PRE AND POSTHARVEST MANAGEMENT OF AVOCADOS

Review

Hort Innovation

Report by Dr Jenny Ekman
Applied Horticultural Research
Jenny.ekman@ahr.com.au
www.ahr.com.au

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Contents

1 Executive summary

As product progresses through the supply chain its value increases. Just as potential gains increase, so do potential losses if things go wrong.

Some estimates suggest that 60% of all the costs in horticultural production are incurred during harvest and postharvest handling and marketing. Good postharvest management of avocados is essential to ensure consumers can buy quality product and the avocado supply chain stays profitable and growing.

However, in reality, there is no pre- and postharvest. The basis of good quality product can be traced back to the way the fruit was picked, the tree on which it was grown, the rootstock it was grafted to, and even the soil preparation before planting.

This review aims to summarise the key research findings in the published literature as they relate to practical tools that growers and supply-chain members can use. This is no easy task. Simply entering the subject "avocado" into a scientific literature search engine reveals 8,750 peer-reviewed papers. A wider search of the general literature using Google Scholar lists about 150,000 results.

Clearly, much has been written about avocados! The following summarises some key points:

Pre-harvest effects on postharvest quality

Avocados can be grown in diverse climates, however these create challenges for postharvest quality. Wet weather during flowering, or variable soil moisture leading up to harvest, can result in poorer quality fruit. High temperatures can also cause damage, especially as the fruit flesh may be much warmer than the surrounding air.

Rootstocks have been shown to have major effects on postharvest quality. Results vary by location and by season, making it hard to make general recommendations. Despite this, it is clear that healthy trees produce healthy fruit. Calcium levels are particularly important to fruit quality, but increasing the amount in fruit has proven problematic.

Many of the postharvest diseases that emerge after ripening actually infect fruit while it is still on the tree. Fungicides during flowering and fruit growth can reduce infection and inoculum load.

Harvest

Avocados are unique in that fruit will not ripen on the tree. This allows picking over an extended period. However, fruit picked immature cannot ripen properly, while that picked overmature is more likely to suffer rots and disorders. Maturity is usually estimated by measuring dry matter, and there are now automated devices that make this quicker and easier.

It is widely recognised that fruit should not be picked while wet. Even irrigating trees just before harvest is enough to make the skin more susceptible to injury.

In much of the world avocados are clipped from the plant, whereas in Australia they are "snap" harvested. Snapping is quicker, but clipping can help reduce stem end rots that enter via the picking wound. Either way, it is important to avoid physical damage, and cool the fruit as soon as possible after harvest.

Pre-cooling, postharvest treatments and packing

Leaving fruit warm for more than a few hours can have significant impact much further down the supply chain. Avoiding delays in cooling will help ensure that fruit remain inhibited from ripening for as long as possible. Treating fruit with fungicides can also help manage postharvest rots, but the effects may be relatively minor. Latent infections cannot be controlled with topical fungicides, especially if application is 24 hours or more after picking.

New methods of preserving fruit include surface coatings, short heat treatments, low temperature conditioning and treatment with the ethylene inhibitor 1-MCP (SmartFresh). All of these treatments can help prevent chilling injury caused by low temperature storage. The effects of SmartFresh are perhaps the most dramatic. However, avocados need to ripen to be edible, and SmartFresh is not easily turned off.

Variability is a major issue for avocados. Systems such as NIRS (near infrared spectroscopy) may offer non-destructive grading of fruit into different maturities during packing. This could result in more evenly ripened fruit.

Cooling

Cooling after packing is critical for good quality. Delays in cooling can allow ripening processes to start. Room cooling is widely used, but is slow and allows hot and cold areas within trays and between pallets. Forced air cooling is faster, energy efficient, and ensures products cool evenly. Hydrocooling is the fastest method, but does not appear to be widely used in Australia.

Recognised best practice is to pack fruit within 24 hours of picking, then immediately forced air cool to approximately 5°C. Once product is cool, it must be kept cold. Breaks of only five hours in the cold chain increase physiological disorders and rots, especially if they occur after more than two weeks' storage. Temperature fluctuations allow condensation, so should be avoided.

Selecting the best storage temperature is challenging for avocados. Low temperatures can cause chilling injury, while high temperatures can allow product to start to ripen, with significant increases in disorders as a result.

Chilling sensitivity varies between orchards and regions, according to maturity at harvest, and over time. Optimum storage temperature recommendations therefore range from 1°C to 5.5°C, or even higher, and may change during the season. Reducing temperature in stages (preconditioning) and keeping relative humidity high can reduce the risk of chilling injury.

Other methods of extending storage life include ethylene scrubbers, controlled atmosphere (CA) storage and modified atmosphere (MA) packaging. CA has been demonstrated to have excellent effects in terms of reducing chilling sensitivity and preventing ripening during long term storage. However, cost and availability remain issues.

Ripening

Ripening in avocados is both complex and unstoppable. Commercially, ripening is usually induced by treatment with ethylene. Triggering ripening ensures it is as fast and even as possible. However, treatment has less benefit if fruit has been stored for an extended period or kept warm.

Ripening is increased in more mature fruit, as well as by moisture loss after harvest. It is thought that moisture loss is one of the key triggers for ripening.

Ripening at 15°C provides optimum quality, but good results can also be achieved at 20°C. After ripening, just sprung fruit can be cooled to 2°C, however, more advanced fruit are best stored at 5°C. Storage life is relatively short for ripening fruit, being maximised at around two weeks.

2 Pre-harvest effects on postharvest quality

While there appears to be a division between fruit production and postharvest handling, in reality no such division exists. The origin of a good quality avocado begins before the tree is even planted. The effects of rootstock, site selection and climate can be clearly observed in the quality of the harvested product.
The strong inhibition of ripening that occurs while avocados remain attached to the tree makes it unique among climacteric fruit. It should therefore be no surprise that plant nutrition and tree health also strongly affect postharvest quality. The balance of nutrients in the tree, how it is pruned and particularly the measures used to control fungal diseases have a great influence on development of rots in ripened fruit, although they are by then far removed from the environment in which they grew.

2.1 Climate and temperature

Key finding

Avocados can be grown in diverse climates so long as the weather is dry during flowering. Wet weather at any time increases the probability of disease development. Variable soil moisture leading up to harvest can also result in poorer quality fruit.

Flesh temperatures can be significantly higher than the surrounding air, particularly in sun-exposed fruit. Sunburn can occur in only a few minutes in fruit not previously adapted to high UV light conditions. Although warm temperatures during fruit development can increase disease, very high temperatures can actually make fruit more resistant to rots and chilling damage, due to formation of protective heat-shock proteins in the fruit flesh.

Climate

- All three avocado “races” – West Indian, Guatemalan and Mexican – originated in tropical latitudes. However, both the Guatemalan and Mexican ecotypes are adapted to high, cool forests. Although freezing conditions are rare, average temperatures may be less than 16°C.
- This diversity contributes to the wide range of environments in which avocados can be grown, from hot, humid areas such as Florida, to Mediterranean arid climates and down to the cold subtropics e.g. Tauranga, NZ[1].

Rainfall and water stress

- The fungi that infect avocados and cause postharvest rots are generally dispersed in water. Many fungi need wet, or at least humid, conditions in order to infect plant tissues and grow. High rainfall areas are therefore likely to have higher microbial populations than low rainfall areas.
- The anthracnose pathogen infects avocado fruit during extended wet periods. These infections remain latent in the fruit until it starts to ripen[46]. So, high rainfall is likely to result in increased latent infections of anthracnose.
- One factor that most indigenous areas for avocados have in common is a dry period during flowering. Rain during flowering prolongs the flowering period and increases the risk of anthracnose infection. There is mounting evidence that many latent infections actually

[1] Wolstenholme, BN. 2013. Ecology: Climate and Soils. In ‘The avocado: Botany, Production and Uses’, 2nd ed. Ed B. Schaffer et al. CAB International.

occur during flowering, as fungal spores land on the inflorescence and become internalised as the fruit grows[2].

- Extended flowering also results in fruit of different ages on the same tree. Such fruit has different rates of growth, with the later fruit generally growing faster than the early set fruit. This growth rate means they can overtake fruit initiated up to six weeks earlier. The result is late set fruit that are larger at harvest, but potentially less physiologically mature[3].
- Variable soil moisture in the period leading up to harvest, whether due to rain or uneven irrigation, has been variously reported to result in either faster[4] or slower[5] ripening. Either way, it seems likely that ripening time will be more variable with an increased risk of physiological disorders[4].

Temperature

- The rate of fruit development is strongly affected by temperature. So, for example, Hass can take 12 to 14 months to reach maturity in the Bay of Plenty, NZ[6] but only eight months in Bundaberg, Qld. Fast-growing fruit may be more susceptible to development of disorders, particularly chilling injury[7].
- High temperatures during fruit development are associated with a reduced risk of postharvest disease. In New Zealand, increased mean temperatures during the 40 days prior to harvest were correlated with reduced incidence of body rots[32]. Similarly, field temperatures over 30°C were associated with reduced rots and flesh discolouration in Australian Hass[8].
- The flesh and skin of avocados exposed to direct sunlight may be 6°C[8] to 15°C[11] above that of the surrounding air, with a temperature gradient of around 5–10°C between the sun exposed and shaded sides of the fruit. High temperatures such as these can induce formation of *heat shock proteins* in the avocado flesh.
- *Heat shock proteins* can protect fruit from cold damage[9] during storage as well as injury caused by postharvest heat treatments for disinfestation[10]. Woolf et al.[11] showed that Hass fruit from the outer, exposed parts of the tree were less susceptible to chilling injury when stored at 0°C than fruit from the inner, shaded parts of the tree. However, damage was still observed on the unexposed side of the outer fruit.

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[2] Demoz B, Korsten L. 2006. Bacillus subtilis attachment colonization and survival on avocado flowers and its mode of action on stem-end rot pathogens. Bio. Control. 37:68-74.
[3] Sippel AD et al. 1993. Analysis of Pinkerton avocado fruit growth. SAAGA Yearbook 1993.
[4] Kassim A, Workneh TS, Bezuidenhout CN. 2013. A review on postharvest handling of avocado fruit. African J. Agric. Res. 8:2385-2402.
[5] Kruger FJ, Magwaza LS. 2012. Does orchard soil moisture content at the time of harvest influence the post-storage ripening pattern of Hass avocado fruit? SAAGA Yearbook 35:47-53.
[6] Dixon J et al. 2003. New Zealand avocado fruit quality: The impact of storage temperature and maturity. Proc. World Avocado Congress 2003. pp. 647-652.
[7] Kruger FJ et al. 2004. Establishing appropriate maturity and fruit mineral content norms for the main avocado export cultivars. SAAGA Yearbook 2004. 27:5-10.
[8] Considine M et al. 2004. Separating high harvest temperature effects on postharvest avocado quality. Acta Hort. 687:167-174.
[9] Florissen P et al. 1996. The effects of short heat-treatments on the induction of chilling injury in avocado fruit. Postharvest Biol. Technol. 8:129-141.
[10] Woolf AB, Lay-Yess M. 1997. Pretreatments at 38°C of Hass avocado confer tolerance to 50°C hot water treatments.
[11] Woolf AB, Bowen JH, Ferguson IB. 1999. Preharvest exposure to the sun influences postharvest responses of Hass avocado fruit. Postharvest Biol. Technol. 15:143-153.

- High temperatures can result in sunburned fruit, due to a combination of high surface temperatures, high visible light, and most importantly high ultraviolet radiation. As little has 7 minutes exposure to UV light significantly increases avocado fruit respiration[12]. The effects are most severe if fruit is not previously adapted to high light conditions. Growers have reported that only a few minutes in an uncovered bin is enough to cause sun damage, although this may not be apparent until after packing.
- Temperature affects spore germination and growth of pathogens. Fungal spores are unable to germinate and penetrate the fruit if temperatures are below critical limits for growth. Spores of *Colletotrichum gloeosporioides* (anthracnose) and *C. acutatum* are unable to germinate below 20°C and 16.5°C respectively. *Phomopsis* sp. could not germinate at below 14°C. However, *Botryosphaeria parva*, a major cause of body rots in New Zealand, was able to germinate at all temperatures tested (10–30°C)[13].
- Temperature can affect shape. According to Arpaia et al., avocados grown in cooler environments tend to be rounder, whereas the same variety grown in warmer conditions is more likely to be elongated[14]. However, the opposite effect has been reported in Australia (N. Delroy pers. com.).

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[12] Glenn DM et al. 2008. Ultraviolet radiation effects on fruit surface respiration and chlorophyll fluorescence. J. Horrt Sci. Biotech. 83:43-50.

[13] Everett KR, Pak HA. 2002. Infection criteria for pathogens causing body rots in avocados. NZGA Ann Res. Rep. 2:1-7.

[14] Arpaia ML et al. 2004. Grower practices will influence postharvest fruit quality. 2nd Seminario International de Paltos. 29 September-1 October 2004, Chile.

2.2 Tree management

Key finding

Rootstocks can have a major influence on postharvest disease development. However, results are highly variable by location, seedling vs. clonal, and year by year. In general, healthy trees yield the best quality fruit, so long as vigour is not related to excess nitrogen fertilisation.

Rootstock

- In Australia, rootstock has been shown to significantly affect susceptibility to disease. This may be partly due to changes in antifungal compounds in the leaves, but also to changes in mineral uptake by the roots.
- Willingham et al.[15] found that fruit from Hass grafted onto Velvick seedling rootstock had 34% lower incidence and 82% less severe anthracnose compared to fruit from Hass grafted onto Duke seedling rootstock.
- These results were partially confirmed by Marques et al[16]. Hass grown on clonal Velvick or A-10 rootstocks in Hampton, Qld produced a higher percentage of fruit with no defects than Hass grown on clonal rootstock of Reed, Duke 7 or Hass.
- Coates[17] also reported positive results with Velvick rootstock for trees grown in Childers, Hampton and Walkamin (Qld) and Pemberton (WA). Despite variation between sites, it was concluded that rootstocks 'A10', SHSR-03' and 'Velvick' produced fruit with reduced disease levels after ripening. Fruit from these rootstocks also had a reduced ratio of N:Ca, confirming the important role of calcium in reducing disease.
- However, virtually the opposite results were achieved the following year in Pemberton, WA. In this season Velvick produced the lowest percentage of sound fruit. In Childers and Walkamin there were no differences between the rootstocks. The results suggest that benefits from rootstocks can be highly site and season specific[16].
- Results were also variable when comparing seedling to clonal rootstocks. Seedling rootstocks yielded more marketable fruit than clonal rootstocks of the same variety in some seasons, but not in others. High variability in both yield and the anthracnose development overwhelmed differences between rootstocks propagated clonally vs. by seed[18].
- An examination of Hass fruit quality in New Zealand was inconclusive as to whether rootstock affected fruit quality. In this case grafted trees were not grown in a replicated design. Rather, the researchers compared trees in commercial plantings, which had been grafted to different rootstocks. While differences in disease incidence and severity were observed, these were not consistent year by year, or between different orchards.

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[15] Willingham SL et al. 2001. Rootstock influences postharvest anthracnose development in Hass avocado. Aust. J. Agric. Res. 52:1017-1022.
[16] Marques J et al. 2011. Rootstocks affect quality of Hass avocado fruit after storage. Proc. VII World Avo. Congress. 5-9 September 2011, Cairns Australia.
[17] Coates LM et al. 2011. Effects of rootstock on avocado fruit quality – assessment of postharvest disease, major cations and biochemical traits.
[18] Dann EK et al. 2016. Rootstock selection, nitrogen and calcium influence postharvest disease in avocado. Acta Hort. 1120:391-398.

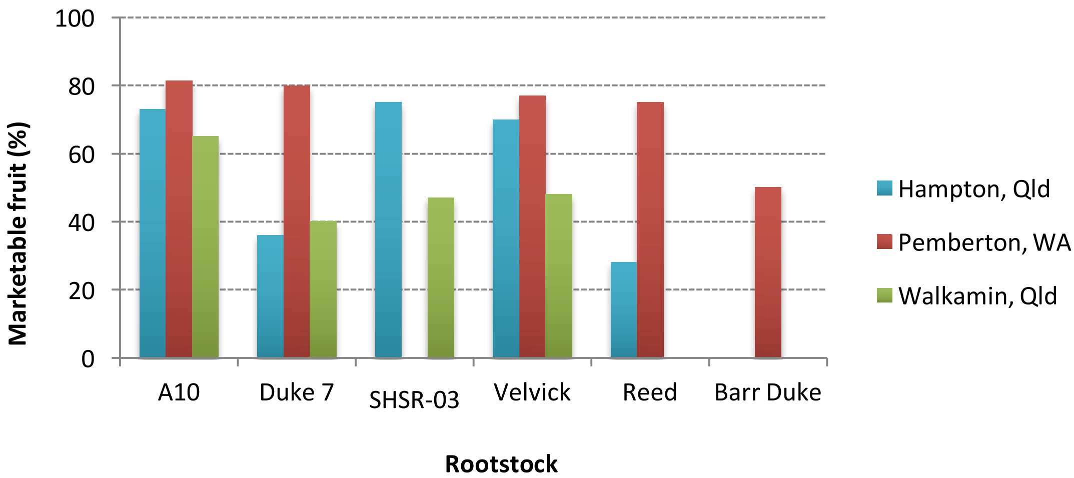

Figure 1. The percentage marketable fruit from Hass (Hampton and Pemberton) and Shepard (Walkamin) avocado trees grown on different rootstocks at three sites. Data from 2010 harvest only. Derived from Coates et al, 2011.

Tree health

- Mulching has many benefits for avocado plant health in that it can help manage *Phytophthora* root rot, improve soil permeability and increase water-holding capacity[19].
- Mulching has been reported to increase avocado fruit size and yield[20], and may increase calcium content, with benefits for fruit robustness[21].
- Trees with moderate *Phytophthora* root infection lack vigour. Perhaps surprisingly, fruit from such non-vigorous trees had lower incidence and severity of anthracnose infection. The researchers suggest this related to a 40% increase in calcium in the fruit flesh. However, fruit from these trees were small, which reduced their commercial value[22].
- In contrast, Dann et al[18] found that high-yielding trees had lower incidence and severity of anthracnose, although this correlation did not occur every season or in all areas. Marques et al[44], also found that fruit from high yielding trees tended to have higher dry matter and increased calcium, in contradiction to the results from South Africa cited above. These Australian results are consistent with local grower experience, which has generally found that high yields are associated with good quality, and low yields need to be marketed as quickly as possible (N. Delroy pers. com.).
- Vigour may also reflect nitrogen status. High N content in fruit is associated with increased physiological disorders, particularly susceptibility to chilling injury[43], which may account for some of the observed variability in results.

