) on fruits which later become reddish brown eventually becoming hard, then cracking especially during humid conditions and high temperatures. Check leaves for brown to purple 2.5 mm spots, each surrounded by a yellow halo. During the rainy season, a hand lens can observe greyish spore masses on the surface of the angular spots. These spots may join to form irregular areas of brown tissue. Twigs and fruit pedicels may have dark brown to black irregular lesions (2–10 mm), causing premature fruit fall (CABI, 2021).

CONTROL BY GOOD CULTURAL PRACTICES

ACTION	JUSTIFICATION) AND/OR DESCRIPTION	EFFECT/IMPACT
PRE-PLANTING CHOICES		
Use of disease-free seedlings	Prevents introduction of inoculum in the field.	Reduce inoculum.
PREPARING THE PLOT (ORCHARD)		
/	/	/
PLANTING		
Resistant cultivars where available	Reduce disease severity.	Effective and environmentally sustainable.

ORCHARD MANAGEMENT		
Field sanitation	— If previously infested, avoid intercropping the orchard with bean, beetroot, capsicum, okra, carrot and coffee which are alternative hosts of the disease — Remove dead twigs and branches as they can host the fungus in readiness for attack — Remove all fallen fruits from the surroundings as they harbour insects that transmit the fungus — Disinfect farm implements with Sodium hypochloride (500 ml / 20 L water) after working in one field, before moving to another	Reduce inoculum
HARVESTING AND POST-HARVEST HANDLING		
Harvesting and storage	Harvest and sort diseased from clean fruits before storage	Reduce spread of inoculum in harvested fruits

CONTROL WITH PLANT PROTECTION PRODUCTS

USE OF BIOPESTICIDES

Biopesticides based on *Bacillus subtilis* are used to control fungal pathogens in field and in post-harvest operations. For field application ensure even coverage of canopy.

CHEMICAL CONTROL

Chemicals recommended for field spray application as protectants such as Captan, Copper oxychloride and Copper Hydroxide which are approved in EU:

— **Captan (Phthalimide-active substance)**

Mode of action: non-systemic with protective and curative action. Multi-site activity.

Application: apply it as foliar spray.

— **Prochloraz (active substance- Imidazole)**

Mode of action: broad-spectrum with protectant and eradicant properties. Disrupts membrane function.

Application: apply it at post-harvest.

— **Azoxystrobin**

Mode of action: broad-spectrum systemic fungicide which has curative, translaminar and preventative action.

Application: first application should be made when the fruits are approximately pigeon-egg size. You should not exceed 2 sprays in 1 season.

— **Copper based fungicides**

Mode of action: broad-spectrum and mostly contact fungicides with protectant and curative properties. They are classified as multisite and act by disrupting the cellular proteins.

Application: Apply from the end of flowering to harvest. During extended wet weather, spray every 14 days. Start use preferably during low infestation and preferably as a last spray in a spray program. Apply a minimum of 3 full cover sprays in a season with 4-week intervals. Optimum pH 6.5–7. Always follow label instructions for use.

— **Thiabendazole**

Mode of action: It is a broad-spectrum systemic fungicide with protective and curative activity by impairing fungal growth and development.

Application: apply it at post-harvest.

Note: rotate active ingredients with different modes of action to avoid resistance development.

6.6.6. STEM END ROTS

SCIENTIFIC NAME

The fungi *Lasiodiplodia theobromae*, *Neofusicoccum parvum*, *Nectria pseudotrichia*, and *Fusarium solani* are the disease-causing agents.

LIFE CYCLE AND BIOLOGY

STAGE	DESCRIPTION
Inoculum sources	Infected fruits, leaves and plant debris. Most of the stem end rot pathogens are saprophytes.
Infection	Fungal pathogens that enter fruits via the stem or via the unprotected snap point if fruits are picked without the stem.
Development, sporulation	Infections usually become active after the fruit is picked and starts to soften. As fruit ripens, decay spreads and rots the entire fruit, which becomes dark and shrivelled.
Dissemination	These pathogens spread by wind-blown or water-splashed spores produced in or on cankers, dead twigs and branches, and dying fruit and leaves. Spores infect through wounds and lenticels (tiny natural openings) on fruit. Infection occurs in the grove, but disease usually is not obvious until after fruit is picked and starts to ripen (https://www2.ipm.ucanr.edu/agriculture/avocado/Fruit-and-stem-end-rots/).

DESCRIPTION/IDENTIFICATION

Decay from stem end rot begins as slight shrivelling around the stem button. Fungal mycelium are often visible on fruit if the button is removed. Conspicuous dark decay with a well-defined margin develops at the stem end. As fruit ripens, decay spreads and rots the entire fruit, which becomes dark and shrivelled. Depending on the causal organisms, flesh may be watery and soft, or initially dry and corky, becoming watery later as secondary organisms colonize tissue. These stem end rotting species are saprophytes (decay organisms) or weak pathogens, which are present in soil and most dead or dying avocado tissue, including senescing flowers and injured bark, fruit, and leaves (https://www.plantwise.org/KnowledgeBank/pmdg/20157801505).

OTHER HOST PLANTS

Citrus, mango, banana, tomato.

AFFECTED STAGES OF THE CROP

NURSERY	YOUNG, PLANTED TREES	VEGETATIVE STAGE	FLORAL BUDS AND FLOWERING	FRUIT ENLARGEMENT	FRUIT MATURITY / HARVESTING	POST-HARVEST
+	+	++	++	++	+++	+++

QUARANTINE ORGANISM

Wide spread throughout the world.

SYMPTOMS AND DAMAGES

FRUITS

Small, superficial lesions can develop on fruit in the grove, but the disease usually is apparent only on fruit that is very overmature, hanging on dead limbs or dropped on the ground.

Figure 98 — Avocado stem end rot (flickr.com)

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Economic	Reported to cause up to 30% to producers and marketers link.

FAVORABLE CONDITIONS TO THE INFESTATION

TYPE	FAVORABLE CONDITION	IMPACT / EXPLANATION
Temperature, rainfall and humidity	Warm humid conditions.	Favour sporulation of fungal pathogen spores.

MONITORING

Monitor regularly during the development of fruits for symptoms. Fruits: light decay begins as slight shrivelling around the stem button and spreads until everything inside the fruit rots. Brown necrosis at grafting union, which advances downwards and results in dead tops to the trees.

CONTROL BY GOOD CULTURAL PRACTICES

ACTION	JUSTIFICATION) AND/OR DESCRIPTION	EFFECT/IMPACT
PRE-PLANTING CHOICES		
Field sanitation	Remove plant debris in case there were old trees.	Reduce infective inoculum.
PREPARING THE PLOT (ORCHARD)		
/	/	/
PLANTING		
Use clean planting material	/	Effective and environmentally sustainable.
ORCHARD MANAGEMENT		
Field sanitation	Prune out dead limbs and twigs. Dispose of dead wood and old fruit away from trees. Prune and harvest only during dry conditions.	Reduce inoculum.

HARVESTING AND POST-HARVEST HANDLING		
Harvesting and storage	Harvest and sort diseased from clean fruits before storage.	Reduce spread of inoculum in harvested fruits.
	Minimize the time between harvest and storage (less than 6 hours). To reduce the incidence of the disease, store rapidly at 5°C and control the temperature and postharvest conditions (hot and dry).	

CONTROL WITH PLANT PROTECTION PRODUCTS

USE OF BIOPESTICIDES

Trichoderma spp. (*T. atroviride*, *T. virens*, *T. asperellum*, and *T. harzianum*) have been shown to be effective against avocado stem-end rot (SER) fungal pathogens (*Lasiodiplodia theobromae*, *Neofusicoccum parvum, Nectria pseudotrichia*, and *Fusarium solani*) (Wanjiku, Waceke and Mbaka, 2021) in post-harvest treatments. Therefore, use of biofungicides based on *Trichoderma* spp. where available can control stem end rot pathogens).

Bacillus amyloliquefaciens (strain QST 713) can also be used preventively for the management of SER. Application should begin as soon as the susceptible stages for SER infections to occur have been reached. Applications of *Bacillus amyloliquefaciens* (strain QST 713) can be rotated with other registered fungicides and repeat applications can be done every 7–21 days.

CHEMICAL CONTROL

— **Fludioxonil + Azoxystrobin**

Mode of action: Fludioxonil is a broad-spectrum fungicide which is non-systemic with a long residual activity and Azoxystrobin is a broad-spectrum systemic fungicide which has curative, translaminar and preventative action. A combination of these two can be used as protectant and post-harvest treatment.