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[19] Downer J et al. 2001. The effect of yard trimmings as mulch on growth of avocado and avocado root rot caused by *Phytpohthora cinnamomi*. Yearbook Calif. Avocado soc. 83:87-104.
[20] Mavuso Z. 2008. Effect of different mulch materials composts and organic treatments on tree condition and root health. SAAGA Yearbook 31:32-35.
[21] Nzanza B, Pieterse P. 2013. Soil health, fruit yield, quality and nutritional value of avocado as influenced by different mulch types. SAAGA Yearbook 36:42-46.
[22] Willingham SL et al. 2004. Tree vigour influences disease susceptibility of Hass avocado fruits. Aust. Plant Path. 33:17-21.

- Studies in Australia have also found that fruit from high-yielding trees has the best shelf life[23], while in South Africa, fruit from high-yielding trees was less likely to suffer from internal disorders.[24] (Figure 2).

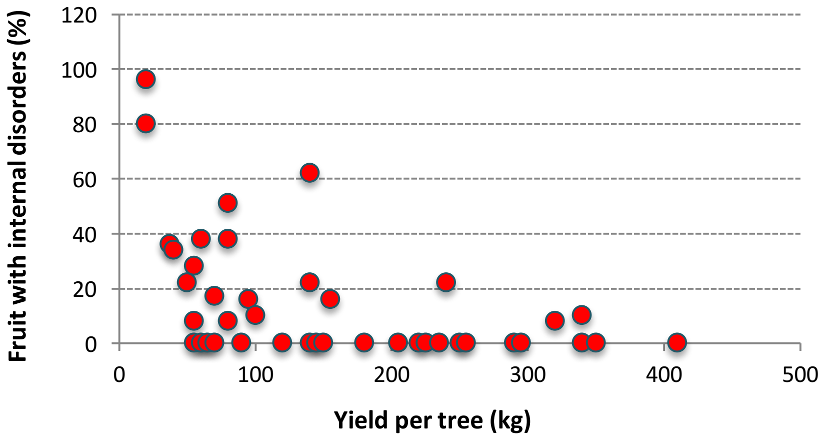

Figure 2. Effect of tree yield on the percentage of Fuerte fruit with internal disorders. Derived from Kohne et al., 1992.

[23] Hofman PJ et al. 2002. Tree yield and fruit mineral concentrations influence Hass avocado fruit quality. Scientia Hort 92:113-123.
[24] Kohne JS, Kremer-Kohne S, Schutte T. 1992. Recent developments in avocado production research. Unpub. Rep. Merensky Tech. Svc. South Africa. 12pp.

2.3 Tree nutrition

Key finding

Tree nutrition has a major influence on fruit quality. Calcium is the most important, with increased levels reported to reduce postharvest disorders, slow ripening, and improve resistance to disease. Unfortunately, as calcium moves passively through the plant, it is difficult to increase fruit calcium with either foliar or soil applications.

Nitrogen is essential for growth and productivity. However, excess nitrogen can increase shoot growth at the expense of fruit development, which may be why it is associated with increased disease and postharvest disorders.

Deficiencies of nutrients such as boron and zinc can lead to poor fruit development. The effects of supplements are more variable, so, for example, iron is associated with resistance to chilling injury but also increased incidence of other disorders.

Calcium

- Calcium (Ca) is strongly implicated in many fruit disorders. It has a key role in strengthening cell walls and membranes, and is involved in many enzymic reactions. High fruit calcium is associated with reduced disorders for many fruit, including apples, tomatoes and also avocados.
- Increased Ca in fruit reduces respiration rate and inhibits the respiratory climacteric. As a result, these fruit are slower to ripen than fruit with low Ca levels[25]. For example, Hass and Fuerte fruit that were vacuum infiltrated with high levels of calcium (0.3M) remained only slightly softened after eight days at 20°C, whereas untreated fruit were fully ripe within four days[26].
- Increased Ca levels in fruit are associated with reduced incidence of anthracnose after ripening. In Hass, this effect was found to be particularly pronounced if flesh Ca concentration was >400mg.kg^{-1} dry weight[27].
- High Ca also increases fruit resistance to internal discolouration[27] and vascular browning[28] following cold storage and ripening. Susceptibility to injury is reduced in areas of the flesh containing high Ca levels. The effect can be further enhanced by vacuum infiltration of whole fruit with $CaCl_2$[29].

[25] Tingwa PO, Young RE. 1974. The effect of calcium on the ripening of avocado fruits. J. Amer. Soc. Hort. Sci. 99:540-542.
[26] Eaks IL. 1985. Effect of calcium on ripening, respiratory rate, ethylene production and quality of avocado fruit. J. Amer. Soc. Hort. Sci. 110:145-148.
[27] Hofman PJ et al. 2002. Tree yield and fruit minerals concentrations influence Hass fruit quality. Scientia Hort. 92:113-123.
[28] Thorp TG et al. 1997. Survey of fruit mineral concentrations and postharvest quality of New Zealand grown Hass avocado. NZ J. Crop Hort. Sci. 25:251-260.
[29] Chaplin GR, Scott KJ. 1980. Association of calcium in chilling injury susceptibility of stored avocados. HortSci. 15:514-515.

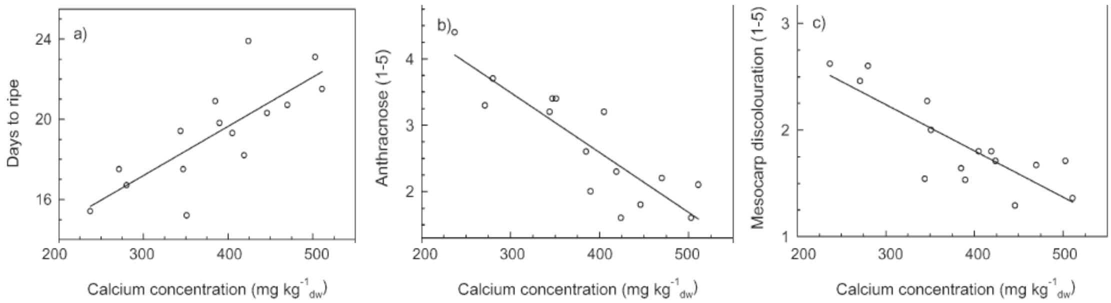

Figure 3. Relationship between Ca concentration in ripe flesh of Hass avocados and a) days from harvest to ripe, b) anthracnose severity and c) mesocarp discolouration. From Hofman et al, 2002.

- Fruit from non-vigorous trees has been found to have either higher[22] or lower[44] levels of Ca compared to fruit from vigorous trees. In both cases, this factor was used to explain differences in postharvest development of anthracnose. Witney suggested that competition for Ca from actively growing leaves and shoots may be reducing Ca in fruit on vigorous trees[30]. However, if soil Ca is high, then this may be less of a factor.
- Avocado fruit can develop on either determinate shoots (where the terminal bud is a flower) or indeterminate shoots (where the terminal bud is a leaf). Fruit-borne on indeterminate shoots contain higher Ca than those from determinate shoots. In apparent contradiction of Witney[30], this is suggested to be due to transpiration by the leaves, which increases flow of water and nutrients (including Ca) into the stem[31].
- One New Zealand study found that fruit grown with higher rainfall tended to have high content of Ca and magnesium. While high rainfall is normally associated with increased rots, in this case the high Ca appeared to have a protective effect[32].
- As Ca moves passively through the tree via the xylem sap, it is difficult to increase Ca in fruit flesh. Soils with low cation-exchange capacity, which are common in avocado growing areas, do not retain Ca in the upper root zone, where they are most easily taken up by the plant[33].
- Foliar applications failed to increase Ca in fruit flesh[34]. Some soil applications have had positive results[35], but others have failed to provide an effect. There is some evidence that Ca applications early in the season (e.g. as Calcimax 1%) have more effect than those later in fruit development[36], and that small and frequent applications have better effect than large single applications[37].

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[30] Witney GW, Hofman PJ, Wolstenhome BN. 1990. Effect of cultivar, tree vigour and fruit position on calcium accumulation in avocado fruits. Scientia Hort. 44:269-278.
[31] Boyd LM et al. 2007. Comparison of strategies for determining fruit mineral concentrations in Hass avocado. J. Hort. Sci. Biotech. 82:611-612.
[32] Everett KR et al. 2007. Calcium, fungicide sprays and canopy density influence postharvest rots of avocado. Aust. Plant Path. 36:22-31.
[33] Hofman PJ, Bower J, Woolf A. 2013. Harvesting, packing, postharvest technology, transport and processing. In 'The Avocado: Botany, Production and Uses'. 2nd ed. Eds B Schaffer et al. CAB Int.
[34] Partridge CJ, Pak HA, Brookbanks P. 2002. An investigation into the effects of pre-harvest sprays of calcium containing formulations in reducing post-harvest rots in Hass avocados. NZ AGA Ann. Res. Rep.
[35] Everett KR et al. 2008. Orchard treatments other than spray application of fungicides that reduce postharvest rots of avocados. NZ AGA Ann. Res. Rep. 8:93-98.
[36] Penter MG, Stassen PJC. 2000. The effect of pre- and postharvest calcium applications on the postharvest quality of Pinkerton avocados. SAAGA Yearbook. 23:1-7.
[37] Hofman P et al. 2005. Improving avocado fruit quality through tree nutrition – present knowledge. NZ Aust. Avocado Conference. 20-22 September 2005, New Zealand. Session 6, 15pp.

- If root temperatures are high then Ca uptake is reduced, partly due to Ca being replaced by potassium. High levels of micronutrients such as magnesium and sodium can also inhibit uptake of Ca, and greatly reduce distribution of Ca to the shoots. However, if these minerals are deficient then that will also reduce Ca. Maintaining the right balance of minerals in the soil is therefore essential for good uptake and distribution of Ca[38].

Nitrogen

- Nitrogen plays a key role in avocado nutrition, but also in productivity. High rates of nitrogen (N) fertilisation have been widely reported to increase shoot growth at the expense of fruit development, an effect originally observed more than 50 years ago[39].
- High levels of N in fruit have been associated with increased rots and internal disorders[33]. For example, nitrogen fertilisers increased both the severity and incidence of anthracnose and stem-end rots over two seasons when applied to trees growing in a rich ferrosol soil in northern NSW[40].
- A link between high rates of N fertilisation and increased incidence of grey flesh has been clearly demonstrated, particularly for the Pinkerton variety. In South Africa, it is recommended that nitrogen content of fruit pulp should not exceed 1.7% during December, decline to less than 1% by the end of January, and remain at that level until harvest[7].
- High nitrogen also led to physiological disorders and decreased yield of Fuerte[41] and has been shown to increase the severity of internal defects in Pinkerton[42]. High levels of N tend to be associated with low levels of Ca, which may account for some of this effect[43].
- However, such effects are likely to vary depending on the existing soil and tree N status at the trial site. Soils derived from heavy clay and/or with high organic matter are likely to be high in N, whereas sandy soils in a hot, dry climate may be very N-deprived[43]. In Australia, many avocado orchards have low residual soil N, so reducing N further is likely to impact yield[37].

Other nutrients

- While there is extensive literature regarding the effects of various nutrients on avocado yield and fruit quality, any benefits vary considerably between different studies. As with N fertilisation, many results seem likely to be site-specific rather than general rules that growers can follow.
- For example, magnesium and potassium content in fruit flesh was found to reduce body rots at some Queensland trial sites, but not at others, while boron and zinc did not significantly affect fruit quality[44].

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[38] Wallace A, Mueller RT. 1980. Calcium uptake and distribution in plants. J. Plant Nutrition. 2:247-256.
[39] Embleton TW, Jones WW, Garber MJ. 1959. Curvilinear relationship between leaf nitrogen and yield of Fuerte avocados. Proc. Amer. Soc. Hort. Sci. 74:378-382.
[40] Willingham SL et al. 2006. Effects of rootstock and nitrogen fertiliser on postharvest anthracnose development in Hass avocado. Aust. Plant Path. 35:619-629.
[41] Kremer-Kohne S, Kohne JS, Schutte JM. 1993. Effect of potassium, magnesium and nitrogen soil applications on Fuerte avocado fruit quality. SAAGA Yearbook 1993.
[42] Van Rooyen Z, Bower JP. 2005. The role of fruit mineral composition on fruit softness and mesocarp discolouration in Pinkerton avocado. J. Hort. Sci Biotech. 31:89-98.
[43] Wolstenholme BN. 2004. Nitrogen – the manipulator element: managing inputs and outputs in different environments. SAAGA Yearbook. 27:45-61.
[44] Marques JR, Hofman PJ, Wearing AH. 2006. Between tree variation in fruit quality and fruit mineral concentrations of Hass avocados. Aust. J. Exp. Agric. 46:1195-1201.

- Another Queensland study found that high magnesium was positively associated with yield and reduced anthracnose development, whereas high potassium had the opposite effect[27]. High potassium can replace calcium in the plant, which may explain this effect.
- Increased iron content has been reported to reduce cold damage[7], but also to increase pulp disorders[42]. High fruit phosphorus levels may protect against chilling injury, whereas potassium can increase sensitivity[45].
- There does appear to be agreement that deficiencies of boron and zinc, especially during early fruit development, can lead to distorted fruit. Queensland researchers recommend that mature summer leaf concentrations of these micro-nutrients should be 50–60mg.kg^{-1} boron and 40–50mg.kg^{-1} zinc[46].
- Applications of foliar nutrients are likely to be most effective if applied when environmental conditions limit uptake from the soil and/or nutrient demand is high. For example, boron and potassium phosphite applied before flowering improved yield and quality of Hass fruit[47]. Foliar applications with micro-nutrient solutions just before harvest significantly reduced peel spotting of Fuerte avocados grown in Israel[48].

[45] Koen TJ, du Plessis SF, Terblanche JH. 1990. Nutritional factors involved in physiological post-harvest fruit disorders of avocados (cv Fuerte). Acta Hort. 543-550.
[46] Whiley AW, Hofman PJ, Coates, LM. 1997. From seed to tray, some field practices to improve avocado fruit quality. Searching for Quality conf. 23-26 Sept 1997. Ed JG Cutting.
[47] Lovatt CJ. 2013. Properly timing foliar applied fertilisers increases efficacy: a review and update on timing foliar applications to citrus and avocado. HortTech. 23:536-541.
[48] Zilkah S et al. 2001. Influence of preharvest nutritional treatments on postharvest disorders of Fuerte avocado fruits. Acta Hort 553:65-66.

2.4 Fungicides

Key findings

Pre-harvest fungicides are key tools for managing postharvest disease. Many research papers have demonstrated that they can reduce the potential for latent infections in fruit as well as microbial load on the fruit surface at harvest.

The current industry standard involves regular sprays of copper compounds alternated with strobilurin fungicides. Copper fungicides need to be applied every 14-28 days. Copper oxide (cuprous oxide – red) has the best adhesion if it rains and is reasonably compatible with phosphoric acid applications. Amistar® and Flint® are suitable alternate fungicides.

Cytokinins and phosphoric acid can increase anti-fungal compounds in fruit. Other biological control strategies are less effective.

- The two major postharvest diseases affecting avocados in Australia are anthracnose and stem-end rots. In addition to field hygiene and crop nutrition, field management of these diseases still relies on regular copper fungicide sprays[49].
- There are currently 170 registered fungicide products for use on avocados in Australia (APVMA, acc. 21/10/2016). These include both pre- and postharvest chemicals and include a range of active ingredients:
    - Azoxystrobin
    - Phosphorous (phosphonic) acid present as mono-di potassium phosphonate
    - Foestyl-aluminium
    - Propiconazole
    - Copper present as cupric hydroxide, copper oxychloride, tribasic copper sulphate, and ammonium acetate
    - Difenoconazole
    - Prochloraz
    - Thiram
- Traditionally, fungicides are applied to fruit during the growing season. However, application of suitable fungicides during flowering may help to suppress spore germination and hyphae development in the flowers. Sprays can then be maintained until harvest[50].
- Fungicides reduce the inoculum load in the orchard. Perhaps for this reason, increasing numbers of fungicide applications per season have been shown to have a linear effect on the percentage of fruit developing postharvest stem-end rots in New Zealand[32]. Everett and Pak[51] suggested that at least five fungicide applications per season were needed for reasonable disease control; fewer than this resulted in significantly increased postharvest disease. However, later work by Everett et al[52] indicated that fruit sprayed less than eight times per season had more body rots than unsprayed fruit, suggesting that a reduced number of sprays still killed any beneficial microbes that were present, without controlling pathogens.

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[49] Willingham SL et al. 2001. Field management of avocado postharvest diseases. Acta Hort. 553:435-438.
[50] Coates L et al. 2001. Field and postharvest management of avocado fruit diseases. Final Report. Horticulture Australia Ltd.
[51] Everett KR, Pak H. 2001. Orchard survey: effect of pre-harvest factors on postharvest rots. NZ AGA Ann. Res. Rep. 2001.
[52] Everett KR et al. 2007. Calcium, fungicide sprays and canopy density influence postharvest rots of avocado. Aust. Plant Path. 36:22-31.

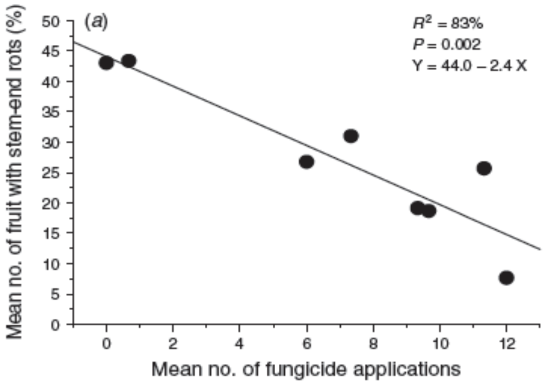

Figure 4. Relationship between fungicide applications per season and the incidence of stem-end rots in New Zealand. From Everett et al, 2007.

- More recent work in New Zealand has shown that there is a strong correlation between fungi isolated from leaves and the incidence of fruit rots after harvest, even though fruit rots generally remain quiescent until after harvest and ripening. It is suggested that this could be used as a decision tool for pre-harvest fungicide applications as well as marketing of harvested fruit[53].
- Copper fungicides offer reliable disease control. They need to be applied every 28 days, or every 14 days during wet weather, from fruit set to harvest, to be effective for anthracnose control[54]. Regular applications are needed because the copper particles are dislodged as fruit expands, leaving the fruit uncovered.
- Smaller particle sizes in copper sprays can give better coverage and longevity, particularly in terms of rain-fastness. Particles >3µm can be blown off the fruit[55] .
- Copper oxide (red copper or cuprous oxide) has the best adhesion after rain (Figure 5). It is reasonably compatible with foliar applications of phosphorous acid (H_3PO_3) for control of phytophthora root rot. Copper needs to be applied first, then the phosphorous acid. Copper hydroxide (blue copper) is phytotoxic if it combines with phosphorous acid, while copper oxychloride (green copper) is intermediate in terms of compatibility with phosphorous acid.

[53] Everett KR et al. 2015. Towards commercialisation of avocado rot prediction. Proc. VII Congreso Mundial de la Palta, Lima Peru. 2015. 159-164.
[54] Coates LM et al. 2001. Field and postharvest management of avocado fruit diseases. In Proc. Aust. NZ Avocado Growers Conf. Brisbane 2001.
[55] Dann L. 2011. Pathology challenges in avocado. Powerpoint presentation.

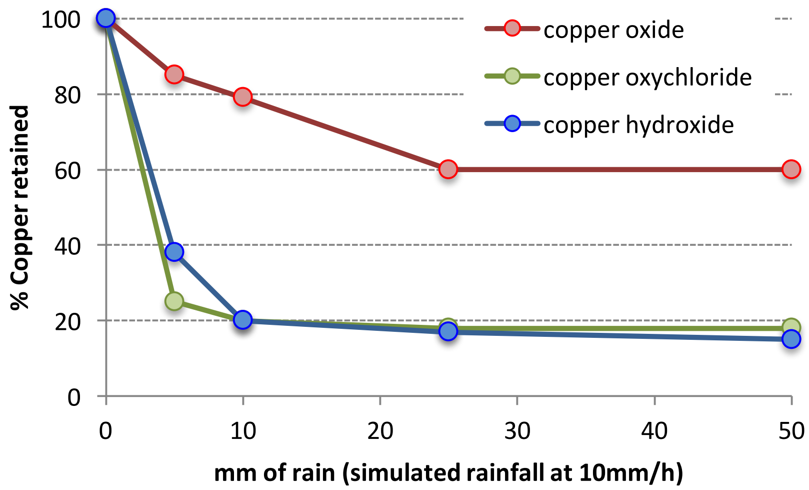

Figure 5. Retention of different copper formulations after rainfall. Derived from Centrilab, Holland data.

- However, there are concerns about negative effects of repeated use of copper sprays on soil biology[56]. Copper based products also leave a residue on the skin, which is particularly difficult to remove from rough skinned cultivars such as Hass[49]. Sprays are also labour intensive and expensive[54].
- The industry standard in Australia involves regular copper sprays plus 1–2 applications of strobilurin fungicide. Strobilurins were extracted from a fungus and are considered environmentally benign. To avoid resistance, it is recommended to apply no more than 3 strobilurin sprays per season, combining applications with copper sprays at a rate of 1 strobilurin : 2 copper and avoiding consecutive applications[55].
- Several Qld trials have shown that the strobilurin fungicides Amistar® and Flint® can reduce anthracnose infection by up to 74%, while Stroby® is less effective. Integrating Amistar® with Kocid (copper hydroxide) also significantly reduced stem end rot caused by *Dothiorella* spp.[57].
- The standard industry regime was compared to a range of alternative fungicides including Serenade® (*Bacillus subtilis*), Kasil 2040 (silicon based), Rainshield™ (rainfast Mancozeb), Aminogro (chitosan), EcoCarb (potassium bicarbonate), naturalGreen (mainly $CaCO_3$). Only the industry standard increased the percentage of marketable fruit compared to untreated controls, although Rainshield™ did provide some control[58].
- Fruit resistance to pathogens including anthracnose is increased if the fruit is high in anti-fungal dienes. During ripening these antifungal dienes decline, which is one reason why ripening fruit become increasingly susceptible to decay[59].
- Application of the plant cytokinins BAP (benzylaminopurine) or TDZ (thidiazuron) to trees 90, 75 and 60 days before harvest increased levels of dienes in the fruit and reduced anthracnose rots by around 30% in harvested fruit[60].

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[56] Everett KR et al. 2008. Field testing alternatives to copper for controlling avocado fruit rots. NZ Plant Prot. 61:65-69.
[57] Willingham SL et al. 2001. Field management of avocado postharvest diseases. ActaHort 553:435-438.
[58] Smith LA et al. 2011. Exploring non-traditional products for management of postharvest anthracnose and stem end rot in avocado. Proc. 7th World Avocado Conf. Cairns Sept. 5-9 2011.
[59] Prusky D, Keen NT. 1993. Involvement of preformed antifungal compounds in the resistance of subtropical fruit to decay. Plant Dis. 77:114-119.
[60] Beno-Moualem D, Vinokur Y, Prusky D. 2001. Cytokinins increase epicatechin content and fungal decay resistance in avocado fruit. J. Plant Growth reg. 20:95-100.

- Products that induce systemic acquired resistance (SAR) also increase antifungal compounds in fruit. For example, phosphorus acid is used to control phytophthora root rot through this mechanism; it inhibits fungal growth at high concentrations, while at low concentrations it stimulates plant defences[61]. Foliar sprays of phosphorus acid can decrease development of anthracnose, with best results gained when sprays were applied 14 days before harvest[62].

2.5 Orchard hygiene

Key findings

Hygiene can help control disease by reducing inoculum levels in the orchard, aerating the canopy to prevent build-up of pathogens, and preventing insect damage to developing fruit.

- Orchard hygiene is an important strategy in managing anthracnose infections in fruit. Removing infected fruit, along with dead wood, can reduce levels of inoculum in the field[63].
- Pruning trees in general increases ventilation through the canopy, helping to prevent build-up of pathogens including anthracnose and stem end rot[64].
- Controlling pest insects in the orchard can also affect postharvest fruit quality. Fruitspotting bugs (*Amblypelta* spp.) cause cracks and spots on developing fruit. These may not be obvious immediately but facilitate infection by anthracnose[65].

[61] Guest D, Grant B. 1991. The complex action of phosphonates as antifungal agents. Biol. Rev. Cambridge Phil. Soc. 66:159-187.
[62] Bosse RJ, Bower JP, Bertling I. 2012. Systemic acquired resistance inducers applied pre-harvest for anthracnose control in 'Fuerte' avocados. SAAGA Yearbook 35:69-71.
[63] Hartill WFT, Sale PR, Sawden D. 1991. The use of copper sprays and pruning out dead wood to control postharvest rots of avocado. NZ AGA Sci. Res. Tech. Supp. 10:5-8.
[64] Dann EK et al. 2013. Foliar, fruit and soilborne diseases. In "The Avocado: Botany, Production and Uses. 2nd ed. Eds B. Schaffer et al.
[65] Huwer RK et al. 2015. A multi-targeted approach to management of fruitspotting bugs – major pests in tropical and subtropical horticulture in Australia. 1105:27-34.

3 Harvest

3.1 When to harvest

Weather and water

Key finding

It is widely recommended that fruit should not be picked while wet. Wet harvest can increase skin marking due to lenticel damage, postharvest rots and internal disorders. Continual rain can reduce the impact on disease – as microbes may be washed off the plant surfaces – but the other types of damage may still occur. Fruit that is turgid due to rain or recent irrigation is also likely to suffer increased lenticel damage, leading to skin spotting and development of dark patches on the fruit skin. Harvesting fruit when hot increases moisture loss even if bins are shaded, so may also affect end quality of fruit.

- It is widely recommended that avocados are not picked while wet, regardless of whether moisture is due to rain or even just dew. Fruit picked wet are more likely to develop stem-end rots, body rots and vascular browning[66].
- As little as 5mm rain in the 24 hours prior to harvest can increase postharvest rots (Figure 6). However, if rain continues for 48 hours or more, then the effect on rots is less, and may even revert to that observed in dry fruit. It seems possible that continual rain washes fungal spores off the trees, reducing the probability of infection during harvest[67].

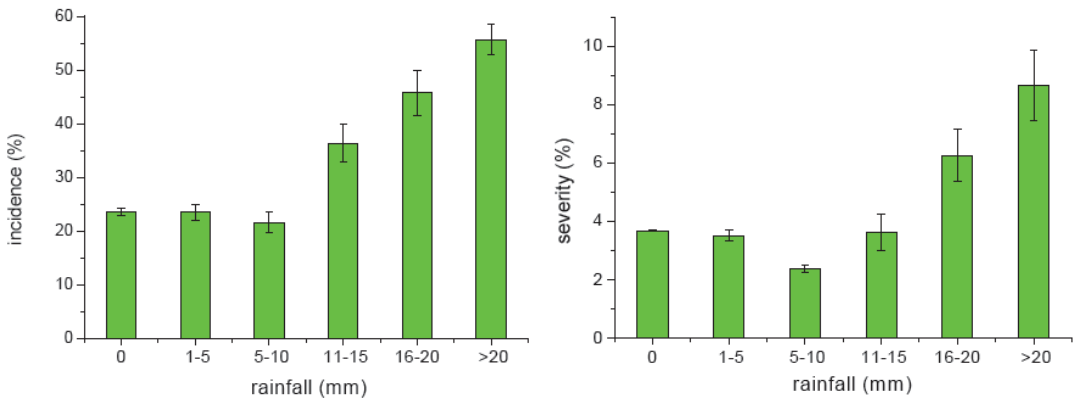

Figure 6. Impact of rain in the 24 hours prior to harvest on the incidence of stem-end rot (left) and the severity of body rots (right). From Pak et al., 2003.

- Both rain and irrigation increase turgidity of the fruit, swelling the lenticels in the fruit skin. Such fruit are more likely to suffer lenticel damage during harvest and normal handling, resulting in spotting and, sometimes, browning of the underlying tissue[67]. Damaged areas are prone to secondary rots, which can develop during cold storage[68].

[66] Duvenhage JA. 1993. The influence of wet picking on post harvest diseases and disorders of avocado fruit. SAAGA Yearbook 16:77-79.
[67] Pak HA et al. 2003. Impact of rainfall prior to harvest on ripe fruit quality of Hass avocados in New Zealand. NZ AGA Ann. Res. Rep. 3:22-
[68] Everett KR et al. 2008. Avocado lenticel damage: the cause and effect on fruit quality. Postharvest Biol. Technol. 48:383-390.

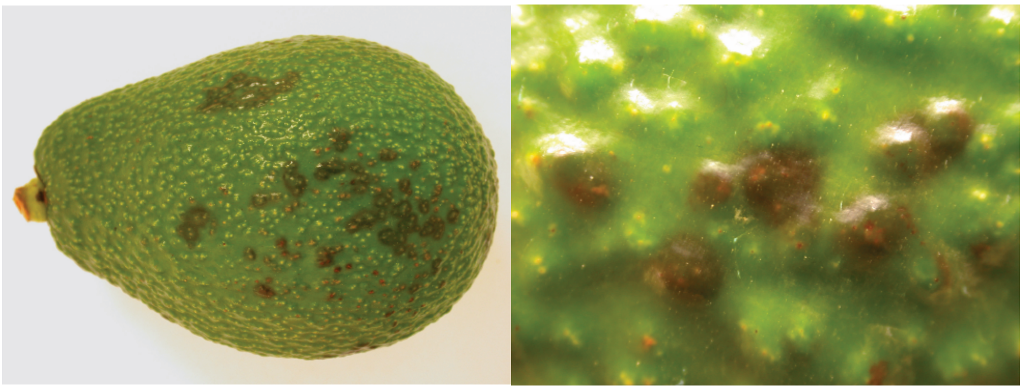

Figure 7. Symptoms of peel handling damage (left) and close-up of damaged lenticels (right) following harvest of turgid fruit and jostling. From Pak et al., 2003.

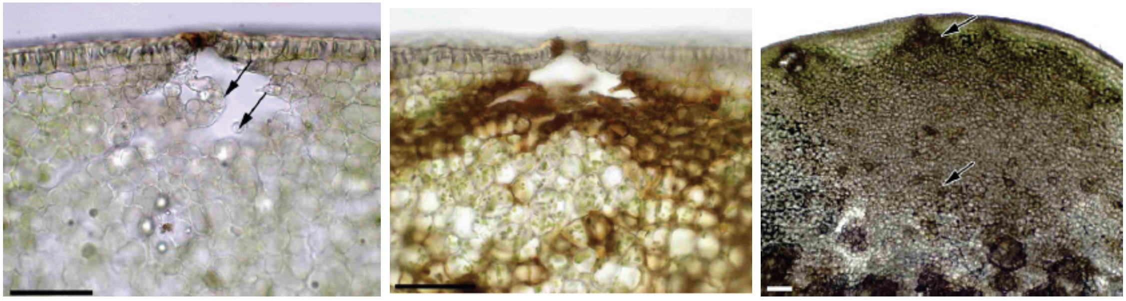

Figure 8. Cross-section of a normal lenticel (left), a damaged lenticel showing browning in the sub-epidermal cells (centre), and spread of the browned area through the internal tissue (right). From Everett et al., 2008.

- Turgidity at harvest could also explain why Hass harvested at dawn in New Zealand generally suffered less incidence of body rots than fruit harvested mid-afternoon, although the results were highly variable between orchards and harvest dates[69].
- Harvest temperature is also important, as exposed fruit can be significantly hotter than the surrounding air. Hot fruit lose moisture quickly, which can reduce quality. Despite this, a WA study suggested that rots and flesh browning were slightly reduced in Hass when fruit were harvested at above 32°C, although the results were highly variable[8]. This may be due to the formation of heat shock proteins in the fruit, as discussed in section 0.

Maturity of fruit

Key finding

Harvesting fruit at correct maturity is essential. Maturity relates to oil content at harvest, which is most easily measured by recording percentage dry matter (DM). Under-mature fruit are more likely to develop postharvest diseases and disorders. They also fail to ripen well, developing a watery rather than creamy texture and providing a poor eating experience for consumers. Over-mature fruit still eat well, but internal disorders and rots in ripe fruit may increase by up to 40%. A sample of fruit should be ripened and tasted to confirm readiness for harvest.

- Maturity at harvest is a key factor determining postharvest quality. Although avocados can hang on the tree for many months, apparently unchanged and unripe, the postharvest attributes of the fruit changes considerably over time.

[69] Elmsly TA et al. 2007. Influence of time of day of harvest on Hass avocado ripe fruit quality. NZ AGA Ann. Res. Rep. 7:91-96.

- Maturity is generally defined by the ability of the fruit to ripen to a creamy texture (not watery) and without shrivelling. External appearance, size and picking date are all highly unreliable as indicators of fruit maturity[70].
- Maturity is generally related to oil content of the fruit. Oil content has a major effect on eating quality, being responsible for the creaminess of the flesh and is the most reliable measure for estimating fruit maturity. However, measurement of oil content is not easy. Measurement of oil requires a chemical method, of which the most common is the Soxhlet extraction method.
- Percentage dry matter (DM) has been repeatedly shown to be a reliable indicator of oil content. In the case of Hass, this relationship has been proven in Australia, New Zealand, California and Hawaii, despite huge variations in rainfall, soil and climate[33].
- This strong relationship means that DM (or moisture content) is used as a standard maturity measure in most, if not all, avocado growing countries[71].
- However, once fruit has matured, oil content and DM become less reliable as indicators of fruit quality. The readiness of fruit for harvest needs to be confirmed by ripening and tasting a sample of fruit, not simply by taking measurements of DM. Attempts to find alternative markers for poor quality fruit have not, so far, been successful[72].
- If DM is either too high or too low, fruit is more likely to develop storage disorders and rots. Immature fruit also have poor flavour and texture, and are likely to leave consumers dissatisfied. Many researchers have reported that the effect of harvest date on fruit quality is much greater than the effect of other treatments (nutrition, irrigation, etc.) applied. For example;
  - New Zealand Hass avocados harvested with less than 22% DM had increased incidence of body rots, vascular browning and stem-end rots. There was a linear relationship between maturity and evenness of ripening within a sample (checkerboard rating)[73].
  - Incidence and severity of vascular staining of Maluma avocados declined as fruit matured to DM >22%[74].
  - Avocados harvested before they reached 23% DM (Hass), 21% DM (Fuerte) or 20% DM (Bacon) did not have a taste acceptable to consumers, but were considered watery, rubbery and flavourless[75].
  - Consumer liking of Australian Hass avocados increased, as did purchase intent, as DM increased from 20 to 38%[76]. Consumer acceptance was only 70% when fruit had 22%

[70] Magwaza LS, Tesfay SZ. 2015. A review of destructive and non-destructive methods for determining avocado fruit maturity. Food Bioprocess Eng. 8:1995-2011.
[71] Obenland D et al. 2012. Influence of maturity and ripening on aroma volatiles and flavor in Hass avocado. Postharvest Biol. Technol. 71:41-50.
[72] Lallu N et al. 2005. Is the poor quality of late season New Zealand Hass avocado fruit related to fruit characteristics at harvest? NZ AGA Ann. Res. Rep. 5:57-66.
[73] Pak HA, Dixon J, Cutting JGM. 2003. Influence of early season maturity on fruit quality in New Zealand Hass avocados. NZ AGA Ann. Res. Rep. 3:54-59.
[74] Mhlophe SD, Kruger FJ. 2013. Addressing the postharvest vascular staining disorder of Maluma avocado fruit. Acta Hort. 1007:145-152.
[75] Lee SK et al. 1983. Maturity studies of avocado fruit based on picking dates and dry weight. J. Amer. Soc. Hort. Sci. 108:390-394.
[76] Gamble J et al. 2010. The impact of dry matter, ripeness and internal defects on consumer perceptions of avocado quality and intentions to purchase. Postharvest Biol. Technol. 57:35-43.

DM, but increased to 90-95% acceptance at 26% DM. As a result, the Avocados Australia Board recommends a minimum maturity standard of 23% DM at harvest[77].