Application: Apply as a dip, drench or flood spray at post-harvest. Ensure fruit is immersed in dip or exposed to solution for a minimum of 30 seconds and up to 60 seconds. Do not apply to avocados if a Group 11 fungicide was the final pre-harvest application.

Note: rotate active ingredients with different modes of action to avoid resistance development.

6.6.7. AVOCADO SCAB

SCIENTIFIC NAME

The fungus *(Sphaceloma perseae*) is the disease-causing agent.

LIFE CYCLE AND BIOLOGY

STAGE	DESCRIPTION
Inoculum sources	Infected plant materials.
Infection	*Sphaceloma perseae* persists across seasons on avocado in lesions. The pathogen generates the asexual fruiting body that erupt from these lesions, present on either fruit or leaves, as small cream or olive-colored masses of clustered conidiophores and spores.
Development, sporulation	During cool, moist weather, conidia may be formed on infected leaves, twigs and fruit.
Dissemination	*S. perseae* can be spread locally by wind, rain and insects. Insect wounds can increase entry of the pathogen and make scab development worse. Long distance transport is possible through fruit movement but most likely in infected propagation material.

DESCRIPTION/IDENTIFICATION

Leaf symptoms begin as small discrete lesions which are often concentrated along the midrib and main veins, but lesions may coalesce into star-like patterns. Shot-holes may also develop. As the disease progresses, leaves become distorted and stunted. Lesions may also occur on leaf petioles, twigs and fruit pedicels. Symptoms on fruit initially appear as corky, raised, oval or irregular shaped brown to purplish-brown spots. As the disease progresses, spots enlarge and coalesce to form large rough areas over the fruit surface. Cracking of these rough areas may allow secondary organisms to penetrate and rot the fruit.

AFFECTED STAGES OF THE CROP

NURSERY	YOUNG, PLANTED TREES	VEGETATIVE STAGE	FLORAL BUDS AND FLOWERING	FRUIT ENLARGEMENT	FRUIT MATURITY / HARVESTING	POST-HARVEST
+	++	++	+++	+++	+++	+++

QUARANTINE ORGANISM

Wide spread throughout the world.

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Economic	It is of low economic importance and causes more aesthetic damage that real economic losses. It has been shown to cause losses of 5.78 and 5.68% in farms and packinghouses, respectively (Ramírez-Gil, López, and Henao-Rojas,2020).

FAVORABLE CONDITIONS TO THE INFESTATION

TYPE	FAVORABLE CONDITION	IMPACT / EXPLANATION
Temperature, rainfall and humidity	Warm humid conditions.	Favour sporulation of fungal pathogen spores.

MONITORING

Look for fruit drop and marking of mature fruit, discrete spots on the leaves along the midrib, which may merge into star-like patterns. As disease progresses leaves become distorted and stunted. Symptoms on fruit appear as corky, raised brown to purplish brown spots which enlarge to form large rough areas.

CONTROL BY GOOD CULTURAL PRACTICES

ACTION	JUSTIFICATION) AND/OR DESCRIPTION	EFFECT/IMPACT
PRE-PLANTING CHOICES		
Field sanitation	Remove plant debris in case there were old trees.	Reduce infective inoculum.
PREPARING THE PLOT (ORCHARD)		
/	/	/
PLANTING		
Use clean planting material	Source plant material only from clean, accredited suppliers, and preferably material that is certified.	Effective and environmentally sustainable.
ORCHARD MANAGEMENT		
Field sanitation	Remove dead branches and twigs since they harbour the fungus. Remove fallen rotten fruits from the field.	Reduce inoculum.
HARVESTING AND POST-HARVEST HANDLING		
Harvesting and storage	/	Reduce spread of inoculum in harvested fruits.
	/	

CONTROL WITH PLANT PROTECTION PRODUCTS

USE OF BIOPESTICIDES

Biopesticides based on *Bacillus subtilis* are used to control fungal pathogens in field and in post-harvest operations. For field application, apply concentration of 10^7 cells ml^{-1} and even coverage of canopy.

CHEMICAL CONTROL

— **Captan (Phthalimide-active substance)**

Mode of action: Non-systemic with protective and curative action. Multi-site activity.

Application: apply it as a foliar spray.

— **Prochloraz (active substance- Imidazole)**

Mode of action: broad-spectrum with protectant and eradicant properties. Disrupts membrane function.

Application: apply it at post-harvest.

— **Azoxystrobin**

Mode of action: broad-spectrum systemic fungicide which has curative, translaminar and preventative action.

Application: first application should be made when the fruits are approximately pigeon-egg size. A follow-up application should be made 28 days later. You should not exceed 3 sprays in 1 season. Always follow label instruction for use.

— **Copper based fungicides**

Mode of action: broad-spectrum and mostly contact fungicides with protectant and curative properties. They are classified as multisite and act by disrupting the cellular proteins.

Application:. apply it as a full cover spray from the end of flowering to harvest.

— **Thiabendazole**

Mode of action: broad-spectrum systemic fungicide with protective and curative activity by impairing fungal growth and development.

Application: apply it at post-harvest.

Note: rotate active ingredients with different modes of action to avoid resistance development.

6.7. BACTERIAL DISEASES OF AVOCADO

6.7.1. BACTERIAL CANKER

SCIENTIFIC NAME

The bacteria *Xanthomonas campestris* is the disease-causing agent.

LIFE CYCLE AND BIOLOGY

STAGE	DESCRIPTION
Inoculum sources	Infected plant materials and debris, infected seedlings, he pathogen can also be introduced through nursery practices.
Infection	Begins when infective spores come into contact with avocado tress
Development, sporulation	It can infect through wounds and branch stubs and spread within the plant's vascular system. Drought stress and boron deficiency may promote development of disease symptoms. The disease most typically shows up in drought years, at the end of irrigation lines, or at points where irrigation system water pressure is lowest.
Dissemination	Through water, wind and infected plant materials.

DESCRIPTION/IDENTIFICATION

Bacterial cankers appear as slightly sunken, dark areas on the bark and vary in size from about 1 to 4 inches in diameter. Bark around cankers may crack. Fluid often oozes and dries, leaving a white powder around or over the lesion. Usually, cankers appear and spread upward in a line on one side of the trunk or branch.

AFFECTED STAGES OF THE CROP

NURSERY	YOUNG, PLANTED TREES	VEGETATIVE STAGE	FLORAL BUDS AND FLOWERING	FRUIT ENLARGEMENT	FRUIT MATURITY / HARVESTING	POST-HARVEST
+++	+++	+++	0	0	0	0

QUARANTINE ORGANISM

Wide spread throughout the world.

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Economic	Bacterial canker is widespread but is a relatively unimportant disease. In some groves the bacterium infects over 60% of the trees, but most of these trees will perform well if otherwise cared for appropriately.

SYMPTOMS AND DAMAGES

LEAVES	LEAVES SHOW NO SYMPTOMS BUT USUALLY HAVE LATENT INFECTION
Bark	Bacterial cankers appear as slightly sunken, dark areas on the bark and vary in size from about 1 to 4 inches in diameter. Bark around cankers may crack. Fluid often oozes and dries, leaving a white powder around or over the lesion. Usually, cankers appear and spread upward in a line on one side of the trunk or branch. Cutting under the bark surface reveals a decayed, reddish brown necrotic pocket, which may contain liquid. Dark streaks in the wood radiate out both above and below from the lesions. These necrotic streaks are usually in the bark cortex or xylem, but sometimes extend deeper into the centre of branches or trunks. Often the disease will become inactive and canker wounds will close, except that a bark flap over the wound will remain.

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Economic	Bacterial canker is widespread but is a relatively unimportant disease. In some instances, the bacterium infects over 60% of the trees, but most of these trees will perform well if otherwise cared for appropriately.

FAVORABLE CONDITIONS TO THE INFESTATION

TYPE	FAVORABLE CONDITION	IMPACT / EXPLANATION
Temperature, rainfall and humidity	Wet, warm and humid conditions.	Its reproduction and spread is favoured by wet plants and humid conditions.

MONITORING

Look out for the symptoms that vary from small, sunken, dark areas with watery, reddish-brown tissue beneath the bark to large, watery areas up to 10 cm in diameter, with the bark split open and a white powdery exudate on the surface. Multiple cankers on trunks and branches were usually connected by reddish brown necrotic streaks beneath the bark and often in the wood.