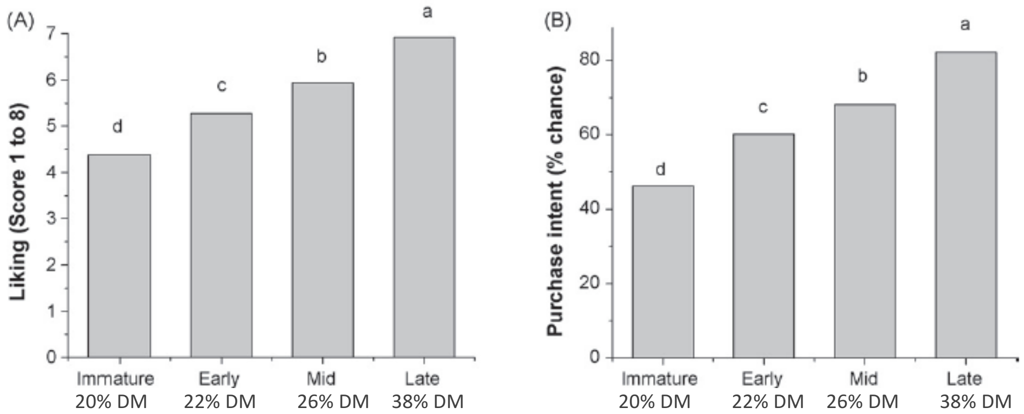

Figure 9. Consumer scores for liking (A) and purchase intent (B) for Hass avocados harvested at different maturities. From Gamble et al., 2010.

- The current Australian standard for Shepard avocados remains at 21% DM. However, in general, studies indicate Australian consumers prefer avocados with at least 25% DM[78].
- A USA study linking harvest date to consumer taste tests also found that consumers strongly preferred avocados with an initial dry matter >25%. These fruit had reduced concentrations of "grassy" aroma volatiles and increased amounts of volatiles such as acetaldehyde and pentanal, which may have contributed to their appealing flavour[71].
- Days to ripen and chilling injury decreased as DM increased in NZ Hass avocados. However, stem-end rot tended to increase in the late harvested fruit, suggesting it may have become over-mature[79].
- Although DM of Queensland-grown Hass remained high between October and January (31–29%), the incidence of body rots, grey pulp and vascular browning all increased with delays in harvest[80].
- A South African study found that fruit harvested late in the season had up to 40% more disorders than early harvested fruit[41].

[77] 2008. Avocados Australia new maturity standard. Talking Avocados Summer 2008, p24.
[78] Harker FR et al. 2007. Australian consumers perceptions and preferences for Hass avocados. Horticulture Australia Final Report.
[79] Dixon J, Smith DB, Elmsly TA. 2004. Fruit age, storage temperature and maturity effects on Hass avocado fruit quality and ripening. NZ AGA Ann. Res. Rep. 4:47-53.
[80] Hofman PJ, Jobin-Décor M, Giles J. 2000. Percentage of dry matter and oil content are not reliable indicators of fruit maturity or quality in late-harvested Hass avocado. HortSci. 35:694-695.

Measuring maturity

Key finding

Dry matter (DM) can be measured by simply drying samples of peeled, sliced or cored fruit. Standardising the sampling method used is essential as avocado dry matter varies considerably in different parts of the flesh. DM can also vary considerably within a tree and between trees.

A number of new, faster, methods for measuring DM are now under development. Of these, near infrared spectroscopy (NIR) shows great promise for field applications and commercial devices are now available. Removing the fruit skin and calibrating over multiple seasons improves accuracy of these devices.

- Dry matter (DM) assessment is usually based on a 20-fruit sample, with a restriction in variability such that, for example, 18 of 20 fruit tested must exceed 20.8%. DM can vary considerably between trees as well as within trees[31].
- Dry matter can be assessed using:
  - The peel method, which uses peeled slices from quartered fruit. These are dried, or grated then dried.
  - The Hofshi core method, where a plug of core tissue is extracted from the equator of the fruit and dried.
- The method used needs to reflect average DM in the fruit. It is clear that DM varies through the fruit, but there is little agreement about where it is high or low;
  - The core method has been claimed to underestimate DM by approximately 0.4%, as flesh at the ends of the fruit was higher DM than in the centre[81].
  - Other researchers have found that DM is highest at the stem and lowest at the blossom end, the central zone being intermediate[85] (Figure 10).
  - The opposite was found by a New Zealand study, which states that DM was always highest at the blossom end and lowest at the stem end[31]. In this study, measuring core plugs gave consistently higher %DM values than those calculated from slices.

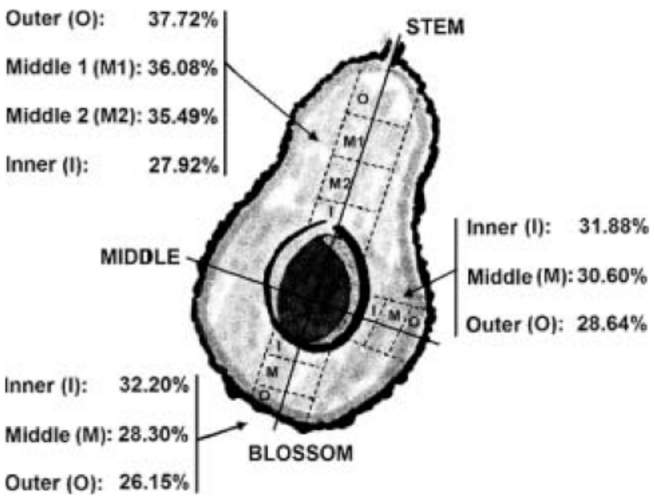

Figure 10. Average DM distribution inside a Queensland grown Hass avocado. From Wedding et al., 2011.

- The Hofshi core method is faster than the peel method and provides consistent results[81].
- Whether the flesh is grated, cored or sliced, DM can be assessed using an automated moisture analyser. These combine a weigh scale with a heated chamber and output display panel. Despite this, measurements of DM are inherently time-consuming, destructive, and limited in terms of the number of samples that can be processed.
- A number of more automated methods have been proposed for measuring avocado fruit maturity. Some could potentially be adapted to handheld instruments for field use, others would require fruit to be assessed at the lab or packing shed. These include:
  - ***Nuclear magnetic resonance*** *(NMR).* NMR can separately detect oil and water content. The ratio between these peaks can then be used to calculate % DM. Consistent results were obtained for intact Reed and Gwen avocados[82]. NMR may also be used to estimate oil content in intact fruit[83]. However, at this time the cost of NMR equipment makes it unlikely to develop commercially[70]

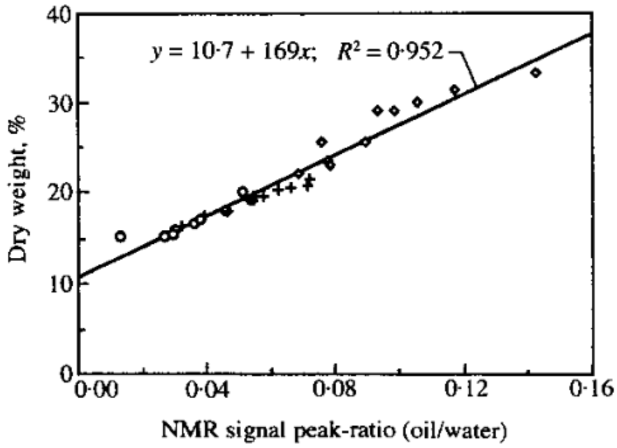

Figure 11. Correlation between the oil/water peak ratio measured with NMR and the % DM of Reed and Gwen avocados. From Chen et al., 1993.

  - ***Ultrasonics.*** High energy, low frequency waves are passed through the fruit. As the flesh changes in moisture content, signal transmission increases. Attenuation of the ultrasonic signal was related to % DM for Fuerte and Ettinger fruit[84]. However, the relationship was non-linear, and the initial calibration method presented does not appear precise enough (especially at DM >20%) to reliably predict harvest maturity
  - ***Near infrared spectroscopy*** *(NIRS).* Visible to near infrared wavelength spectroscopy measures light absorbance at different wavelengths as an indicator of the relative proportions of C–H, O–H and N–H bonds. Avocado flesh and oil are composed of organic molecules that contain these bonds, so NIRS can be used to accurately quantify DM and oil

[81] Mandemaker J et al. 2004. Comparison of core and peel sampling methods for dry matter measurement in Hass avocado fruit. NZ AGA Ann. Res. Rep. 4:36-46.
[82] Chen P et al. 1993. Maturity evaluation of avocados by NMR methods. J. Agric. Eng. Res. 55:177-187.
[83] Marigheto N, Duarte S, Hills BP. 2005. NMR relaxation study of avocado quality. App. Magnetic Resonance. 29:687-701.
[84] Mizrach A et al. 1999. Determination of avocado maturity by ultrasonic attenuation measurements. Scientia Hort. 80:173-180.

- Two significant challenges with NIRS are the significant variations in DM content in different parts of an avocado fruit and blocking of light transmission by the peel. Peel is particularly an issue for Hass, due to its thick skin and irregular surface[85].

- Despite these reservations, a number of researchers have reported good results using NIRS to measure maturity parameters of avocado fruit[86,87]. For example, Wedding et al[85] showed that Fourier transform (FT) NIRS could predict % DM of whole Hass fruit from Qld within ±1.53% of actual value. Accuracy was improved to ±0.84% if the skin was removed. Repeating assessments over three seasons improved the robustness of the calibration model, and reduced the error to ±1.43% for whole, unpeeled avocados[88].

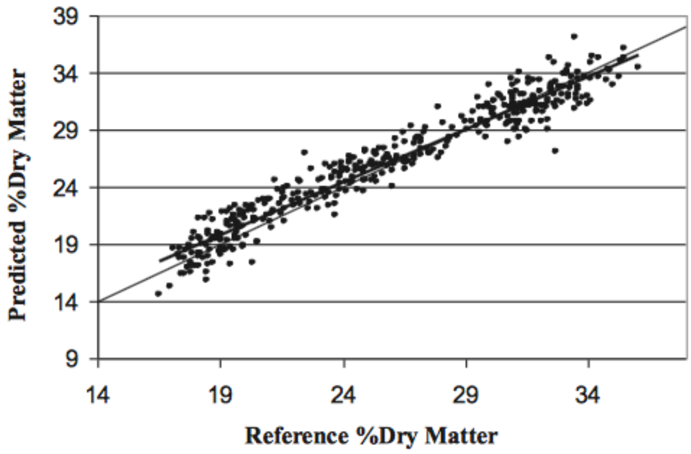

Figure 12. Predicted vs. actual % DM for Hass avocados over three seasons, as measured using FT NIRS. From Wedding et al., 2013.

- Olarewaju et al[89] also found that results were improved when more than one seasons data was included. This study also found that although DM could be predicted accurately, attempts to use NIRS to measure oil content were less successful.

- Whereas the above methods are primarily intended for in-line sorting of fruit, portable handheld devices could be used in the field, so are more suitable for determining harvest maturity. As they are not as powerful as benchtop devices, the peel needs to be removed to gain an accurate measurement. Blakey[90] proposed that a suitable protocol would involve scanning at least 10 fruit per orchard, selected from 10 healthy trees, and repeating weekly as harvest maturity approaches. After removing the peel, each fruit should be scanned on either side of its equator, avoiding the sun-facing side.

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[85] Wedding BB et al. 2011. Non-destructive prediction of Hass avocado dry matter via FT-NIR spectroscopy. J. Sci. Food Agric. 91:233-238

[86] Schmilovitch Z et al. 2001. Determination of avocado maturity by near infrared spectrometry. Acta Hort 562:175-179.

[87] Clark CJ et al. 2003. Dry matter determination in Hass avocado by NIR spectroscopy. Postharvest biol. Technol. 29:300-307.

[88] Wedding BB et al. 2013. Effects of seasonal variability on FT-NIR prediction of dry matter content for whole Hass avocado fruit. Postharvest Biol. Technol. 75:9-16.

[89] Olarewaju OO, Bertling I, Magwaza LS. 2016. Non-destructive evaluation of avocado fruit maturity using near infrared spectroscopy and PLS regression models. Scientia Hort. 199:229-236.

[90] Blakey RJ. 2016. Evaluation of avocado fruit maturity with a portable near infrared spectrometer. Postharvest Biol. Technol. 121:101-105.

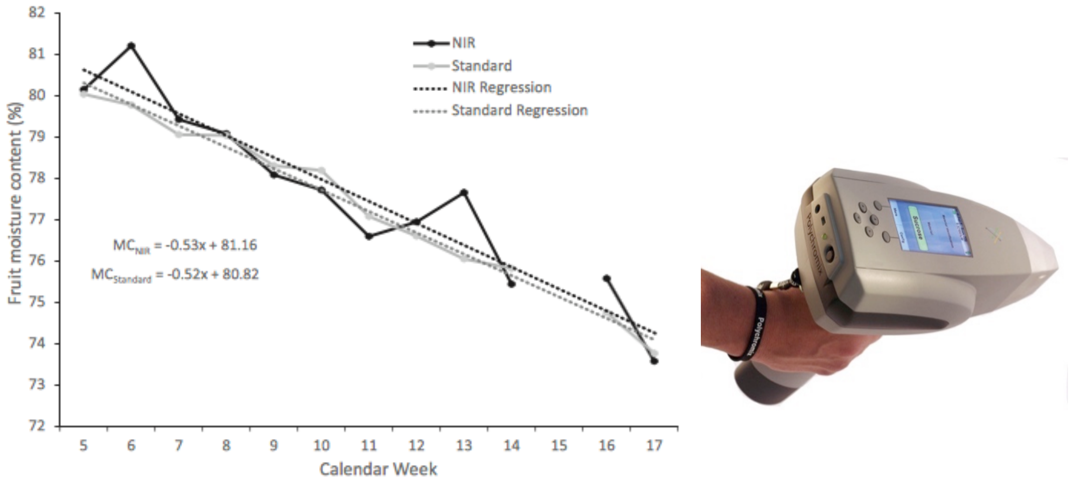

Figure 13. Weekly measurements of moisture content (inverse of DM) using a Phazir 1018 handheld NIR device (right), taken over two seasons in South Africa.

3.2 How to harvest

Key finding

In New Zealand and South Africa avocados are clipped to the button, rather than snapped from the plant. This is due to significant increases in stem-end rots, as pathogens present on leaves and twigs can enter through the picking wound. Clipping is significantly slower than snapping, and increases the risk of stem punctures after avocados ripen. Australian researchers have not found any increase in stem-end rot from snapping fruit. Clipping is most likely to be beneficial if conditions are humid or damp (i.e. microbial populations are high), and/or fruit are to be stored for an extended period before ripening.

Snapping vs. clipping

- There is ongoing debate about the potential benefits of clipping the stems of avocados at harvest instead of simply snapping them from the tree. Snapping is much faster (approx. 2x), and avoids the risk of puncturing fruit due to stem to fruit contact during subsequent handling[91].
- Eaks[92] did not find any difference in weight loss or ripening rate between clipped and snapped fruit in California, while Kohne and Kremer-Kohne[93] also found little effect on ripening or fruit quality between snapped or clipped fruit.
- However, New Zealand researchers repeatedly have found significant increases in rots in snapped fruit compared to those clipped with the end of the pedicel (button) intact (Figure 14). A comprehensive study by Hartill and Everett[94] demonstrated that fruit rot pathogens are found throughout both living and dead twigs, branches and leaves of the avocado canopy. *Colletotrichum acutatum* and *C. gloeosporioides* were the most frequently isolated, followed by *Phomopsis* spp. and *Botryosphaeria parva*. These pathogens were also widely present on fruit pedicels immediately after harvest, and could be isolated from stem-end rots that developed after ripening. The incidence of *C. acutatum* on plucked fruit was significantly higher than all other treatments.
- Further studies demonstrated that stem-end rots enter via the picking wound created at harvest. Again, in the case of snapped fruit, this was due to increased incidence of *Colletotrichum* in the wound site[94].

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[91] Hofman PJ, Fuchs Y, Milne DL. 2002. Harvesting, packing, postharvest technology, transport and processing. In “The Avocado: Botany, production and uses. Eds. AW Whiley, B Schaffer, BN Wolstenholme. CAB International 2002.
[92] Eaks IL. 1973. Effects of clip vs snap harvest of avocados on ripening and weight loss. J. Amer. Soc. Hort. Sci. 98:106-108.
[93] Kohne JS, Kremer-Kohne S. 1995. Picking Hass avocados without pedicels. SAAGA Yearbook 18:66.
[94] Hartill WFT, Everett KR, Pak HA. 2002. Stem-end rots: The infection portal. NZ AGA Ann. Res. Rep. 2:1-8.

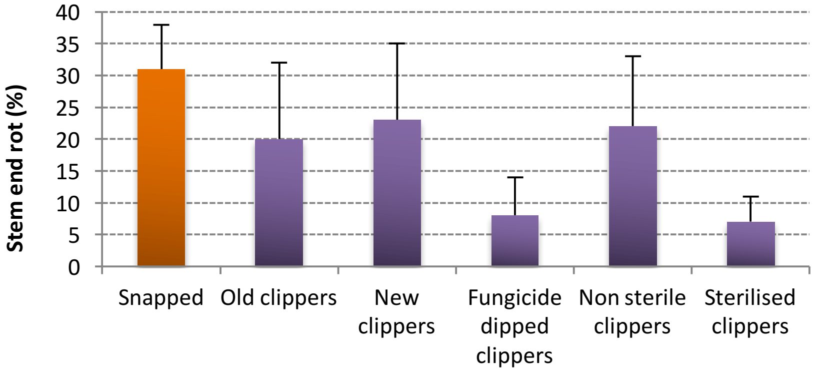

Figure 14. Incidence of stem-end rots in avocados harvested by different methods in TePuke, NZ. Derived from Hartill and Everett, 2002.

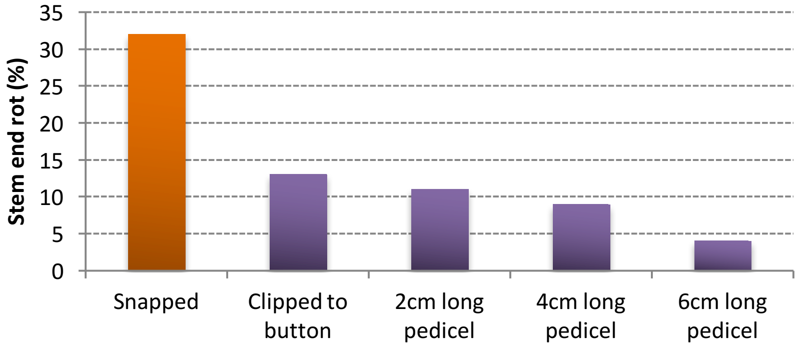

Figure 15. Incidence of stem-end rots in avocados harvested by different methods and with different lengths of pedicel left intact in TePuke, NZ. Derived from Hartill et al., 2002.

- However, trials in Queensland have not found an increase in stem-end rots in snapped compared to clipped fruit[95].
- Differences between snapped and clipped fruit are most likely in high rainfall areas, where stem-end rots can infect the fruit under such wet or high RH conditions. Woolf et al[96] suggest that if fruit grown in humid areas are snapped rather than clipped, they should be triggered with ethylene and ripened at 15°C to minimise development of rots.
- Clipping may also be preferred if fruit are to be stored for extended periods, such as for export to distant markets. For example, in South Africa fruit are not only clipped, but an anti-fungal compound is applied to the cut pedicel to reduce stem-end rot[33].

[95] Muirhead I. 1984. Effects of harvesting method on Hass avocados, with particular reference to stem-end rot. Internal Rep. QDPI, Brisbane.
[96] Woolf AB et al. 1999. Summary of New Zealand and Californian experience with 'snap' picking. In 'Proc. Avocado Brainstorming '99" Eds ML Arpaia, R Hovshi. pp. 161-162.

Physical damage

> **Key finding**
>
> Hard, green avocados can still be damaged by dropping and vibration. Susceptibility varies during the season and according to fruit turgidity. A 10cm drop can increase skin discolouration and double the number of unsound fruit after storage and ripening. Raised areas, such as lenticels and ridges, are easily damaged by rubbing in bins. Rub spots are more likely to discolour or develop rots after ripening. Damage is increased by raised picking platforms, as only 10cm drop can induce skin browning or internal bruising. Physical damage can also occur due to high temperatures and bouncing in bulk harvest bins.

- Although avocados are harvested when hard green, they are still susceptible to bruising and vibration damage. More than 20 minutes' vibration (as can occur during transport to the packing shed) can result in significant internal and external damage. External vibration damage is more easily seen on Fuerte than Hass due to its thinner, green skin[97].
- On Hass, it is the raised areas on the skin that are most easily damaged[97]. Fruit rubbing against each other during harvest and transport to the packhouse can damage the nodules / raised lenticels on Hass avocado skin[68]. The likelihood of physical injury is increased if fruit are harvested while wet or turgid[67].
- Raised ridges and deformities are extremely susceptible to damage by bruising or abrasion. The higher the ridging, the more damage is likely, and the greater the probability of rot developing. For example, more than 75% of Hass avocados with a 3–4mm high ridge suffered bruising during harvest and packing. Moreover, surface rots developed in 96% of these fruit, compared to 56% of normal shaped fruit[98].
- While picking does not generally result in bruising of the flesh, it can increase brown patches and spots on the avocado skin. These can make the fruit more susceptible to flesh diseases after ripening[99].
- Early-season Hass are more susceptible to skin damage than mid- to late-season fruit[97]. Susceptibility is also likely to vary between seasons, according to fruit turgidity at harvest and by microbial load[100].
- Conversely, if fruit are bruised during picking or packing, the severity of flesh discolouration is increased in more mature fruit. Fruit are also more susceptible to bruising if they start to soften due to being overmature. Bruises caused by impacts to green fruit may not be visible externally, but appear as central brown patches inside the fruit flesh once fruit ripens[154].
- Elevated work platforms are needed to harvest fruit from larger trees. However, using such platforms can increase damage to fruit. This is not visible immediately, but becomes evident after storage and ripening. The biggest impact is in the increased appearance of brown patches on the skin. However, harvesting from an elevated platform also significantly increased incidence of stem-end rot and the number of unsound fruit. These effects were only slightly mitigated by adding a fungicide during grading[100].

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[97] Arpaia ML et al. 1987. Susceptibility of avocado fruit to mechanical damage as influenced by variety, maturity and stage of ripeness. SAAGA Yearbook. 10:149-151.
[98] Pak HA, Bettesworth D, Dawes HM. 2001. The role of surface ridging and protuberances on avocado fruit in the development of ripe rots. NZ AGA Ann. Res. Rep. 1:20-25.
[99] Hofman PJ. 2002. Bruising of Hass avocado from harvest to the packhouse. HIA Final Report AVO2015.
[100] Mandemaker AJ, Elmsly TA, Smith DB. 2006. Effects of drop heights and fruit harvesting methods on the quality of Hass avocados. NZ AGA Ann. Res. Rep. 6:97-104.

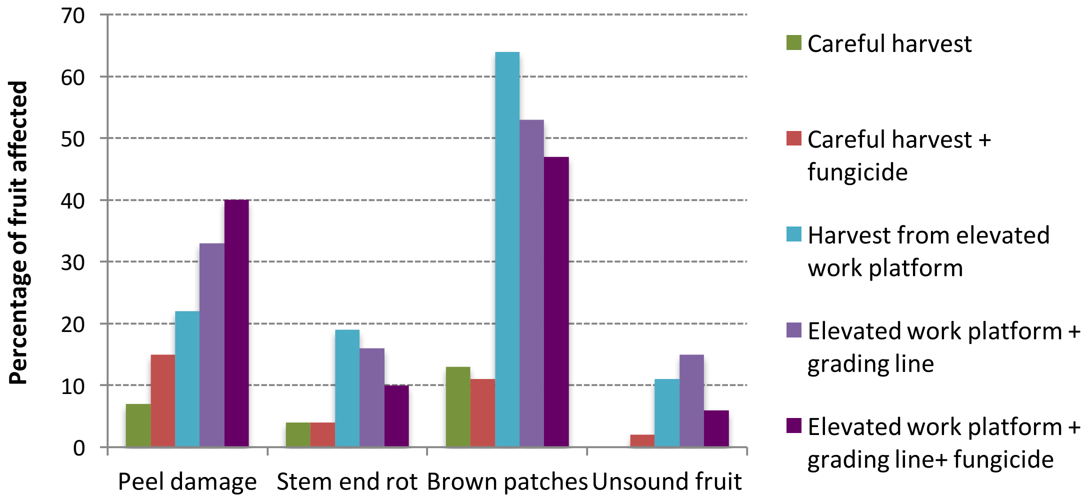

Figure 16. Effects of handling at harvest on defects after storage and ripening of Hass avocados in NZ. Derived from Mandemaker et al., 2006.

- As little at 10cm drop increased brown patches on the skin of carefully harvested Hass fruit, and doubled the number of unsound fruit after storage and ripening. Nearly all fruit dropped 1m at harvest had brown patches on the skin, with 47% rated as unsound when ripe[100].

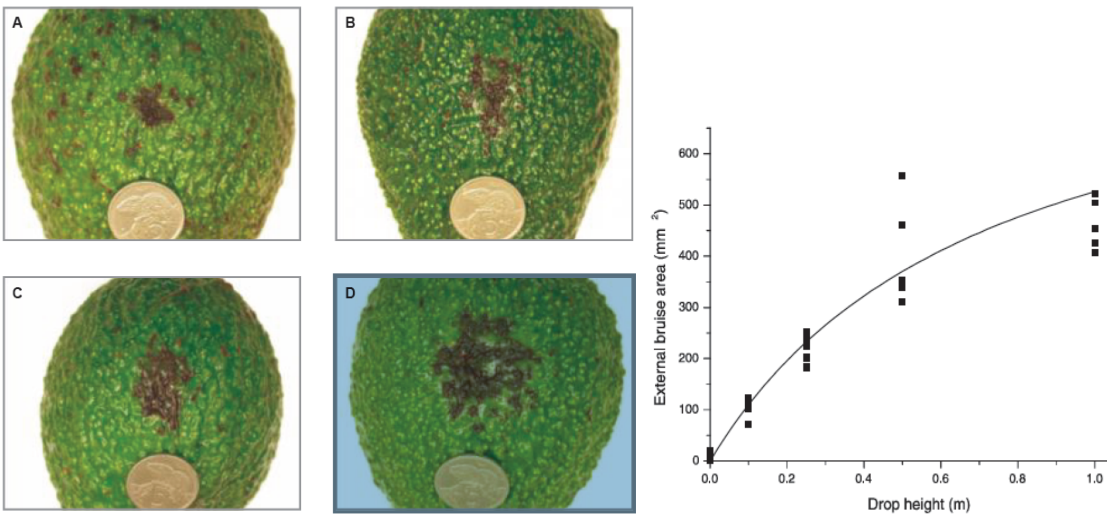

Figure 17. Typical brown patches on Hass fruit dropped 10cm (A), 25cm (B), 50cm (C) or 1m (D) at harvest, and graph indicating the relationship between drop height at harvest and external bruising after storage and ripening. From Mandemaker et al., 2006.

- In Australia, avocados are normally harvested into 400kg bins. Bin size is a compromise between compression damage to fruit at the bottom, and rub damage from fruit in the top layers due to bouncing during transport from field to packhouse[33].

- The main causes of physical damage inside bins may be contact with the sides and base. Zauberman et al[101] found that 13.6% of fruit were injured in bulk wooden bins, compared to 33.4% in field boxes (due to reduced surfaces relative to volume), and that injury was halved when the bins were lined with canvas. The plastic bins now used throughout the Australian industry may be less damaging than wooden bins, but this does not appear to

[101] Zauberman G et al. 1969. Factors causing injury during transportation of avocado pears to packing. Volcani Institute report, Israel. P656.

have been quantified. Bin trailers need to have good suspension, and travel at a speed that does not allow top fruit to bounce[33].

- In Chile, thick, foam lined boards are placed on top of bins to stop fruit bouncing during transport from the field to the packhouse (N. Delroy pers. com.).
- Physical damage can also occur due to high temperatures in bins, especially if fruit are left in the sun. Excess heating will cause dehydration and sunburn, reducing quality[33]. Only 5-10 minutes exposure can damage fruit, especially if they have been picked from a shaded area of the tree and are not sun-adapted. Bins should be covered (eg using suspended shadecloth), and brought to the packhouse within two hours of picking[102].

[102] Arpaia ML, Ontai SL, Reints JS. 1992. Protecting the postharvest quality of avocado fruit. Calif. Avocado Sco. Yearbook 76:93-97.

4 Pre-cooling, postharvest treatments and packing

4.1 Time and temperature from picking to packing

Key findings

Avocados do not ripen on the tree because of an unidentified "tree factor" – a substance that inhibits ripening. This substance degrades after harvest, allowing the fruit to ripen. The speed at which it degrades is a function of time, temperature and moisture loss.

Cooling delays, especially when combined with high harvest temperatures, allow the fruit to initiate ripening. Such fruit ripen more quickly after storage, but have significantly increased rots and physiological disorders. As avocados are not normally fully cooled until after packing, minimising the time from pick to pack is critical for maintaining fruit quality.

Impact of detachment from the tree

- After harvest, avocados are transported to a central packing shed. Here they may be stored for a period before grading and packing. Unlike many other products, avocados are usually not fully cooled until after packing.
- As previously noted, avocados do not ripen while attached to the tree due to the presence of a mysterious, unidentified "tree factor". Several potential candidates have been identified, including the unusual seven carbon sugars found in avocados[103] (most fruit contain six carbon sugars such as fructose and glucose). The tree factor prevents synthesis of ACC (1-aminocyclopropane-1-carboxylic acid), the precursor of ethylene[104].
- Although present at harvest, the tree factor degrades over a number of days, thereby allowing the fruit to ripen. This initial inhibition stage after harvest is important for fruit management. If fruit can be cooled before entering the pre-climacteric stage they will still be firm when removed from cold storage and have improved storage and shelf life[105].
- The inhibition stage usually lasts at least 24 hours after harvest, during which time the fruit will not ripen even if treated with exogenous ethylene[106]. Depending on initial fruit maturity, ripening will start naturally within 4–5 days at 20°C. However, the length of the inhibition stage is also a function of temperature, and can be affected by water loss. Ethylene production will trigger sooner if temperatures after harvest remain high or the fruit loses moisture[107,108].

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[103] Liu X et al. 2002. Postulated physiological roles of the seven-carbon sugars, mannoheptulose and perseitol, in avocado. J. Amer. Soc. Hort. Sci. 127:108-114.
[104] Blumenfeld A, Sitrit Y, Riov J. 1986. Avocado fruit ripening and ethylene biosynthesis. Acta Hort. 179:787-791.
[105] Dixon J et al. 2005. Increasing pick to pack times increases ripe rots in Hass avocados. NZ AGA Ann. Res. Rep. 5:43-50.
[106] Eaks IL. 1980. The effect of ethylene upon ripening and respiratory rate of avocado fruit. Calif. Avocado Soc. Yearbook. 50:128-133.
[107] Bower JP, Cutting JG. 1988. Avocado fruit development and ripening physiology. Hort. Rev. Ed. J. Janick. 10:229-271.
[108] Lallu N et al. 2004. Role of water loss in ripening of Hass avocados. NZ AGA Ann. Res. Rep. 4:70-79.

Pre-storage temperature and humidity

- Avocados exposed to the sun, whether attached to the tree or inside a picking bin, can develop flesh temperatures much higher than the surrounding air. Gradients of up to 15°C have been reported[11] with the result flesh temperatures can exceed 38°C[102]. As temperature is the most important factor affecting storage life and quality of horticultural products, keeping fruit cool is vital to ensure good shelf life and quality.
- Temperature and humidity during the holding period before packing affect water loss from fruit. Increased rates of water loss are consistently associated with higher rates of rots after ripening[109]. For example, trials in New Zealand indicated that an increase of 0.5% in water loss during the holding period is likely to increase the incidence of rots by 5–10%.
- Arpaia et al[102] examined the effect of different types of shading during a 5-hour period after harvest. Fruit pulp temperatures were only 18°C in the bottom of the bins, but reached 23°C, 28°C, 38°C and 41°C at the top of bins covered with leaves, a space blanket, paper or left uncovered respectively. After ripening, large differences were observed in internal discolouration and the onset of rots (Figure 18). The results suggest that high flesh temperatures after harvest, due to fruit being left uncovered in harvesting bins, has a major effect on postharvest quality of ripe fruit.

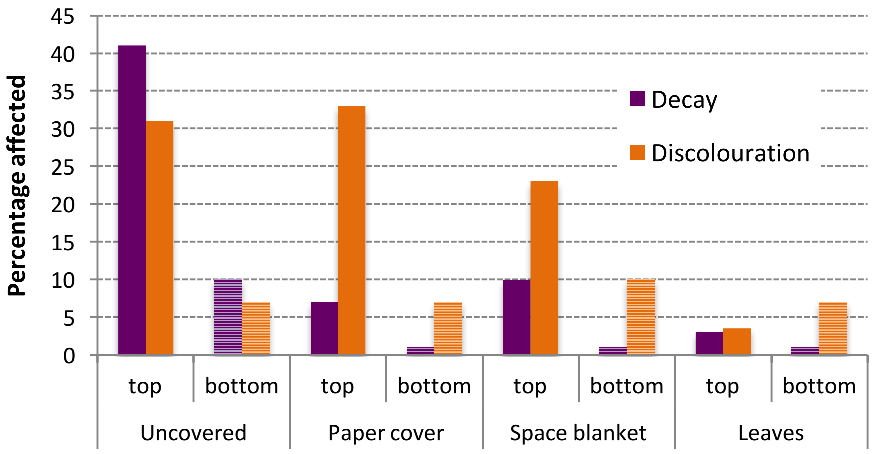

Figure 18. Percentage of avocados affected by decay or internal discoloration after ripening. Sampled fruit were left in the top or the bottom of harvest bins for approximately 5 hours after harvest. During this time they were exposed to direct sunshine (uncovered) *or* covered with paper, a space blanket or leaves. Derived from Arpaia et al., 1992.

Pre-storage time delays

- Damage is a factor of time as well as temperature. Fruit held at 30°C (flesh temperature) for 24 hours had significantly higher rates of decay and internal discolouration after ripening[102]. Even holding fruit at 20°C for 24 hours before packing resulted in significantly higher rates of decay and faster ripening compared to fruit held at 7°C or 16°C. Increasing the holding time to 48 hours further increased the number of decayed fruit[109].
- Longer periods before cooling result in shorter periods to ripen after cooling. For example, Hass held for 1, 2 or 3 days before cooling to 5°C were 32%, 54% or 60% ripe three days after transfer to 20°C. These fruit also had increased incidence of stem-end rots, especially if initially held at 20°C or under variable, ambient conditions[110].

[109] Yearsley C et al. 2002. Effects of prepacking holding temperatures on shelf life quality of Hass avocados. NZ AGA Ann. Res. Rep. 12pp.
[110] Lallu N et al. 2003. Effects of prepacking holding temperatures on shelf life of Hass avocados. NZ AGA Ann. Res. Rep. 3:108-117.

- Arpaia[102] recommended that fruit should be cooled within 6 hours of harvest, or at least reduced to below 30°C.
- Thorough pre-cooling is most important if fruit are to be stored for an extended period. For this reason South African exporters recommend cooling harvested bins below 20°C before sorting and packing the fruit[111].
- Many New Zealand studies have indicated that fruit needs to be thoroughly cooled within 24 hours of harvest to minimise rots in ripe fruit (Figure 19). Attempts to reduce the effect of delays using high RH storage have not proven effective. As a result, it is recommended that pick-to-pack should be no longer than 48 hours, and preferably only 24 hours[112].

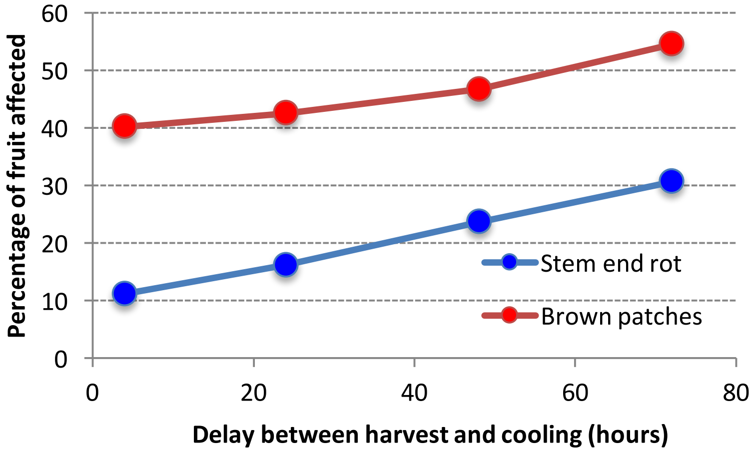

Figure 19. Effect of delays between harvest and packing on the development of brown patches and stem-end rot in NZ Hass avocados. Derived from Dixon et al., 2005.