CONTROL BY GOOD CULTURAL PRACTICES

ACTION	JUSTIFICATION) AND/OR DESCRIPTION	EFFECT/IMPACT
PRE-PLANTING CHOICES		
Use certified/clean planting materials	Prevents introduction and spread of the bacteria.	Reduce infective inoculum.
Disinfect tools used in nursery operations with 20% sodium hypochlorite or any other disinfectant	Prevents spread of bacterial from infected to uninfected seedlings.	Very effective in reducing inoculum.
PREPARING THE PLOT (ORCHARD)		
/	/	/
PLANTING		
Use clean planting material	Prevents spread of bacterial from infected to uninfected seedlings.	Effective and environmentally sustainable.
ORCHARD MANAGEMENT		
Field sanitation	Regularly inspect young trees and remove and dispose of young trees if they are infected, prune trees to ensure light penetration in the canopy.	Reduce inoculum.

USE OF BIOPESTICIDES

Biopesticides based on antagonistic pathogens such as *Bacillus subtilis* are used to control fungal pathogens in field and in post-harvest operations.

6.8. OTHER PATHOGENS CAUSING AVOCADO DISEASES

6.8.1. AVOCADO SUNBLOTCH VIROID (ASBVD)

SCIENTIFIC NAME

Avocado sunblotch viroid (ASBVD)

Sunblotch is caused by dozens of variants of sub microscopic particles of genetic material (viroids) that alter development and growth of infected plants.

LIFE CYCLE AND BIOLOGY

STAGE	DESCRIPTION
Inoculum sources	Infected plant materials, contaminated tools.
Infection	Mechanically through contaminated tools, through infected seedlings.
Development, sporulation	Sunblotch viroid can move systemically within avocado, and it persists in host tissues.
Dissemination	Transmission of the viroid most often occurs during grafting by using infected budwood or rootstock seedlings from infected trees with or without symptoms. Natural root-to-root grafts are important in transmitting sunblotch. Mechanical transmission through wounds caused by contaminated harvest clippers, pruning tools, and injection equipment is also known to occur. Spread via pollen from an infected tree to the flower ovule of a noninfected avocado, resulting in infected seed, can cause fruit to be culled, but does not further spread the disease unless seed is propagated. There is no evidence of insect transmission.

DESCRIPTION/IDENTIFICATION

ASBVD replicates and accumulates in the chloroplast, and it is the smallest plant pathogen. This pathogen is a circular single-stranded RNA of 246–251 nucleotides. ASBVD.

OTHER HOST PLANTS

Has a restricted host range and only few plant species of the family *Lauraceae* have been confirmed experimentally as additional hosts.

AFFECTED STAGES OF THE CROP

NURSERY	YOUNG, PLANTED TREES	VEGETATIVE STAGE	FLORAL BUDS AND FLOWERING	FRUIT ENLARGMENT	FRUIT MATURITY / HARVESTING	POST-HARVEST
+++	+++	+++	+++	0	0	0

QUARANTINE ORGANISM

In ACP countries it is only present in Ghana and South Africa.

IMPACT ON YIELD AND QUALITY

TYPE OF IMPACT	DESCRIPTION
Economic	Trees with visible sunblotch symptoms often produce avocado fruits with reduced quality and yield (18%–30%) (Semancik, 2003a). A significant and dramatic reduction (95%) in fruit yield may also occur in some avocado trees in which ASBVd is latent (symptomless carriers) (Desjardins, 1987).

SYMPTOMS AND DAMAGES

Leaves	Twigs can develop narrow, necrotic, red or yellow streaks on their surface or in shallow lengthwise indentations along the twig.
Twigs	Leaves may have white or yellowish variegated areas and be deformed, but leaf symptoms are uncommon.
Bark	Rectangular cracking and checking of the bark, called "alligator bark," often occurs on the trunk and larger branches.
Fruits	Symptoms of sunblotch include necrotic, red, yellow, or white discolorations on fruit, often in depressions or scars in the fruit surface.
Whole tree	Infected trees may be stunted and have a disproportionate amount of horizontal growth or sprawling lateral low limbs. Trees with visible sunblotch symptoms often have reduced yields.

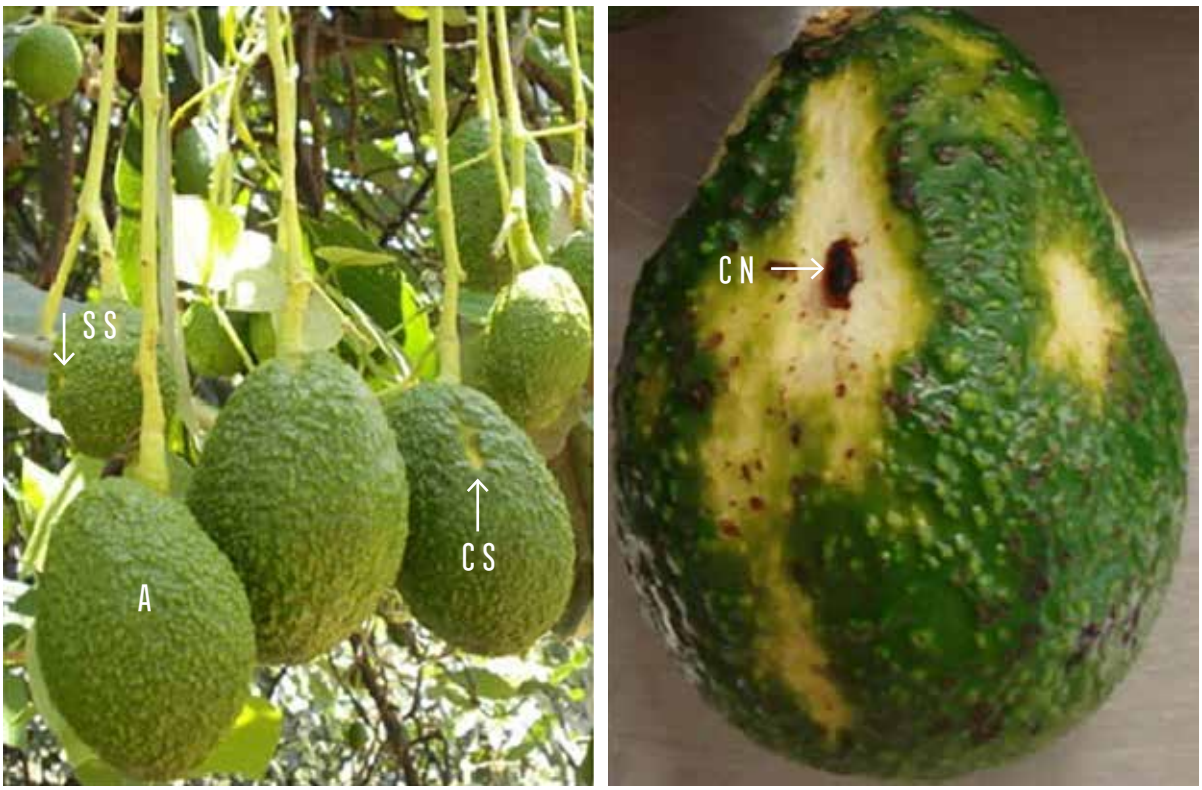


Figure 99 — Avocado sunblotch viroid (semanticscholar.org)

FAVORABLE CONDITIONS TO THE INFESTATION

TYPE	FAVORABLE CONDITION	IMPACT / EXPLANATION
Temperature, rainfall and humidity	Environmental stress (moisture stress and elevated temperatures).	Favour development of the disease.

MONITORING

Look for fruit drop and marking of mature fruit, discrete spots on the leaves along the midrib, which may merge into star-like patterns. As disease progresses leaves become distorted and stunted. Symptoms on fruit appear as corky, raised brown to purplish brown spots which enlarge to form large rough areas.

CONTROL BY GOOD CULTURAL PRACTICES

ACTION	JUSTIFICATION) AND/OR DESCRIPTION	EFFECT/IMPACT
PRE-PLANTING CHOICES		
Sanitation Disinfect tools used in nursery operations with 1.5% sodium hypochlorite	Prevent spread from infected to uninfected seedling.	Reduce infective inoculum.
Use resistant root stocks where available	Prevents transmission and development of the disease.	Excludes the viroid from planting materials.
PREPARING THE PLOT (ORCHARD)		
/	/	/
PLANTING		
Use clean planting material/source from certified nurseries	Prevents transmission and development of the disease.	Effective and environmentally sustainable.
ORCHARD MANAGEMENT		
Field sanitation	Promptly remove symptomatic trees from the orchard and kill the stumps.	Reduce inoculum.

NB: Although there is no cure for infected trees, sanitation practices may have a significant impact on avoiding the spread of this pathogen (Saucedo Carabez *et al.*, 2019).

CONTROL WITH PLANT PROTECTION PRODUCTS

CHEMICAL CONTROL

— **Fludioxonil**

Mode of action: broad-spectrum fungicide which is non-systemic with a long residual activity.

Application: first application during early bloom and repeat on 7–10 day intervals if conditions remain favourable for disease development. Always refer to label instructions for use.

Resistance management: Alternate after two applications with another fungicide with different mode of action for two applications. Do not exceed 4 applications per year.

6.9. SUMMARY TABLE OF ACTIVE INGREDIENTS/BIOLOGICAL AGENTS AGAINST AVOCADO PESTS

ACTIVE INGREDIENT OR BIOLOGICAL AGENT	GROUP MODE OF ACTION	*BACTROCERA DORSALIS* (ORIENTAL FRUIT FLY)	*CERATITIS CAPITATA* (MEDITERRANEAN FRUIT FLY)	*CERATITIS ROSA* (NATAL FRUIT FLY)	*CERATITIS COSYRA* (MANGO FRUIT FLY)	*THAUMATOTIBIA LEUCOTRETA* (FALSE CODLING MOTH)	*HELIOTHRIPS HAEMORRHOIDALIS* (BLACK TEA THRIPS/GREENHOUSE THRIPS)	*SELENOTHRIPS RUBROCINCTUS* (RED-BANDED THRIPS)	*ALEURODICUS DISPERSUS* (SPIRALING WHITEFLY)	*TRIALEURODES VAPORARIORUM* (WESTWOOD WHITEFLY/GREENHOUSE WHITEFLY)	*EUWALLACEA PERBREVIS* (TEA SHOT-HOLE BORER)	*EUWALLACEA FORNICATUS* (POLYPHAGOUS SHOT-HOLE BORER)	*XYLOSANDRUS COMPACTUS* (SHOT-HOLE BORER)	*PSEUDACYSTA PERSEAE* (LACE BUG)	*NEZARA VIRIDULA* (GREEN STINK BUG)	*HEMIBERLESIA LATANIAE* (LATANIA SCALE)	*COCCUS HESPERIDUM* (BROWN SOFT SCALE)	*POLYPHAGOTARSONEMUS LATUS* (BROAD MITE)	*PRATYLENCHUS VULNUS* (WALNUT ROOT LESION NEMATODE)
Abamectin	6						X	X										X	
Acetamiprid	4a					X	X	X	X	X					X	X	X		
Acetamiprid + lambda-cyalothrin	4a + 3					X													
Amblyseius spp.	predator								X	X								X	
Aphytis chrysomphali	parasite															X			
Bacillus Thurigiensis	bm02					X													
Beauveria bassiana	unf: fungal agent of unknown or uncertain moa	X	X	X	X	X			X	X	X	X	X	X					
Biosteres arisanus/ Opius oophilus	parasite	X	X	X	X														
Buprofezin	16								X	X						X	X		
Callimerus sp	predator												X						
Chilocorus spp.	predator															X	X		
Chlorantra-niliprole	28					X													
Cypermethrin	3a					X							X						
D. protuberans	parasite												X						
Dazomet	8f																		X
Deltamethrin	3a	X	X	X	X	X	X	X											
Dendrosoter enervatus	parasite												X						
Emamectin benzoate	6					X					X								

ACTIVE INGREDIENT OR BIOLOGICAL AGENT	GROUP MODE OF ACTION	*BACTROCERA DORSALIS* (ORIENTAL FRUIT FLY)	*CERATITIS CAPITATA* (MEDITERRANEAN FRUIT FLY)	*CERATITIS ROSA* (NATAL FRUIT FLY)	*CERATITIS COSYRA* (MANGO FRUIT FLY)	*THAUMATOTIBIA LEUCOTRETA* (FALSE CODLING MOTH)	*HELIOTHRIPS HAEMORRHOIDALIS* (BLACK TEA THRIPS/GREENHOUSE THRIPS)	*SELENOTHRIPS RUBROCINCTUS* (RED-BANDED THRIPS)	*ALEURODICUS DISPERSUS* (SPIRALING WHITEFLY)	*TRIALEURODES VAPORARIORUM* (WESTWOOD WHITEFLY/GREENHOUSE WHITEFLY)	*EUWALLACEA PERBREVIS* (TEA SHOT-HOLE BORER)	*EUWALLACEA FORNICATUS* (POLYPHAGOUS SHOT-HOLE BORER)	*XYLOSANDRUS COMPACTUS* (SHOT-HOLE BORER)	*PSEUDACYSTA PERSEAE* (LACE BUG)	*NEZARA VIRIDULA* (GREEN STINK BUG)	*HEMIBERLESIA LATANIAE* (LATANIA SCALE)	*COCCUS HESPERIDUM* (BROWN SOFT SCALE)	*POLYPHAGOTARSONEMUS LATUS* (BROAD MITE)	*PRATYLENCHUS VULNUS* (WALNUT ROOT LESION NEMATODE)
Encarsia spp.	parasite								X	X									
Eretmocerus spp.	parasite								X	X									
Fatty acids of potassium salts	UNE: botanical essence including synthetic extracts and unrefined oils with unknown or uncerain MOA						X	X	X	X									
Fenpyroximate	21A																	X	
Fopius arisanus	parasite	X	X	X	X														
H. coccophagus	parasite															X	X		
Heterorhabditis amazonensis	nematode	X	X	X	X														
Lambda-cyalothrin	3					X									X				
Malathion	1B	X	X	X	X	X	X	X	X	X									
Maltodextrine	-					X													
Metarhizium anisopliae	UNF: fungal agent of unknown or uncertain MOA	X	X	X	X	X													
Methoxyfenozide	18					X													
Montanoa bipinnatifida	botanical													X					
Neem extract (azadirachtin)	UN: compound of unknown or uncertain MOA	X	X	X	X	X	X	X	X	X					X				

ACTIVE INGREDIENT OR BIOLOGICAL AGENT	GROUP MODE OF ACTION	*BACTROCERA DORSALIS* (ORIENTAL FRUIT FLY)	*CERATITIS CAPITATA* (MEDITERRANEAN FRUIT FLY)	*CERATITIS ROSA* (NATAL FRUIT FLY)	*CERATITIS COSYRA* (MANGO FRUIT FLY)	*THAUMATOTIBIA LEUCOTRETA* (FALSE CODLING MOTH)	*HELIOTHRIPS HAEMORRHOIDALIS* (BLACK TEA THRIPS/GREENHOUSE THRIPS)	*SELENOTHRIPS RUBROCINCTUS* (RED-BANDED THRIPS)	*ALEURODICUS DISPERSUS* (SPIRALING WHITEFLY)	*TRIALEURODES VAPORARIORUM* (WESTWOOD WHITEFLY/GREENHOUSE WHITEFLY)	*EUWALLACEA PERBREVIS* (TEA SHOT-HOLE BORER)	*EUWALLACEA FORNICATUS* (POLYPHAGOUS SHOT-HOLE BORER)	*XYLOSANDRUS COMPACTUS* (SHOT-HOLE BORER)	*PSEUDACYSTA PERSEAE* (LACE BUG)	*NEZARA VIRIDULA* (GREEN STINK BUG)	*HEMIBERLESIA LATANIAE* (LATANIA SCALE)	*COCCUS HESPERIDUM* (BROWN SOFT SCALE)	*POLYPHAGOTARSONEMUS LATUS* (BROAD MITE)	*PRATYLENCHUS VULNUS* (WALNUT ROOT LESION NEMATODE)
Neoseiulus barkeri	predator																	X	
O. californicus	parasite														X				
Oligosita sp.	parasite													X					
Ooencyrtus johnsoni	parasite														X				
Orius thripoborus	predator						X												
Paecilomyces fumosoroseus	UNF: fungal agent of unknown or uncertain MOA								X	X									
Potassium soap	-						X	X										X	
Predatory thrips	predator													X					
Pyrethrin extract	3A	X	X	X	X		X	X											
Pyridazinone	-																	X	
Pyriproxyfen	7C															X	X		
Pythium oligandrum	fungi																		
quercivorol	attractant													X					
Spinetoram	5					X	X	X											
Spinosad	5	X	X	X	X	X	X	X											
Spiromesifen	23																	X	
Spirotetramat	23																	X	
Steinernema carpocapsae	nematode	X	X	X	X														
Sulphur	-						X	X										X	
T. urichi	parasite														X				
Tebufenozide	18					X													
Teflubenzuron	15					X													
Telenomus podisi	parasite														X				