[111] Hardy J et al. 1995. SAAGA avocado exporters packing guide. 23pp.
[112] Dixon J et al. 2005. Increasing pick to pack times increase ripe rots in Hass avocados. NZ AGA Ann. Res. Rep. 5:43-50.

4.2 Postharvest treatments

Fungicides

Key findings

Postharvest fungicides are commonly applied during grading. However, their effectiveness is unclear, especially if they are applied more than 24 hours after harvest. Reported control ranges from 0 to ~50%. Promising results have recently been reported for thyme oil, applied as a fumigant or in wax.

- Reducing the potential for rots in the orchard, then adding an effective postharvest treatment, should deliver the best quality fruit[113]. For example, in New Zealand rot development potential can theoretically be reduced from 100% to 6.8% by combining copper fungicide applications before harvest, Sportak® application postharvest, cold storage and ripening at 15°C[114].
- Management of postharvest diseases in avocado is particularly challenging as infection commonly occurs during flowering or fruit development. This means that pathogens may be already present inside the fruit, starting to grow only once fruit begins ripening.
- Fungicides are commonly applied during grading and packing to control postharvest diseases. However, their effectiveness is limited by internalisation of the pathogen. For example:
  - A Queensland study evaluated Sportak® (Aventis) and Cabrio® (Nufarm) for control of anthracnose and stem-end rot of Hass avocados. While Cabrio® slightly reduced the severity of anthracnose infection, incidence was reduced only from 80% to 73%. Neither fungicide proved effective[115]
  - Another Queensland study also tested the effectiveness of a range of postharvest dips. Dann et al[116] found that Sportak® significantly reduced the incidence of anthracnose on Hass in two trials of four trials, but not on Reed in either of two trials. The reduction for Hass was from 91% to 71% incidence or from 94% to 60% incidence, neither of which represent commercial control. A number of other fungicides were also tested including EcoCarb, Aminogro, Bion and Scholar®. None provided significant, consistent control of disease on either Hass or Reed fruit
  - Data from New Zealand suggest that Sportak can reduce postharvest rots by approximately half, although results are highly variable[117]. When fruit was stored for longer than 28 days, no fungicides were effective at managing rots[118]
  - In South Africa, postharvest treatment with prochloraz increased the percentage of marketable fruit from 79% (Fuerte) or 88% (Hass) to 97% and 93% respectively.

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[113] Everett KR, Timudo-Torrevilla OE, Pushparajah HIS. 2007. Evaluation of a new chemical and two biological control agents for postharvest rot control in avocados. NZ AGA Ann. Res. Rep. 7:73-78.
[114] Everett KR. 2002. Avocado fruit rots: A review of industry funded research. NZ AGA Ann. Res. Rep.
[115] Giblin FR et al. 2007. Improved management of avocado disease. Final Report AV04001 Horticulture Australia Ltd.
[116] Dann EK et al. 2010. Improving yield and quality in avocado through disease management. Final Report AV07000 Horticulture Australia Ltd.
[117] Hartill WFT, Everett KR, Sale PR. 1994. A comparison of sodium hypochlorite and benlate with Sportak for postharvest rot control in avocados. Sci. Res. Tesch. Supp. 19:7-9.
[118] Everett KR, Pushparajah IPS. 2008. Postharvest fungicide treatments and their effect on long term storage of avocados from three growing regions in New Zealand. NZ AGA 8:85-92.

However, even high doses of prochloraz in postharvest dips could not control anthracnose or stem-end rots if seasonal conditions favour infection[119].

- ✦ Adding an acidifier can increase the effectiveness of prochloraz. The concentration of prochloraz could be reduced from 810ppm to 200ppm without losing any efficacy when 50mM citric acid was added to the solution[119].

- The timing of application is critical for success, especially for management of stem-end rots. As infection often occurs at harvest, fungicide can only be effective if applied before the fungal mycelium penetrate the fruit flesh. For example, fungicide needs to be applied within 24 hours of harvest at 15°C or 15 hours of harvest at 25°C to control mould on citrus (BL Wild pers. com.). Similar effects have been reported for Sportak on avocados[114] (Figure 20).

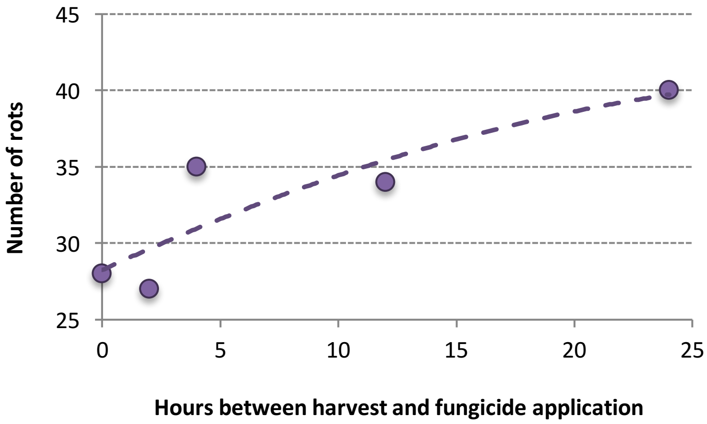

Figure 20. Effect of a delay in fungicide application on development of anthracnose on Hass avocados. Derived from Everett, 2002.

- A number of other treatments have been trialled for their fungicidal effects. These include SARs (systemic acquired resistance elicitors), which stimulate the plants natural defences against rots. However, results so far have been disappointing, with compounds such as methyl jasmonate proving ineffective[114]. Another SAR compound potassium silicate has been shown to stimulate enzymes associated with disease resistance[120] and increase phenolic compounds[121]. However this has not yet been tested against disease in vitro.

- Chitosan is a natural biodegradable compound that has been found to be fungicidal. Dipping avocados in a 1% solution of chitosan reduced incidence and severity of anthracnose on Breda avocados, as well as limiting weight loss and slowing softening[122].

- Essential oils have also been tested for use on avocados. Of these, thyme oil appeared the most promising. Thyme oil can be mixed with carnauba wax for easy application. Rates of 500µl.L^{-1} or higher applied in wax were found to almost halve rates of anthracnose

[119] Mavuso ZS, van Niekerk JM. 2013. Development of a more effective postharvest treatment for the control of postharvest diseases of avocado fruit. SAAGA Yearbook. 36:23-26.

[120] Bosse RJ, Bower JP, Bertling I. 2011. Systemic resistance inducers applied postharvest for potential control of anthracnose (*Colletotrichum gloeosporoides*). Proc. VII World Avocado Con. 5-9 Sept, Cairns Australia.

[121] Tesfay SZ, Bertling I, Bower JP. 2011. Effects of postharvest potassium silicate application on phenolics and other anti-oxidant systems aligned to avocado fruit quality. Postharvest Biol. Technol. 60:92-99.

[122] Marques KM et al. 2016. Use of chitosan for the control of postharvest anthracnose and quality in avocados. Acta Hort. 1120:225-232.

development on Hass avocado in Brazil[123]. Trials in South Africa using thyme oil as a fumigant have reported a 65% reduction in the incidence of anthracnose, which was better than the results gained with prochloraz[124]. .

Surface coatings

Key findings

Surface coatings such as waxes can have significant benefits for avocado quality. They can reduce water loss, improve appearance and even improve shelf life. Carnauba wax appears particularly promising. If combined with a fungicidal compound such as thyme oil, surface coatings could have major benefits for postharvest quality.

- Surface coatings can have benefits for avocado quality through reducing moisture loss and improving appearance. As moisture loss is associated with development of physiological disorders, this suggests coatings may have additional benefits. However, fruit coatings also interfere with gas movement in and out of the fruit. If skin permeability is too restricted, fruit may fail to ripen or develop off flavours[125].
- Waxing Hass with “Avocado and passionfruit wax” (Colin Campbell Chem.) 0 to 96 hours after harvest reduced weight loss during ripening by up to 80%. Ripening was delayed by about 40%, which increased effective shelf life of these fruit[126].
- Biocoat™ wax is a mixture of olive oil and beeswax. It is designed to block lenticels in the fruit skin, slowing ripening and reducing sensitivity to chilling injury[127]. Biocoat applied at 33ml.L^{-1} reduced brown patches on NZ Hass avocados but had no effect on disease or ripening[128].
- Large differences exist between different coating in terms of their effect on the atmosphere inside the fruit and the rate of moisture loss. Johnston and Banks[125] found that a polyethylene based avocado wax applied at 11% concentration reduced weight loss by 18% at 20°C without adversely affecting internal atmospheres but with the added benefit of improving fruit sheen.
- Like Muniz et al[123], Mendieta et al reported benefits from application of carnauba wax[129]. Waxing halved chilling injury, reduced weight loss and was stated to have extended storage life at 3°C to 46 days. It is hypothesised that reducing weight loss reduced stress on the fruit, thereby reducing susceptibility to cold damage.

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[123] Muniz ACC et al. 2016. Evaluation of essential oil on the growth in vitro and in vivo of anthracnose in Hass avocados. Acta Hort. 1120:207-214.
[124] Bill M et al. 2015. New methods of disease control: using thyme oil fumigation. SAAGA Yearbook 38:98-104.
[125] Johnston JW, Banks NH. 1998. Selection of a surface coating and optimization of its concentration for use on Hass avocado (*Persea Americana*) fruit. NZ J. Crop Hort. Sci. 26:143-151.
[126] Joyce DC, Shorter AJ, Jones PN. 1995. Effect of delayed film wrapping and waxing on the shelf life of avocado fruit. Aust. J. Exp. Agric. 35:657-659.
[127] Feygenberg O et al. 2005. Postharvest use of organic coating for maintaining bio-organic avocado and mango quality. Acta Hort. 682:507-512.
[128] Elmsly TA et al. 2007. Effect of the fruit coating Biocoat on ripe rots of Hass avocados. NZ AGA Ann. Res. Rep.
[129] Mendieta B et al. 2016. Reduction of cold damage during cold storage of Hass avocado by a combined use of pre-conditioning and waxing. Scientia Hort. 200:119-124.

- In contrast, Bower and Papli[130] found few benefits from avocado wax applied to Hass before storage at 1°C for 30 days. Only mid-season fruit showed any response in terms of reductions in dark patches on the skin. In these fruit, rind discolouration was reduced from nearly 90% to 60% – a statistically, but not commercially, significant result.

SmartFresh – 1MCP

Key findings

SmartFresh, or 1-MCP, has been widely demonstrated to inhibit ripening of avocado fruit. It can also reduce physiological disorders such as vascular browning, flesh discolouration and chilling damage. Effects on disease are variable, and may be affected by fruit maturity and season. Unfortunately, 1-MCP cannot be "turned off", so ripening variability is a major issue.

- More than 40 scientific papers have already been published discussing the benefits or otherwise of 1-methylcyclopropene (1-MCP) application to avocados. Marketed as SmartFresh, 1-MCP is applied as a gas. It binds irreversibly to the ethylene receptors in plant tissue. In the case of climacteric fruit such as avocado, this prevents it from ripening. After a certain amount of time new ethylene receptors are created, and the fruit can ripen normally[131].
- 1-MCP is most widely used for apples, a fruit where postharvest softening is undesirable. In contrast, avocados need to ripen and soften to become edible. Application of 1-MCP can delay ripening and softening at ambient temperatures by at least 12 days[132]. During this time fruit are insensitive to external application of ethylene; recovery from 1-MCP cannot be hastened artificially[133].
- The effects of 1-MCP on ripening are increased during cold storage. Treatment with 1-MCP allowed storage of Hass avocados for seven weeks, after which time only 10% of fruit was unacceptable compared to 50-90% of the controls[134].

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[130] Bower JP, Papli G. 2006. Effect of fruit coatings and packaging on chilling injury of Hass avocados. SAAGA Yearbook 29:69-72.
[131] Sisler EC, Serek M. 1997. Inhibitors of ethylene responses in plants at the receptor level: recent developments. Physiol. Plant. 100:577-582.
[132] Feng X. et al. 2000. Control of ethylene responses in avocado fruit with 1-methylcyclopropene. Postharvest Biol. Technol. 20:143-150.
[133] Adkins MF et al. 2005. Manipulating avocado fruit ripening with 1-methylcyclopropene. Postharvest Biol. Technol. 35:33-42.
[134] Woolf AB et al. 2005. 1-MCP reduces physiological storage disorders of Hass avocados. Postharvest Biol. Technol. 35:43-60.

Figure 21. Effect of 1-MCP of appearance of Hass stored for 4 (top row) or 7 (bottom row) weeks at 5.5°C + one day at 20°C. Untreated fruit at left, central trays treated with 100nl.L^{-1} 1-MCP, right trays treated with 250nl.L^{-1} 1-MCP. From Woolf et al., 2005.

- Once fruit has started to ripen, 1-MCP is relatively ineffective at slowing down this process. If application of 1-MCP was delayed for more than two days after harvest it had no effect on ripening processes[133].
- Individual fruit vary in their maturity at harvest, as well as how quickly the ethylene receptors regenerate. Perhaps for this reason, avocados treated with 1-MCP are likely to have variable ripening after storage[135]. Variable ripening is an issue not only between fruit, but within fruit, with different parts of an individual avocado softening at different rates[136].
- Exogenous ethylene is unable to correct this issue unless it is applied over several days[136]. Shorter treatments with ethylene did not hasten ripening, but increased body and stem-end rots and discolouration in the flesh[135].
- However, treatment with 1-MCP has effects on fruit other than delaying ripening. There are numerous reports that 1-MCP can reduce physiological disorders, particularly chilling injury and flesh discolouration [134,137]. For example, 1-MCP significantly reduced vascular

[135] Marques JR et al. 2010. A comparison of various systems for long term storage of Hass avocado fruit. Act Hort. 880:317-324.
[136] Pereira MEC, Sargent SA, Huber DJ. 2015. Delayed and prolonged ethylene treatment alleviates firmness asynchrony enhanced by 1-methylcyclopropene exposure in Guatemalan-West Indian avocado. Postharvest Biol. Technol. 108:54-60.
[137] Hershkovitz V, Saguy SI, Pesis E. 2005. Postharvest application of 1-MCP to improve the quality of various avocado cultivars. Postharvest Biol. Technol. 37:252-264.

staining in Maluma avocados in South Africa[138]. It has also been shown to eliminate flesh discolouration of Hass during storage at 6°C and significantly reduce stem-end rots in both early and late season fruit[139]. This treatment is now used commercially to export fruit to Europe[140].

- Export of Australian fruit by sea could also be facilitated by treating with 1-MCP; 1-MCP significantly reduced body rots, stem-end rots, flesh discolouration and vascular browning in Hass avocados ripened after 42 days at 5°C, compared to fruit stored in air alone[135].
- Because 1-MCP increases the number of days for fruit to ripen, rots may be increased[133]. However, results are variable, with other researchers reporting significant decreases in rots in 1-MCP treated fruit. Wang et al[141] suggest differences may be due to initial levels of anti-fungal compounds (AFDs) in fruit. Early harvested fruit had high AFD levels, so no increase in anthracnose development was found. However, in late harvested fruit initial levels of AFD were less. When combined with inhibition of formation of AFDs following 1-MCP treatment, levels fell below the threshold that prevented development of disease.

Heat treatments

Key findings

Postharvest heat treatments have been shown to reduce chilling sensitivity and rots in many other crops. However, the results for avocados appear variable, with a relatively narrow band of effective time/temperature combinations. While they may provide some protection from chilling damage during quarantine cold treatments, they are unlikely to be useful for general quality improvement.

- The development of heat shock proteins in avocado fruit was discussed in section 0. Exposure to heat can stimulate production of compounds that protect the fruit from further temperature stresses, hot or cold[9].
- Short hot water treatments have shown to protect a range of fruit from chilling damage, as well as reducing postharvest disease[142].
- Low temperature (<5°C) storage of avocados could potentially help increase storage and shelf life. It could also be used as a disinfestation treatment against fruit fly, as part of a quarantine protocol to access sensitive markets. Reducing chilling sensitivity therefore appears to have many potential benefits.
- Woolf[143] determined that 60 minutes in 38°C water was optimal in terms of reducing chilling sensitivity and avoiding skin damage. This treatment significantly reduced internal breakdown, vascular browning and uneven ripening following 28 days storage at 0.5°C.

[138] Mhlophe SD, Kruger FJ. 2013. Addressing the postharvest vascular staining disorder of Maluma avocado fruit. Acta Hort. 1007:145-151.
[139] Lemmer D, Kruger FJ. 2010. Effect of cold chain breaks on the ripening and quality of Hass avocados. SAAGA Yearbook 33:14-24.
[140] Kruger FJ, Lemmer D. 2011. Commercialisation of SmartFresh (1-MCP) in the South African avocado industry. SA Fruit J. 10:51-55.
[141] Wang X et al. 2005. 1-MCP prevents ethylene-induced accumulation of antifungal diene in avocado fruit. Phys. Mol. Plant Path. 67:261-267.
[142] Lurie S. 1998. Postharvest heat treatments. Postharvest biol. Technol. 14:257-269.
[143] Woolf AB. 1997. Reduction of chilling injury in stored Hass avocado fruit by 38°C water treatments. HortScience 32:1247-1251.

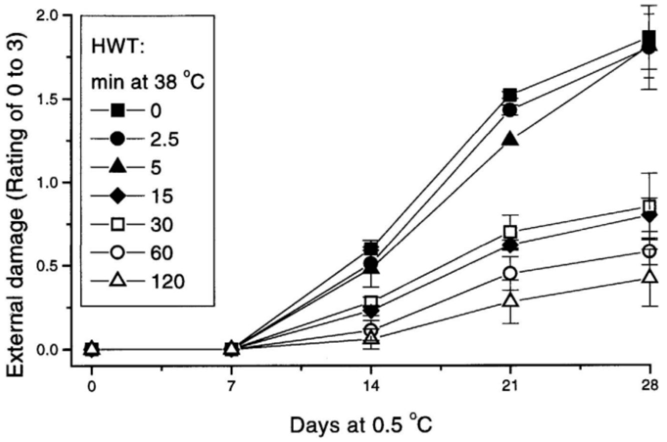

Figure 22. Effect of different durations of hot water treatment on appearance of Hass avocados after up to 28 days storage at 0.5°C. Avocado at right has been half immersed in water, so the left half is extremely chill damaged but the right half is ripening normally. Form Woolf, 1997.