ACTIVE INGREDIENT OR BIOLOGICAL AGENT	GROUP MODE OF ACTION	*BACTROCERA DORSALIS* (ORIENTAL FRUIT FLY)	*CERATITIS CAPITATA* (MEDITERRANEAN FRUIT FLY)	*CERATITIS ROSA* (NATAL FRUIT FLY)	*CERATITIS COSYRA* (MANGO FRUIT FLY)	*THAUMATOTIBIA LEUCOTRETA* (FALSE CODLING MOTH)	*HELIOTHRIPS HAEMORRHOIDALIS* (BLACK TEA THRIPS/GREENHOUSE THRIPS)	*SELENOTHRIPS RUBROCINCTUS* (RED-BANDED THRIPS)	*ALEURODICUS DISPERSUS* (SPIRALING WHITEFLY)	*TRIALEURODES VAPORARIORUM* (WESTWOOD WHITEFLY/GREENHOUSE WHITEFLY)	*EUWALLACEA PERBREVIS* (TEA SHOT-HOLE BORER)	*EUWALLACEA FORNICATUS* (POLYPHAGOUS SHOT-HOLE BORER)	*XYLOSANDRUS COMPACTUS* (SHOT-HOLE BORER)	*PSEUDACYSTA PERSEAE* (LACE BUG)	*NEZARA VIRIDULA* (GREEN STINK BUG)	*HEMIBERLESIA LATANIAE* (LATANIA SCALE)	*COCCUS HESPERIDUM* (BROWN SOFT SCALE)	*POLYPHAGOTARSONEMUS LATUS* (BROAD MITE)	*PRATYLENCHUS VULNUS* (WALNUT ROOT LESION NEMATODE)
Telsimia nitida	ladybird beetle															X	X		
Tetrastichus sp	parasite												X						
Thripobius semiluteus	parasite						X												
Trichoderma spp.	biofungi-cide																		
triflumuron	15					X													
Trissolcus basalis	parasite														X				
Trissolcus brochymenae	parasite														X				
Typhlodromus spp.	predator								X	X									
Verbenone	deterrent													X					
Verticillium	fungi								X	X									X
Xylebororum	parasite												X						

6.10. SUMMARY TABLE OF ACTIVE INGREDIENTS/BIOLOGICAL AGENTS AGAINST AVOCADO DISEASES

ACTIVE INGREDIENT OR BIOLOGICAL AGENT	MODE OF ACTION	ANTHRACNOSE (*COLLETOTRICHUM GLEOSPORIOIDES*)	FRUIT ROT (*DOTHIORELLA*)	PHYTOPHTHORA ROOT ROT (*PHYTOPHTHORA CINNAMOMIC*)	VERTICILLIUM WILT OF LUCERNE (*VERTICILLIUM ALBO-ATRUM*)	CERCOSPORA SPOT /SPOT BLOTCH (*PSEUDOCERCOSPORA PURPUREA*)	STEM END ROTS (*LASIODIPLODIA THEOBROMAE, NEOFUSICOCCUM PARVUM, NECTRIA PSEUDOTRICHIA, AND FUSARIUM SOLANI*)	AVOCADO SCAB (*SPHACELOMA PERSEAE*)	BACTERIAL CANKER (*XANTHOMONAS CAMPESTRIS*)	AVOCADO SUNBLOTCH VIROID (*ASBVD*)
Azadirachtin	UN: compound of unknown or uncertain MOA	x	x							
Azoxystrobin	11	x	x			x		x		
Bacillus amyloliquefaciens (strain QST 713)	BM02	x	x				x			
Bacillus subtilis	BM02	x	x			x		x	x	
Captan	M04					x		x		
Copper based fungicides	M01	x	x			x		x	x	
Cypronil-fludioxonil	0	x	x							
Fludioxonyl + azoxystrobine	12	x	x				x			x
Fluopyram + tebuconazole	7;3	x	x							
Fluopyram + tryfloxystrobin	7;11	x	x							
Fosetyl	0			x						
Mefenoxam	4			x						
Metalaxyl	4			x						
Methyl bromide	1				x					
Metiram	M03	x	x							
Prochloraz	3	x	x			x		x		
Pseudomonas putida	BM02			x						
Pythium oligandrum	fungi				x					
Thiabendazole	1					x		x		
Trichoderma spp.	BM02	x	x				x			

7

AVOCADO HARVESTING AND POSTHARVEST HANDLING

7.1. AVOCADO HARVESTING

7.2. INTRODUCTION

Avocado is a climacteric fruit that shows an increase in respiration and ethylene production during ripening. Ripening starts only after the mature fruit is detached from the plant. The fruit quality is influenced by maturity stage, time after harvest, temperature and humidity. Timely harvesting and postharvest handling is crucial in maintain the quality of the fruits from the field to the market outlets and eventually to the consumers.

7.3. COMMERCIAL QUALITY

The avocado fruits may be mature for picking but not ready to eat. As such, the practice is that they are softened off the tree before they are ready for consumption. The softening process usually takes from a few days to a week and is depended on the degree of maturity, variety and storage temperature.

When the fruit on the tree begins to mature, it usually loses some of its "bloom" and changes color. Small, rusty brown specks may develop on some varieties and other fruit may become somewhat duller in appearance. Internally, the seed coat turns from ivory to dark brown upon maturity.

Storing fruits is difficult hence the best place to keep avocado fruit until used is on the tree. The period for holding the fruits on the tree varies with variety ranging from some weeks to several months. Harvesting period of avocado can be extended by picking only a few fruits at a time as per the need.

7.4. COMMERCIAL STANDARDS

Common commercial standards require fruits to reach 8% oil content before harvesting. Purple varieties should be allowed to color fully before harvest. Other types discolor quickly and hence require to be consumed immediately.

7.5. CONSUMER PREFERENCES

In many countries, avocado is mainly consumed as a fresh fruit. In countries like Mexico, avocado is considered a traditional food and the consumers may not focus mainly on the quality of the fruit but rather the prevailing market low prices. In cases where the demand outstrips the supply, quality aspects of the avocado fruits by consumers are compromised. Generally, consumers prefer fruit that is already dark in the peel and soft to the touch (FAO Avocado Postharvest Compendium, 2004). Other varieties remain green even on exhibiting softening characteristics. It is worth noting that some field conditions during harvesting may cause softness of the fruits along the maturity quality *e.g.* slight mechanical damage, some lesions from the field such as avocado blight, anthracnose etc. The consumer preferences in non-

producer countries that import avocado may vary. Generally, consumers look for the following aspects (Morales *et al.*, 2000).

- Medium size (275 g approximately)
- 3/4 to fully ripen
- No insect damage
- No toxic chemical residues

Figure 101 — An ideal avocado fruit image at the right ripening stage

Organic avocado is becoming an important part of the national marketing strategy, because of the increasing number of consumers and producers that are concerned about the environment. The industries of developing countries can benefit from the production of oil, cosmetics, and guacamoles elaborated from organic avocado, while consumers can benefit from clean and free of residue fruit (Quintero-Sánchez, 2001). It is also important to note that sometimes the quality standards may depend on the ultimate use of the fruit in other recipes around the world other than consuming the fruit direct.

7.6. MATURITY INDICES FOR HARVESTING AVOCADOS

Maturity indices for harvesting avocados are important in order to prevent harvesting of immature or over mature fruit and to reduce postharvest losses. Harvesting immature fruit can result in inadequate ripening, resulting in an inferior fruit quality. Avocado fruits are highly variable, and even those graded for similar size and appearance do not behave in the same manner after harvest. This is particularly problematic for those involved in sales to the "ready-ripe" market. These operations are faced with a high variation in the rate of ripening within a consignment, causing logistical difficulties. With increasing maturity, the avocado oil content in the fruit increases while the water content or dry matter decreases. On the other hand, their oil content is also influenced by cultivar type, cultural practices and environmental conditions.

Generally, two quantitative indices have been adopted by the avocado industry to harvest their fruit for export or domestic markets i.e. the oil and moisture content indices.

The infrared spectroscopy technique has been used to measure Hass variety fruit water content and has been found that fruits sorted out using this method based on time to ripen, results in less variation of ripening in consignments.

Simple techniques have been used to determine fruit maturity. One involves picking one of the larger fruits and keeping it at room temperature until it softens. The fruit will be mature and ready for picking if it softens to good consistency, is not tough and leathery or bitter, no shrinking or shrivels, and is good to eat. Once this is determined, the `remaining fruits in the field can now be picked. Sometimes "off bloom" fruits may set earlier than the season crop with larger and more advanced mature fruits. These are picked and used earlier than the regular crop.

Oil content maturity index is recommended for cultivars that are rich in oil content whereas dry matter is also used for other specific cultivars. Other complementary indices such as flesh softening, that is related to skin color changes, have been included in the maturity index for Hass. As indicated earlier, the green skin color at immature stage changes to purple which denotes the mature stage of most cultivars.