- Heat treatments for insect control are likely to damage fruit. For example, vapour heat treatment for medfly resulted in severe surface browning and failure to ripen. The treatment was severe; eight hours at 43°C[144].
- Cold disinfestation for Queensland fruit fly requires 16 days storage at 1°C. Hot water treatment for 20–30 minutes at 41°C or 20 minutes at 42°C protected fruit from chilling injury during disinfestation. The lower temperature also reduced body rots. However, vascular browning was slightly increased, with variable results by season[145].
- Generally, treatment temperatures below 34°C have little effect on reducing chilling sensitivity of Hass, while those above 42°C damage fruit[91]. Also, effectiveness may vary, with South African research showing no protective effect from treatments of up to 30 minutes at 40°C across several seasons[146].
- Fuerte avocados appear to be more sensitive to heat treatment damage than Hass. Vapour heat treatment at 40°C reduced chilling injury following storage at 3.5°C, whereas 40°C water caused severe skin blackening[147].

Low temperature conditioning

Key findings

Low temperature conditioning, where fruit are held just above the chilling threshold for a few days before cooling further, has been reported as an efficient way to store fruit over an extended period at low temperatures, as required for cold disinfestation of fruit fly. Although studies of this method in the scientific literature are limited and results appear mixed, there appears to be commercial adoption of this method.

- Low temperature conditioning involves reducing temperature in a series of steps, the first of which is just above the temperature at which injury occurs. Pre-cooling, or low

[144] Kerbel EL, Mitchell G, Mayer G. 1987. Effect of postharvest heat treatments for insect control on the quality and market life of avocados. HortScience 22:92-94.
[145] Hofman PJ et al. 2002. Hot water treatments to improve Hass avocado fruit quality after cold disinfestation. Postharvest Biol. Technol. 24:183-192.
[146] Blakey RJ, Bower JP. 2007. The feasibility of a hot water treatment for South African avocados cv Hass. SAAGA Yearbook 30:66-68.
[147] Donkin DJ, Wolstenholme BN. 1995. Postharvest heat treatments with a view to reducing chilling sensitivity of Fuerte avocado fruit. SAAGA Yearbook 18:80-84.

temperature conditioning, has been demonstrated to reduce chilling sensitivity in fruit such as zucchini, capsicums, grapefruit and papaya[148].

- Both Woolf et al[148] and Hofman et al[149] reported that holding Hass avocados at 6–8°C for three or four days before storage at ~1°C reduced dark patches on the fruit skin, this being an expression of chilling damage. In Queensland, this increased the percentage of fruit that still appeared acceptable after cold disinfestation (16 days at 1°C) from 0 to 100%. This treatment has been used commercially to disinfest and export avocados from Australia to New Zealand[150].
- Pre-conditioning could therefore be used to allow longer storage of fruit, such as during sea freight. Hass which were pre-conditioned at 6°C for three days then stored at 2°C had significantly reduced rots and diffuse discolouration compared to fruit stored at 5°C. After 30 or 40 days storage, 66% and 48% of pre-conditioned fruit remained in acceptable condition, compared to 0% of fruit stored at 5°C[151].

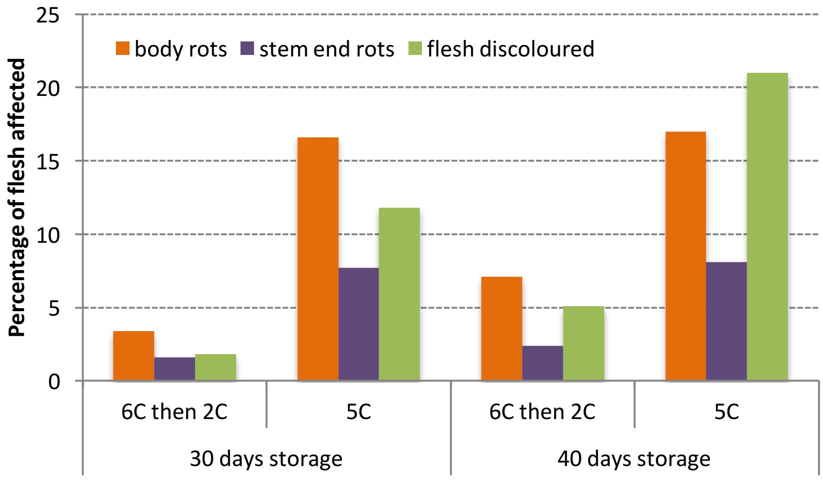

Figure 23. Rots and flesh discolouration of Hass either pre-conditioned at 6°C for 3 days then stored at 2°C or simply stored at 5°C. Quality assessed after storage for 30 or 40 days then ripening at 20°C.

- However, Marques[135] did not find any benefit from low temperature conditioning of Hass at 6°C for three days before storage at 1°C. In this trial both body rots and stem-end rots were increased in pre-conditioned fruit compared to fruit stored at 5°C for 42 days. This suggests that, in this case, the conditioning treatment was insufficient to protect fruit from chilling damage. The reasons for this disparity with previously reported results are not known.

[148] Woolf AB et al. 2003. Low temperature conditioning treatments reduce external chilling injury of Hass avocados. Postharvest Biol. Technol. 28:113-122.
[149] Hofman PJ et al. 2003. Low temperature conditioning before cold disinfestation improves Hass avocado fruit quality. Postharvest Biol. Technol. 28:123-133.
[150] Hofman PJ. 2005. Skin damage to Hass avocados can cause quality problems down the track. Talking Avocados 16:24-26.
[151] Hofman PJ et al. 2010. Using lower temperatures to improve Hass. Talking Avocados 21:26-29.

4.3 Grading and packing

Packing line operation

Key findings

Avocados are often washed or otherwise wet during grading and packing. They need to be dried before packing to reduce the chance of rots developing during storage.

Skin damage caused by grading lines can be significant. This is often caused by rubbing of the raised nodules or lenticels on Hass fruit. Damage may not be obvious immediately, but result in skin spotting and dark patches after extended storage. Symptoms of chilling damage are increased on fruit with pre-existing superficial injuries, which may also be more susceptible to rots.

Bruising is not usually an issue, and can be further reduced if fruit are cold during grading and cooled to 5°C immediately after packing. However, packed fruit must still be handled carefully; dropping a packed tray only 15cm can cause bruising. Effects are most severe if the tray is dropped flat, as onto a pallet.

- Avocados may need to be washed during grading so as to remove dirt or field-applied fungicides from the fruit skin. However, fruit need to be dried before they are packed into trays or boxes. Fruit packed while still wet has an increased risk of disease. Moreover, evaporative cooling from the skin can allow fruit to cool below the room set-point, potentially initiating chilling injury[91].
- In South Africa, avocados are tipped into a water bath, and the fruit floated through the sorting system[152].
- In Australia, and many other avocado growing regions, fruit are usually dry tipped onto the line. As fruit are hard green at this stage, and impacts can be minimised, bruising does not appear to be an issue. Hofman[153] reported that only 0.6% of fruit sampled directly from the packing line had internal bruising when ripe[153].
- Bruising during grading and packing is further minimised if fruit are cold. Avocados impacted while fruit temperature was 2.5°C had significantly less bruising than fruit impacted at 20°C, even after ripening[154].
- The effect of jostling of fruit against each other and hard surfaces was discussed in sections 0 and 0. Just as during harvest, grading can also cause superficial damage, particularly to the raised nodules on Hass fruit skin. The result is the formation of dark spots <1mm diameter on the area, usually appearing 1–4 days after damage occurred[154].
- Hofman[150] has shown that skin spotting and discoloured patches visible on avocados after cold disinfestation (16 days at 1°C) have their origin in skin damage during harvest and packing. The brushing systems used on packing lines are a particular issue, with damage to the nodules on Hass fruit caused by rotating fruit rubbing against each other. This damage intensifies chilling damage and is likely to increase disease, with rots often developing under the damaged area.

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[152] Le Roux Y. Supply chain analysis and improvement = towards high quality ripe and ready avocados. Final Report BPJ420 University of Pretoria and ZZ2 Afrikado.
[153] Hofman PJ. 2003. Bruising of Hass avocado from harvest to packhouse. Horticulture Australia Final Report AV02015.
[154] Joyce DJ, Mazhar S, Hofman PJ. 2015. Reducing flesh bruising and skin spotting in Hass avocado. Hort. Innovation Final Report AV10019.

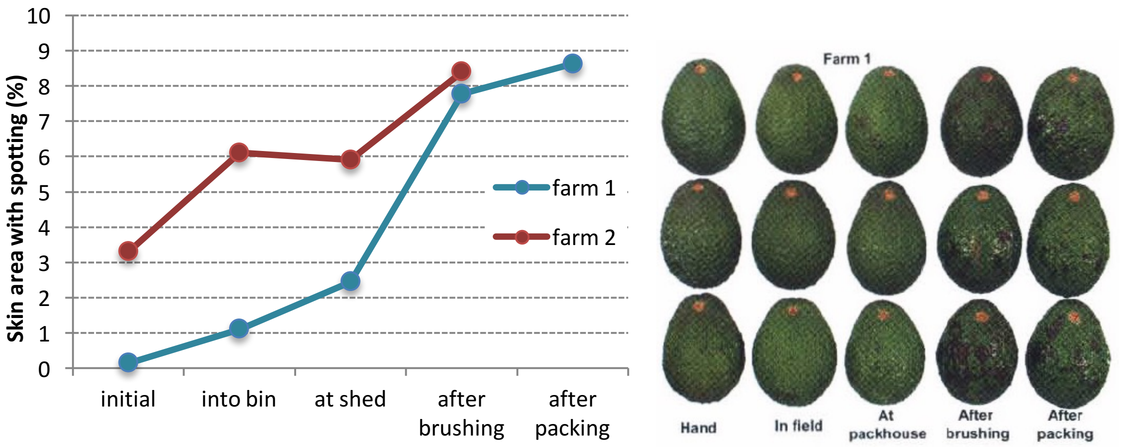

Figure 24. External quality of Hass sampled at different points from picking to packing, effects visible after storage for 16 days at 1°C. From Hofman, 2005.

- Trials in NZ have also demonstrated that the more that fruit are handled after harvest, the greater the likelihood of rots after storage and ripening. This effect is cumulative, so includes harvest and transport as well as impacts during grading[100].
- High pressure water blasting was developed to remove insect pests from the fruit surface. Water blasting can reduce the need for brushing the fruit surface, while still removing hard to remove surface contaminants, such as pollen, and residues from copper sprays[155].
- Packed fruit should still be handled carefully. Joyce et al[154] showed that a 15cm drop causes significant bruising in packed trays of fruit, especially if the tray was dropped flat – as it might be onto a packed pallet. Bruising increases with drop height.

Sorting for quality

Key findings

Variable maturity within a batch of fruit contributes to uneven ripening and different responses to low temperature storage. Commercial sorting machines are available which segregate fruit based on near infrared spectroscopy (NIRS). This method has been shown to accurately predict dry matter of whole avocados, especially if calibrated over several seasons. As well as maturity, NIRS can detect bruising and internal rots with 90% accuracy. Magnetic resonance imaging (MRI) can also detect internal damage of avocados. However, the method is too slow for in-line application, and devices are more expensive than NIRS.

- Avocados are likely to vary considerably in their maturity at harvest. Variability is likely to occur within blocks, between trees and even according to position on the tree. Fruit to fruit variation is even more likely if fruit set over a long flowering period. Fruit maturity has considerable effect on sensitivity to cold, quality after storage and ripening rate[91].
- Avocados are currently sorted on the basis of size and external defects. However, there are now a number of technologies that could be used to sort fruit according to internal quality and firmness. This could permit product to be sorted for local versus export markets, and result in a more homogenous product after ripening. A rapid, non-destructive system that provided more consistent eating quality to consumers could improve industry competitiveness and profitability[156].

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[155] Pak HA, Dixon J. 2002. Influence of water blasting on development of ripe rots. NZ AGA Ann. Res. Rep. 2. 7pp.
[156] Wedding B et al. 2011. Non-invasive assessment of avocado quality attributes. Proc. 7th World Avocado Conf. pp. 5-15.

- ***Magnetic resonance imaging*** (MRI) is used in medicine to form and image of the internal condition of the body. Sensors record the signals given by hydrogen ions when exposed to a magnetic field, mapping the locations of water and fat. Recent Australian research has shown that MRI can detect internal bruising in avocados, even before the damage is visible as browning of the damaged flesh. The injury caused by a 1m drop at the hard green stage or a 25cm drop at the firm ripe stage are clearly visible in an MRI scan. The limitations of this method are that the equipment is large and expensive and scans are slow. However, the authors suggest that low-cost MRI equipment could be used to test samples of fruit for internal damage before retail[157].

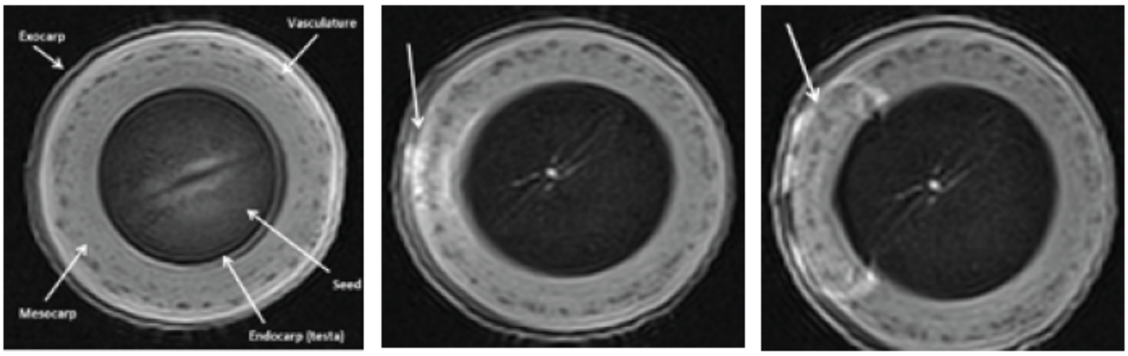

Figure 25. Transverse section MRI scans of an avocado before dropping (left), after dropping 50cm with impact site marked with an arrow (centre) and 3 days after impacting (right). From Mazhar et al., 2013[158].

- ***Near infrared spectroscopy*** (NIRS) uses light absorbance at different wavelengths to estimate internal quality attributes of different products. Use of NIR to measure dry matter (DM) content of avocados is discussed in section 0 of this document.
- In-line NIRS systems are already available which can process 10-15 items per second. These are generally designed to measure sugar content, segregating products such as stonefruit, apples and melons. There has not been good uptake of this technology, however, as the equipment effectively increases wastage. This could be less of an issue for avocados, as the aim would be to reduce variability in storage and ripening, rather than to reject fruit below a certain DM content.
- As previously noted in this review, DM content varies considerably within the fruit flesh. At least two spectra need to be recorded for each fruit, preferably at about the same point between top and base[159].
- There have been a number of papers published on the use of NIR to classify whole avocado fruit during sorting and packing. For example Clark et al[160] investigated using a spectrophotometer to assess maturity of NZ Hass avocados, calibrating the equipment using fruit with DM of 20-45%. Accuracy was within 0.75% at low range and 1.9% at the high range. Smilovitch[161] reported that DM of Ettinger and Fuerte avocados grown in Israel could be predicted within 0.9 and 1.3% respectively.

[157] Mazhar M et al. 2015. Non-destructive H-MRI assessment of flesh bruising in avocado (*Persea americana*) cv Hass. Postharvest Biol. Technol. 100:33-40.
[158] Mazhar M et al. 2013. MRI as a non-invasive research tool. Talking Avocados 23:22-23.
[159] Wedding B et al. 2011. The application of near infrared spectroscopy for the assessment of avocado quality attributes. In 'Infrared Spectroscopy – Life and Biomedical Sciences'. Open access book at intechopen.com/books/infrared-spectroscopy-life-and-biomedical-sciences.
[160] Clark CJ et al. 2003. Dry matter determination in Hass avocado by NIR spectroscopy. Postharvest Biol. Technol. 29:300-307.
[161] Smilovitch Z et al. 2001. Determination of avocado fruit maturity using near infrared spectrometry. Acta Hort. 562:175-179.

- Similar work has been conducted in South Africa. Measurement accuracy was within 1.8%. The authors suggest that in-line sorting of avocados would overcome the issue of ripening variability within consignments, an issue which creates major logistical issues for South African exporters[162].
- In Australia, tests using a commercial, in-line NIR system have also shown it is possible to estimate DM of whole avocado fruit. Results for Sheppard were slightly better than those for Hass, presumably due to the formers thinner skin, and were greatly improved using multiple seasons and location data. The device also proved 90% accurate in classifying rots and bruises on fruit[156].

[162] Blakey RJ, Bower JP, Bertling I. 2008. Influence of water and ABA supply on the ripening pattern of avocado fruit and the prediction of water content using Near Infrared Spectroscopy. Postharvest Biol. Technol. 53:72-76.

5 Cooling and storage

5.1 Cooling

Key findings

Fruit that is warmer than the surrounding air inevitably loses moisture. Cooling products quickly ensures moisture loss is minimised and quality is maintained, and is essential if avocados are to be stored for an extended period. Delays in cooling can significantly reduce quality of ripened fruit.

Room cooling is likely to result in slow cooling rates and development of hot and cold spots inside trays. Forced-air systems significantly increase both speed and uniformity of cooling, reducing moisture loss. Flow rates of 0.34 to 1.0 $L.kg^{-1}.sec^{-1}$ have been proposed. Hydrocooling is even faster, with cooling times as short as 20 to 30 minutes. No moisture is lost, and some may even be gained during this process. Although a fast cooling method, hydrocooling has not been adopted in Australia due to concern about spread of disease and difficulty fitting it into normal packing processes.

- Cooling after packing is the most critical point in the cool chain. Rapid cooling after harvest minimises moisture and quality loss. Most dehydration occurs during initial cooling, when fruit is still significantly warmer than the surrounding air. As a guide for perishable products, it is stated that as much deterioration can occur in one hour at 25°C as in one week at 1°C[163]. Efficient cooling is particularly important if fruit is destined for long term storage[33].
- Delays in cooling, or slow cooling rates, can have negative effects that may not become apparent until after fruit are ripened. For example, delaying cooling by 24 hours reduced the number of sound Hass fruit from around 80% to 60% when fruit were stored for 28 days at 1°C[164]. In another trial, cooling was conducted in stages, with fruit left at 16°C for one to five days before cooling to 5.5°C. In this case, the aim was to reduce chilling sensitivity in the fruit. However, the opposite occurred. The longer the period fruit spent at 16°C the greater the cold damage observed after 28 days storage.
- These effects may be due to loss of the compounds (possibly 7 carbon sugars) associated with ripening inhibition. In effect, delays in cooling allow fruit to progress further down the path to ripening[165]. Fruit which is ripening, so has an increased respiration rate and ethylene production, is most susceptible to cold damage (see section 6.3 for more on this) and likely to have poor quality after removal to ambient conditions.
- Traditional room cooling involves simply placing pallets inside the cold room. In this situation, air flows mainly around the outside of the palletised cartons, resulting in slow and uneven cooling. Cooling rates may be only $0.5°C/h^{-1}$ in a typical cool-room. Non-uniform cooling results in over or under cooling of product in different locations, with corresponding effects on quality[166]. Leaving gaps between pallets or air-stacking cartons increases air flow, but does not solve this issue[33].