Figure 102 — Simple apparatus (Microwave and a digital weighing scale) used to determine maturing level of fruits using dry matter content method

7.7. PHYSIOLOGICAL MATURITY

Countries that import avocadoes require that the fruits to be physiologically mature when they arrive in the market. This ensures that the fruits ripen correctly once they arrive in the destination countries. The following may occur if the physiological maturity requirement is not adhered to that may have cost and quality implications resulting to losses:

- The physiologically "under-mature" avocados take too long to ripen and have a bland taste due to insufficient oil content.
- The immature fruits are more likely to develop stem end rot disease. However, the avocados must not be ripe, since ripe fruits have a very limited shelf life, quickly become too ripe to sell, and rapidly develop rots.
- Unripe (hard) fruits can be stored under refrigeration for a week or two, and are ripened by European traders according to market needs.

It is thus crucial to accurately determine the maturity level of avocados destined for export. Please bear in mind a few important facts:

- Fruit oil contents increase as avocados become more physiologically mature on the tree. Thus, early season avocados are more watery and have a lower dry matter content; and later season avocados have a higher dry matter content and are richer in taste Fruits with less sunlight exposure (*e.g.* hanging inside the tree canopy) will be less mature.
- Small fruits are not necessarily less mature than big fruits.
- The fruit harvesting calendar is not a good or accurate method for determining fruit maturity level for other climatic factors can delay or hasten the harvesting time.
- Not all fruits on the same tree will be at the same stage of physiological maturity, so selective picking is necessary.

The purpose of maturity testing is to determine when the orchard will be ready for harvest and by in-season monitoring, to determine when harvesting or the export market should be terminated.

7.8. DAYS TO HARVEST AFTER PLANTING AND FLOWERING

Several research findings have demonstrated that it takes about three to four years before the planted avocado seedlings can start bearing fruits. It takes even longer if the tree was from planting an avocado seed which can take anywhere from five to 13 years before the tree is mature enough to set fruit. With normal annual climatic conditions, it takes up to eight months between flowering and harvest of edible fruits. It is however important to note that growing conditions and local environment may affect the time for the trees to set fruits from the time they flower.

7.9. OVER MATURITY

A fruit is considered ripe when it is suitable for immediate consumption. As such, a fruit is considered mature when the fruit has reached a sufficient stage of physiological development that it will ripen correctly at room temperatures within 10 days of harvest. Avocado fruits suffer internally if the fruits are left to overstay on the trees past their prime period without being harvested. tree to mature past its prime period, your fruits can suffer internally.

Some varieties take 6–8 months to ripen from flowering while others take up to 12–18 months to ripen after flowering depending on the prevailing climatic factors. It has been observed that some fruits continue enlarging on the tree even after maturity. Under normal circumstances, heavy avocado fruits will drop from the tree and cease their maturing process. The softening and ripening process will start for the fruits are no longer attached to the tree. However, strong fruits that remain on the tree will begin seed growth. Internal, large seeds will create sprouts that destroy the surrounding fruit by cutting into its flesh. As such, choosing the correct time to harvest by pulling a fruit and testing its ripening time within eight days will ensure that your avocados will not be internally damaged from dropping or internal seed growth.

It is important to pick avocados when they are mature, as immature fruit will shrivel and not ripen properly. This adversely affects the quality of the harvested fruits leading to massive losses due to rejections by dealers and consumers. This also affects the reputation of the exporting country not forgetting the losses incurred by producers.

7.10. HARVESTING

Mechanical damage must be avoided during harvesting. Such damages include scratches, cuts and abrasions can affect the fruit appearance and be an entry point for postharvest pathogens that cause decay during storage and transportation. Bruising and scratches can also cause localized fruit softening. Usually, the common method of harvesting avocado fruit is by using a soft picking bag attached to a long stick or pole for the gentle detaching the fruit from the tree.

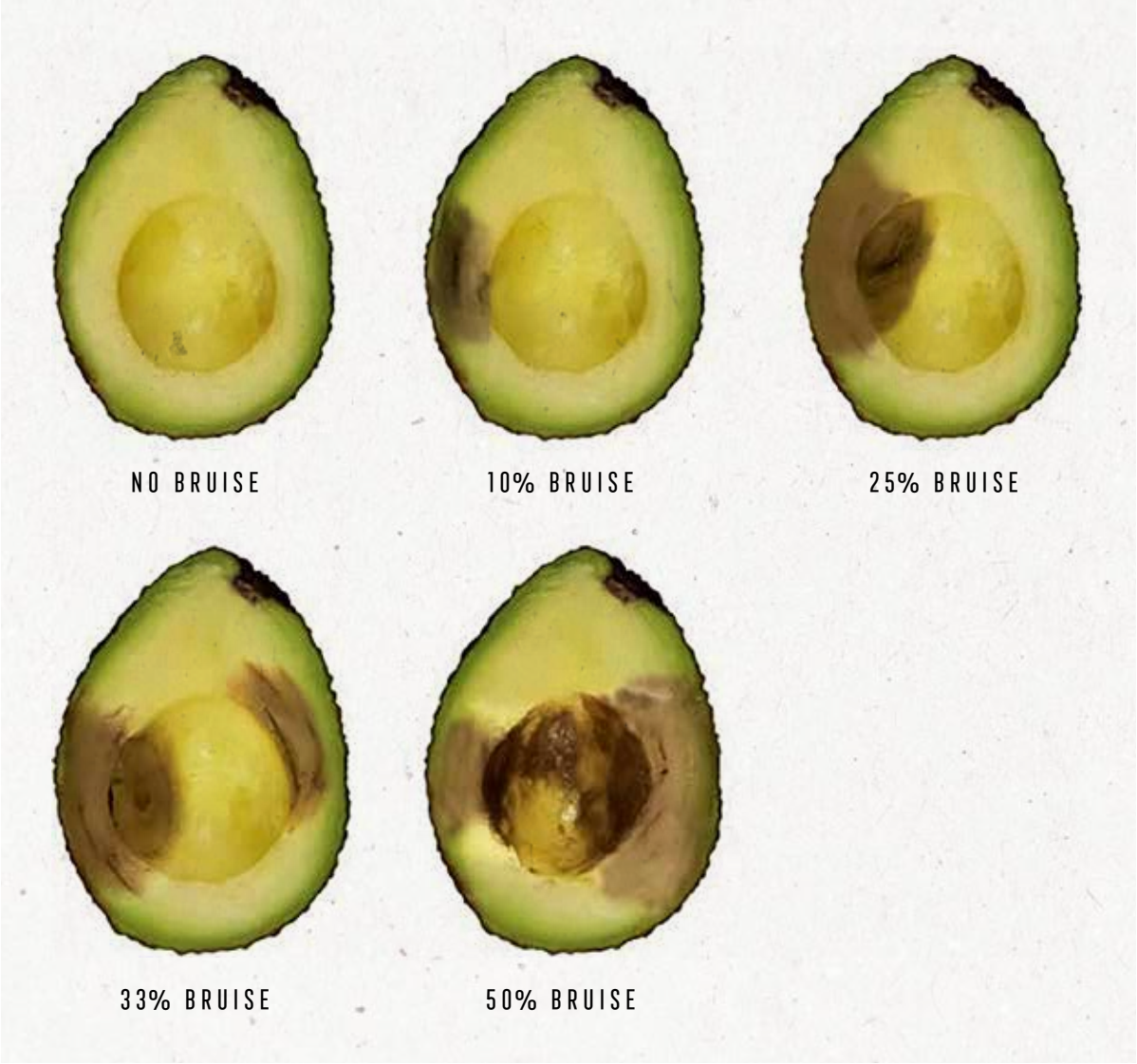


Figure 103 — Physical damage resulting to quality issues of the fruits that occurs due to poor harvesting methods

The detached fruits settle in the bags and are placed in the crates. This process prevents damages of the fruits both at harvesting from the tree and placement in the creates. Ladders can be used to facilitate handpicking or still using the poles for taller trees where one cannot reach them easily from the ground.

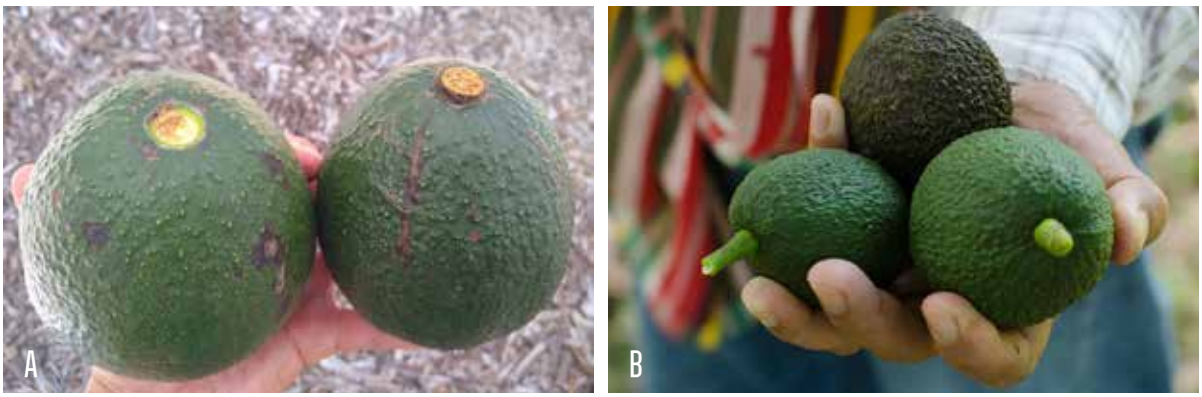


Figure 104 — Harvesting method of leaving a short stalk on the fruit in B unlike no stalks in A. The image on the right shows the correct size of the stalk

A clipper or knife is attached to the end of the picking poles with a catching or collection bag earlier mentioned made preferably of cloth. It is strongly advisable that the fruits are moved immediately to the shade. This will help in preventing exposure to the sun hence reducing rapid weight loss due to moisture loss. The best practice is to ferry the avocado fruits to the pack house within two hours of picking to facilitate the subsequent post-harvest handling procedures.

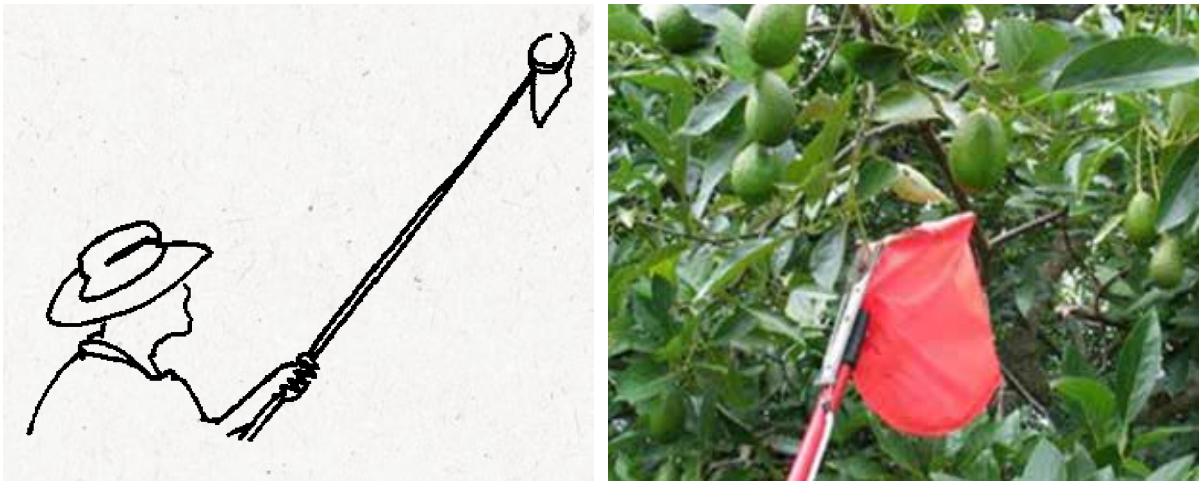


Figure 105 — Harvesting pole with a cloth bag attached to the end where the fruit is collected when detached from the tree.

Harvesting techniques can affect the post-harvest fruit quality. Though the clippers are suitable for removing fruit from trees, it is recommended that about 1 cm of the pedicel should be left attached to the fruit.

Figure 106 — Harvesting clipper fitted with a collection basket

For Fuerte, it is recommended that the pedicels are removed manually while Hass variety can be snap-picked without causing an undesirable effect on their fruit quality. Avoid harvesting avocado fruits in wet weather for water droplets on the fruit surface can accelerate the incidence of postharvest diseases during distribution and storage of the fruits. Lenticels damage to the fruits of both Hass and Fuerte varieties are more pronounced in fruits picked it wet conditions compared to fruit picked in dry weather. However, the lenticel damage to Hass fruits rarely affects the fruit quality for the damage is hidden in the purple color background of the ripened fruits. Fruits picked early in the harvesting season generally exhibit higher lenticel damage than the fruits picked in the season.

Harvesting in wet weather can also increase incidences of vascular browning of the fruits compared to those harvested in dry weather. "Hass" fruits picked during wet conditions and late in the season have recorded high incidences of vascular browning compared to the fruit picked during dry weather conditions or early in the season. Fruits that are picked late especially from those grown in warmer areas tend to ripen much faster hence have a shorter shelf life.

Harvesting avocado needs care and precision with use of right equipment with the right weather and handling procedures. Damage during harvesting affects the quality and shelf life of the harvested fruits.

Figure 107 — Crates for collecting fruits in the field during harvesting.

7.11. HYGIENE

The European market is particularly sensitive on the food quality standards hence growers and exporters should make sure they meet the food safety guidelines. Strict adherence to good hygiene practices along the value chain is important to ensure that fruit handlers, containers and the vehicles that carry the fruits are clean and meet the food safety standards. The EU is very strict on criteria and legislation on the acceptable level of pesticide residues on fresh produce. Kenyan avocados are largely grown without pesticides but it is important to minimize the possibility of exposure to pesticide residues. It is however prudent for avocado exporters to routinely analyze the produce for pesticide contamination to fully comply with importers MRLs requirements. Hygiene and food safety This helps in avoiding postharvest fruit diseases and human guarantee safety of consumers due to microbial contamination. Thus, customer protection as well as the reputation of avocado producers, trading and export companies.

Figure 108 — Disinfecting harvesting tools before the harvesting process and between each tree

Incorrect or inappropriate orchard management and pre-harvest treatments, as well as the manner in which the avocados are harvested and handled, greatly influence ripe fruit quality.

8

POST HARVEST HANDLING

8.1. FIELD HANDLING

The avocado fruit must be carefully transferred from the picking bag after harvesting into the crates in in the field to avoid mechanical injuries, especially bruising. Some means of measuring of size or weight in the field using basic equipment is recommended. Some pickers improvise a plywood with holes of recommended diameter worn around the neck.

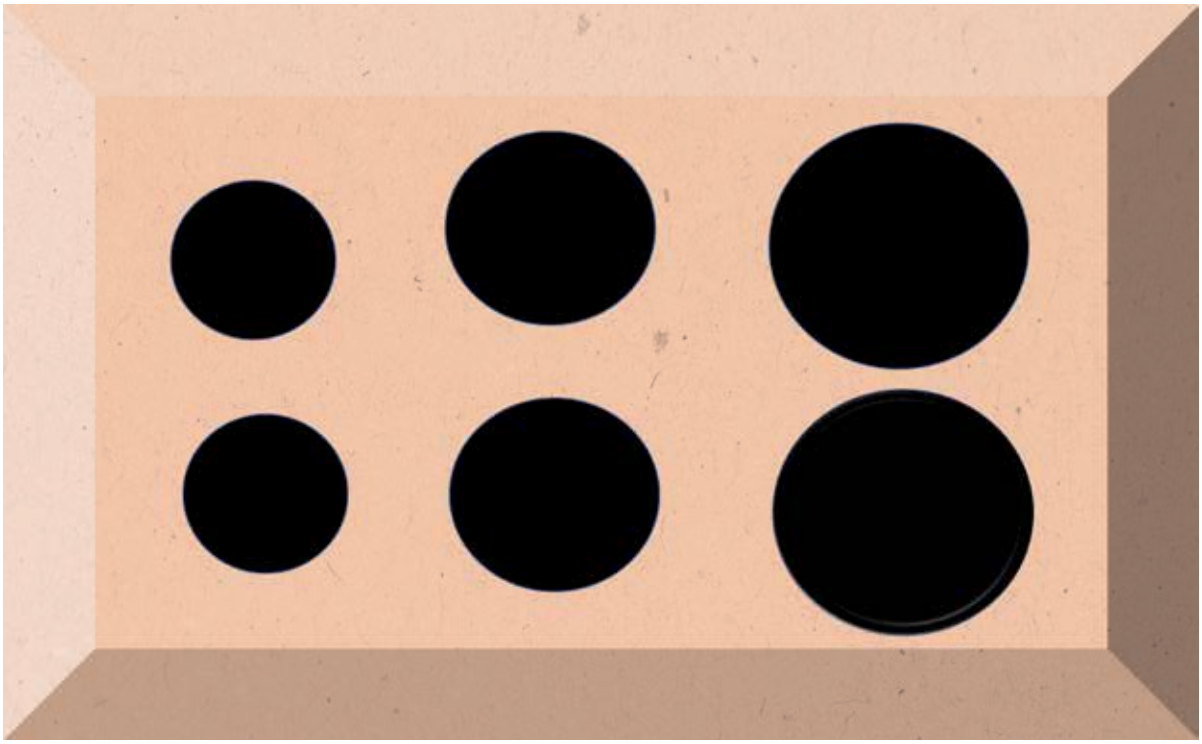


Figure 109: — An illustration of a plywood with different sizes of holes used to sort fruit sizes during harvesting

Avoid placing fruits on the ground to prevent them to come to direct contact with the soil. This will prevent contamination with foodborne pathogens that thrive in the soil like *Listeria monocytogenes*. The crates or containers for collecting the fruits in the field should not be overfilled to avoid pressure on the fruits at the bottom of the containers. The crates/containers should be placed in a shaded area and protected from direct sun which may shorten the shelf life of the fruits by accelerating the ripening process.

The filled crates and other used containers are placed strategically in such a way that they can be accessed easily for loading on transportation means to the pack houses. Wooden crates measuring 119 × 119 × 61 cm are used but shallow ones with a depth of 35.5 cm are more preferred ease of handling in the field and a reduction in the buildup of heat from over stacking. Improved ventilation and reduced bruising is realized with these type of crates.

8.2. TRANSPORT TO THE PACKHOUSE

It recommended that the pack houses should not be very far from the harvesting sites to reduce damage during transportation.

- The filled labelled avocado crates are loaded onto pick-up vehicles or lorries for transportation to the packhouse. Labelling is important for traceability.
- The fruits should not be exposed to the sun in the transportation vehicles hence covering with 80% shade-cloth or a fabric tarpaulin / canvas is recommended for vehicles without a roof.
- Plastic sheets should not be used for the create warm and humid environment that accelerates ripening and sometimes fungal infections.
- Avoid the use of banana leaves to cover the crates as they produce ethylene gas which accelerates avocado ripening and thereby reduces shelf-life.
- The harvested fruits should be transferred to packhouse within six hours of harvest.
- The trucks/pickups carrying the produce should be driven carefully on rough roads to minimize damage during transportation to the packhouse.

Figure 110 — The correct way of transporting avocado fruits from field to pack house in crates and stacked onto each other in a truck

8.3. PACKHOUSE

The packing-house facility system integrates components that function together in preparing the produce for the final market. The packhouse system components include raw materials, equipment, utilities, technologies and personnel. Each of these components affects the final quality of the fresh produce being handled.

The packing-house also serves as a quality management control point for quality assurance of the produce being prepared for supply to the consumers. The consumers concern and requirements for food safety and quality demands that the packhouses offer suitable mechanisms to minimize microbial, chemical and physical contamination that may ultimately compromise the food safety and quality standards.

Figure 111 — Avocado Packhouse reception, handling and packaging

8.3.1. PACKHOUSE RECEPTION OF FRUITS

(Adopted from the COLEAD practical guide: Good practices for harvest and post-harvest handling of avocado, 2019)

i. The fruit is received, weighed, and unloaded from the trucks

ii. Upon delivery to packhouse, the crates should be transferred immediately to a cool, shaded area inside the packhouse.

iii. Packhouse reception staff should verify the crates and the condition of the fruits received. Initial assessment of fruit quality on arrival is important for subsequent steps.

iv. The staff should confirm the delivered fruits are of the same variety and they are not mixed. And that only fruits of the same cultivar have been delivered.

v. Packhouse reception staff should control the presence, severity and percentage incidence of:

— insect or pest-damaged fruits.

— diseased fruits (anthracnose, stem-end rot, etc.).

— fruit injuries caused by rough handling during harvest or transport (*e.g.* cuts or gashes to fruits, fingernail scratches).

— fruits without pedicels ("snap-picked" fruits).

— lenticel damage

8.3.2. SORTING AND GRADING

At the packhouse, fruit from the orchard is sorted and graded according to the following commonly used quality criteria for grading avocados: size, skin color, and the absence of cuts or wounds, blemishes, insect damage and spray residue. Moreover, after ripening, the fruit must be free from diseases (anthracnose and stem-end rot), physiological disorders (grey pulp, vascular browning) and bruising. Fruit quality is determined by its freedom from insect, wind or hail marks hence any fruits with the aforementioned damage are sorted out.

The selection is carried out manually or with the help of machines, and considering the shape, size, and sanitary characteristics of the fruit, as well as all the defects caused by insects, rodents, mechanical mishandling, and illness (viruses, bacteria and fungi). The selection criteria also depend on the final destination of the fruit.

Figure 112 — Fruits sorted using machine in the pack house (left) and graded according to variety, size and same maturity stage

8.3.3. POSTHARVEST TREATMENT

Other important causes of these loses also include desiccated and over-ripe fruit, infection by postharvest diseases like anthracnose and stem-end rots, physiological disorders, unfavorable storage temperatures and pest damage. The fruits affected by these factors may lead to reduced nutritional quality, taste and texture.

In some establishments, the fruit is cleaned with rotating brushes, before selection is done. The fruits can be treated with a spray Sportak (prochloraz) for the control of anthracnose and stem-end rot within 24 hrs. of delivery. Other alternatives approved by Pest Control Products Board (PCPB) such as Fludioxonil and Thiabendazole can also be considered for post-harvest treatment of avocado for they present low risks to food safety.

8.3.4. PRE-COOLING

Thorough cooling of the avocado fruit is highly recommended following harvest to remove the field heat as much as possible. Generally, pre-cooling operation is done after packaging. This slows down the fruit metabolic rate, ethylene gas production, loss of texture, fruit ripening and onset of fungal infections.

Pre-cooling is of prime importance for the shelf life of avocado (Woolf *et al.*, 2003). It diminishes or slows the metabolic rate, ethylene synthesis and its action on the fruit, loss of texture, fungal infections, fruit ripening, and conditions the fruit for preservation at low-temperatures (Hofman *et al.*, 2003; Hofman *et al.*, 2002a). It is advisable to carry out precooling in the first six hours of fruits delivery. All field operations should not allow the internal fruit temperatures to reach 26°C i.e. during harvesting, field handling and transportation to the packhouses.

The freeze-blast method is the best suited for avocado pre-cooling since regular refrigeration in a cold room takes long to drop the produce temperatures due to the high heat levels from the field. It is carried out until the temperature in the fruit reaches 6–7°C for “Fuerte” and “Hass”.

Figure 113 — Freeze-blast cooling of avocado fruits in a cold room (left) and temperature determination using thermos probe (right)

It is worth noting that though precooling is recommended, it is not a general practice and, in many cases, grading and packing is done once the fruits are received from the field. Chilling injury may lead to reduced retail quality especially when the fruits are subjected to fluctuating temperatures.

8.3.5. FRUIT RIPENING

Unlike probably all other climacteric fruit, avocados do not ripen until they have fallen naturally from the tree or have been harvested (Wu *et al.*, 2011). They can remain in a mature but unripe condition on the tree for considerable periods. Ripening involves softening of the flesh and a change in skin color for certain cultivars. The rate of ripening after harvesting is determined by the harvest maturity of the fruit, the temperature and exposure to ethylene. At higher temperatures, fruit ripens unevenly, develops off-flavors and influences the development of postharvest decay.

Ripening fruit at lower temperatures, for example 15 to 20°C, can lead to significant reduction in rots compared with ripening at higher temperatures. Early season mature fruit may take 10 to 12 days to ripen at 20°C, whereas mature fruit harvested late in the season may ripen within five to six days in the same conditions.

Unripe avocados must not be stored with ethylene-producing crops if required to be in a firm unripe condition. Soft ripe fruit has a shelf life of only 3 days. Optimum ripening conditions may also vary with cultivars and harvest season. Generally, under these conditions, fruit ripens after 4 to 7 days.

8.3.6. AVOCADO PACKING AUTOMATION

Automation in the postharvest handling of agricultural produce is fast gaining ground. Recent innovations include the Speed packer which packs avocados ergonomically and efficiently without making concessions to quality.

As demand for avocados increases, there is need to adopt such efficient technologies for growers and handlers for the produce to take shorter times from packhouse delivery to the export market.

Figure 114 — Partial automation of avocado packing in a Kenyan pack house

All postharvest handling activities should focus on further reducing any physical damage to the fruits. The prescribed treatments should prevent deterioration of the quality of the fruits to meet the market quality demands.

9

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