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[163] Brosnan T, Sun D-W. 2001. Precooling techniques and applications for horticultural products – review. Int. J. Refrig. 24:154-170.
[164] Blakey RJ, Bower JP. 2009. The importance of maintaining the cold chain for avocado ripening quality. SAAGA Yearbook 32:48-52.
[165] Kok RD, Bower JP, Bertling I. 2012. The physiological effects of ultra-low temperature shipping and cold chain break on Hass avocados. SAAGA Yearbook 35:28-33.
[166] Redding GP et al. 2016. A review on the use and design of produce simulators for horticultural forced-air cooling studies. J. Food Eng. 190:80-93.

- Forced air (pressure cooling) systems can greatly reduce cooling times. Effectively, they increase the surface area for heat transfer from that of the box or bin to that of the product itself. Cooling rates are determined by how quickly heat transfer can occur, which is governed by factors such as package venting design and stacking arrangement[167].
- For example, forced air cooling (200-400m.min^{-1}) reduces the time to cool boxes of apples from around 12 hours to 4 hours or even 1.25 hours, depending on the venting in cartons and the capacity of the system[168].
- Typical flow rates recommended for forced air cooling are 0.5–2.0 L.kg^{-1}.sec^{-1}. Avocados can be forced air cooled to around 5°C in 8 hours with an air flow rate of 1.0 L.sec^{-1}.kg^{-1} [169]. Increasing the flow rate to 2.0 L.sec^{-1}.kg^{-1} could theoretically reduce the half cooling time by 26%[170], but may not be practical to achieve given the equipment required. In fact, O'Sullivan et al suggest that – at least in the case of kiwifruit – increases in flow rate beyond 0.34 L.sec^{-1}.kg^{-1} provide little additional benefit but drastically increase power requirements [171].
- Hydrocooling offers a faster method of cooling than forced air systems. Cooling times of 20 to 30 minutes are possible. Unlike other cooling methods, no moisture is lost, and some may even be gained as water can be internalised during the process. The adoption of hydrocooling by packing houses in the USA during the 1970's provided a method of consistently and rapidly removing field heat, thereby extending the potential for storage and transport[172].
- Hydrocooling has not been adopted in Australia. This is possibly because of increased cost as well as the complication of subsequently drying fruit. If hot avocados are dipped into cold water the internal airspaces contract, sucking water into the fruit. This means it is essential to properly sanitise the hydrocooling water to prevent spread of human or plant pathogens. In addition, Australian practice is to cool after packing, rather than before. Clearly, avocados in cardboard trays cannot be hydrocooled.

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[167] Pathare PB et al. 2012. Design of packaging vents for cooling fresh horticultural produce. Food Bioproc. Eng. 5:2031-2045.
[168] Hall EG. 1972. Precooling and container shipping of citrus fruit. Fruit World Mkt. Grower. 73:25-32.
[169] Watkins JB, Ledger SN. 1990. Forced-Air Cooling. 2nd ed. Queensland Department of Primary Industries, Brisbane.
[170] De Castro LR, Vigneault C, Cortez LAB. 2004. Effect of container opening area on air distribution during pre-cooling of horticultural produce. Trans. ASAE 47:2033-2038.
[171] O'Sullivan J et al. 2016. Modelling the forced-air cooling mechanisms and performance of polylined horticultural produce. Postharvest Biol. Technol. 120:23-35.
[172] Campbell CA. Handling of Florida-grown and imported tropical fruits and vegetables. HortSci. 29:975-978.

5.2 Cold storage

Maintaining the cold chain

Key findings

Once product has been cooled, it is essential to maintain the cold chain through to ripening. Breaks of only 5 hours can have major impacts on product quality after ripening, especially if they occur after several weeks' storage. Poor cold chain management can allow fruit to initiate ripening processes, making them more susceptible to diseases and disorders.

- Maintaining the cold chain is essential for good outturn quality. A major 3 year study by South African researchers[139, 165] has shown that a break for as little as 5 hours during 28 days storage can have a major impact on fruit quality.
- Cold chain breaks were shown to reduce the number of days taken to ripen as well as increase the incidence of stem-end rot and anthracnose. The longer the break (5 to 20 hours) and the later it occurred during storage (day 5 to day 20), the greater the resulting increase in stem-end rot.
- It was also noted that a break late in storage (20 days) resulted in a sharp increase in respiration, similar to that associated with ripening. If fruit has started to soften in storage, this could explain the dramatic results on rots, especially for late season fruit. For example, stem-end rots and anthracnose increased from 0% and 3% in control fruit to 28% and 15% in fruit subjected to a 20 hour cold chain break at day 20 during storage.
- It had been thought that a break in low temperature storage could reduce chilling injury (expressed as grey pulp), but no such benefit was observed[165].

Temperature

Key findings

Temperature is the most important factor affecting quality of stored avocados. However, finding the optimum storage temperature is not easy. Low temperatures can cause chilling damage, while high temperatures may increase flesh discolouration and rots.

Reports regarding the low temperature storage limits for avocados are mixed, with some researchers reporting improved quality at 1 or 2°C compared to 5°C, while others report increased damage. Cold sensitivity can vary according to growing location, harvest maturity and possibly season. Reducing temperature over time may also mitigate negative effects of cold. If ripening initiates during cold storage then damage is likely to be severe; variability in fruit age and physiology may be one explanation for such varying results.

- Temperature is the most important factor affecting postharvest quality of fruit and vegetables. It affects all biological processes. The challenge with avocados is to slow natural fruit deterioration through cooling without causing chilling injury[91].
- Despite decades of research, chilling injury remains poorly understood. It appears to relate to membrane dysfunction, but the reasons why sensitivity varies between crops and cultivars, and how chilling injury relates to growing conditions, is still not known.
- Confusingly, some apparent symptoms of chilling injury are worse at higher storage temperatures than at 1 or 2°C. This is possibly due to increased metabolic activity, which allows symptoms of damage to develop more quickly. This gives rise to a so-called 'killing

zone'. For example, stonefruit are recommended to be stored either below 2°C or above 7.6°C to reduce development of mealiness and discolouration in the flesh[173].

- A similar effect has been observed with Pinkerton avocados. Flesh discolouration during storage, a disorder previously ascribed to chilling injury, was found to be reduced by storage at 2°C, well below the recommended temperature of 5.5°C[174].
- Similarly, a storage temperature of 1°C is proposed for South African Hass avocados. So long as the cold chain was maintained, and fruit were kept under high relative humidity, 28 days storage at 1°C resulted in 80% sound fruit. In contrast, only around 25% of fruit at 5.5°C were still considered sound after ripening[175].
- Hofman[151] has also suggested reducing storage temperature in order to improve quality. A low temperature pre-conditioning treatment (described in section 0) was used to reduce chilling sensitivity, before fruit were stored at 1, 2, 3, 4 or 5°C for 31 days. Body rots, stem-end rots and diffuse discolouration were significantly reduced in the fruit held at 1 or 2°C after pre-conditioning. Despite this, it should be noted that the percentage of acceptable fruit was generally low in this trial, being less than 60%.

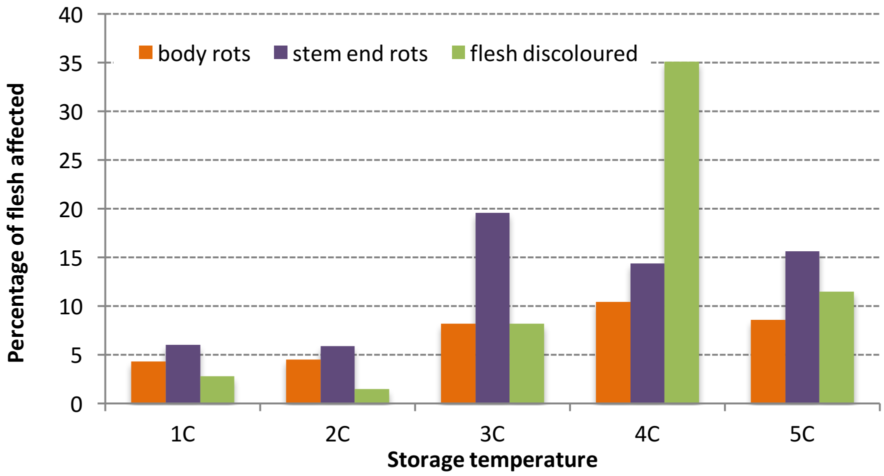

Figure 26. Rots and diffuse discolouration in flesh of Hass avocados pre-conditioned at 6°C for 3 days then stored at 1 to 5°C for 31 days. Quality assessed after ripening at 20°C. Derived from Hofman et al., 2010.

- However, not every research paper reports improved quality at lower storage temperatures. Dixon et al[79] found that stem end rots and brown patches were worse at 2°C than at 5°C for NZ Hass, regardless of harvest date and at storage times of up to 6 weeks. Marques et al[211] also reported better quality during extended storage at 5°C than at 2°C for Hass harvested in Nambour, Qld. Such variable results make it difficult to determine what the best storage temperature should be for any batch of fruit.
- Chilling sensitivity, and therefore optimal storage temperature, does change with harvest maturity. In South Africa, early season fruit have been shown to be more sensitive to low temperatures than late season fruit. However, fruit that are overmature are also more likely to develop internal discolouration under cold storage conditions[176].

[173] Lurie S, Crisosto CH. 2005. Chilling injury in peach and nectarine. Postharvest Biol. Technol. 37:195-208.
[174] Van Rooyen Z, Bower JP. 2006. Effects of storage temperature, harvest date and fruit origin on post-harvest physiology and the severity of mesocarp discolouration in Pinkerton avocado. J. Hort. Sci. Biotech. 81:89-98.
[175] Blakey RJ, Bower JP, Bertling I. 2011. Importance of cold chain maintenance and storage temperature to avocado ripening and quality. Acta Hort. 911:555-564.
[176] Toerien JC. 1986. Temperature control of avocados for sea export. SAAGA Yearbook 9:31-32.

- Similar results have been reported in New Zealand. A study by Dixon et al[177] found that fruit harvested early (DM = 24%), mid (DM = 28%) and late (DM = 34.3%) in the season differed in optimum storage temperature. In this trial, fruit from harvest 2 were the least chilling sensitive, while fruit from harvest 3 suffered the most chilling damage expressed as flesh discolouration, discrete patches and body rots.
- Chilling sensitivity can vary between growing regions and over time. Fruit grown in a high altitude region of South Africa were more chilling sensitive than those grown in more temperate areas. However, if temperature was reduced gradually during storage (by approx. 1.5°C per week) then cold injury could be avoided[176].
- If fruit enters the climacteric stage during storage – as can occur at 5°C, and becomes more likely over time – then chilling injury is likely[176]. Chilling sensitivity of Fuerte and Hass avocados is a function of the stage of the climacteric. According to Kosiyachinda and Young, fruit could be held at 2°C without injury for various time periods during the pre-climacteric and post-climacteric phases. However, during the climacteric rise and at the climacteric peak, fruit became highly cold sensitive[178].
- For example, Zauberman and Jobin-Decor[207] stored Hass avocados at 2, 5 or 8°C for four weeks. Fruit stored at 8°C started to soften and change colour after two weeks, while fruit stored at 5°C started to change after 3 weeks. Flesh discolouration and vascular browning was most severe at 8°C, slight at 5°C, and non-existent at 2°C, the latter fruit ripening normally after transfer to 22°C.
- Initiation of ripening processes during storage is therefore likely to be a key reason why chilling injury can be more severe at higher storage temperatures than at 1 to 2°C.

Humidity and air flow rates

Key findings

Maintaining good airflow during storage and avoiding moisture loss are essential for good outturn quality. Moisture loss not only reduces product weight, but can increase incidence of rots and skin discolouration and potentially trigger ripening during storage. Maintaining high RH around fruit also helps protect it from cold damage, possibly by reducing stress.

- Well-designed cooling systems should maintain the room at above 85% RH. This is best achieved by minimising the temperature differential between the room set-point and the cooling coils. Humidity can also be increased using misting systems[33].
- Good airflow also prevents 'hot spots' developing during storage. Temperature gradients drive moisture loss from products into the room air. Yearsley et al[179] tested the effect of different air flow rates on moisture loss by packed avocados. They determined that avocados held in a higher airflow rate lost less moisture than avocados held in a low airflow rate, largely because the vapour pressure deficit (due to temperature) was minimised. They therefore recommended an airflow rate of at least 0.2 to 0.6m.sec^{-1} over cooled fruit.
- Moisture loss during storage has more effects then simply reducing product weight. The authors of the above work studied moisture loss because of its relationship with rots,

[177] Dixon J et al. 2003. New Zealand avocado fruit quality: The impact of storage temperature and maturity. Proc. V Congreso Mundial del Aguacate pp 647-652.
[178] Kosiyachinda S, Young RE. 1976. Chilling sensitivity of avocado fruit at different stages of the respiratory climacteric. J. Amer. Soc. Hort. Sci. 101:665-667.
[179] Yearsley C et al. 2002. Effects of airflows during storage or shipping on shelf life quality of Hass avocados. NZ AGA Ann. Res. Rep. 2. 13pp.

disorders and ripening. They suggest that an increase in moisture loss of only 0.5% during storage is likely to increase superficial skin rots by 0 to 15%, stem-end rots by 5 to 10% and body rots by 7 to 20%.

- Similarly, Dixon et al also found a relationship between weight loss and the appearance of discrete patches on NZ Hass. Weight loss of >2% resulted in severe skin discolouration and sunken areas, especially if combined with storage below 3°C. Symptoms varied during the season, possibly with changes in fruit DM.
- Increasing RH around avocados may also reduce chilling sensitivity. South African avocados need to be stored at 1°C as a quarantine disinfestation treatment for certain markets. Fruit was stored at 1°C for 28 days inside packaging designed to increase humidity without affecting O_2 or CO_2 concentrations. These samples retained quality better than fruit in a lower humidity environment, ripening normally without skin damage after storage[180].
- Other trials using a 1°C storage temperature for Hass likewise attribute improved cold tolerance to a reduction in moisture loss. Fruit kept continuously at 1°C lost 8.2% moisture, compared to 17.2% loss in fruit kept at 5.5°C[175].

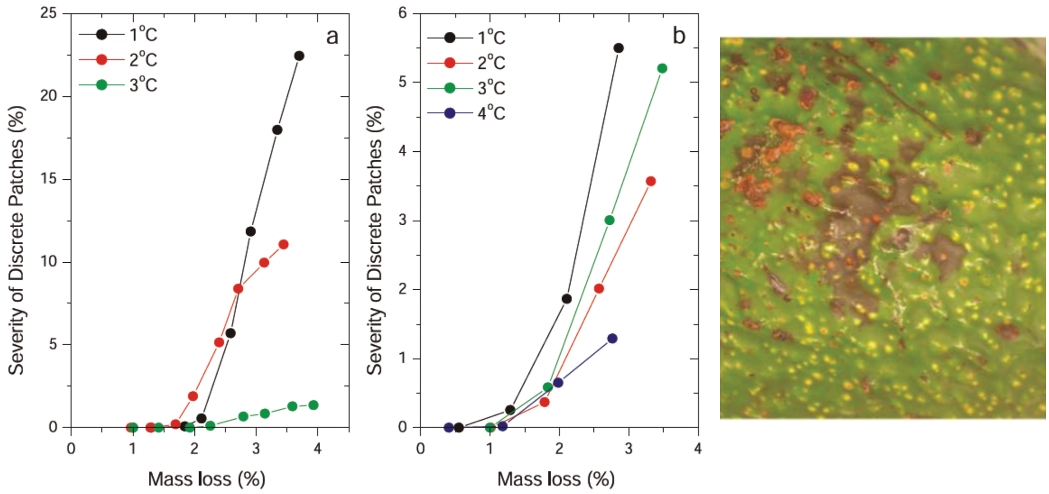

Figure 27. Relationship between development of discrete patches on Hass avocados and moisture loss at different storage temperatures. Fruit harvested in NZ on 9th February (left) or 27th April (centre). Picture at right shows development of discrete patch at 2°C. From Dixon et al., 2008.

[180] Blakey RJ et al. 2014. Ripening physiology and quality of Hass avocado after cold storage at 1°C. J. Hort. Sci. Biotech. 89:655-662.

5.3 Managing the storage environment

Ethylene

Key findings

Removing ethylene from the storage environment has been shown to extend avocado storage life. Unlike fruit treated with the ethylene blocker 1-MCP, fruit protected with an ethylene scavenger can be ripened normally after removal from storage. Newer technologies are now available which may increase the efficacy of this method.

- As with other climacteric fruit, reducing ethylene in the storage environment is essential for preventing ripening and maintaining quality during storage. The use of 1-MCP to block ethylene responses was discussed in section 0.
- An alternative strategy is to remove ethylene using a scrubbing system. Reducing ethylene concentration in the storage environment to 0.005$\mu l.L^{-1}$ (5 parts per billion) has been claimed to reduce chilling injury and increase storage life at 0°C for Hass avocados compared to fruit held in 0.001 to 1.0$\mu l.L^{-1}$ ethylene [181].
- Reducing ethylene below 0.1$\mu l.L^{-1}$ with a palladium promoted ethylene scavenger (e+(R)) slowed softening and colour change of Hass avocados stored at 5°C. While the effect was not as great as that achieved using 1-MCP, the fruit ripened normally after removing from storage. In contrast, the 1-MCP fruit had variable ripeness, remaining firm after 6 days at 20°C[182].
- The e+(R) system is available impregnated into sheets, which can be inserted into avocado trays. Adding a 19 x 26.5cm e+(R) sheet into 4kg trays of avocados prevented ripening during 5 weeks of sea freight form Chile to the UK[183].

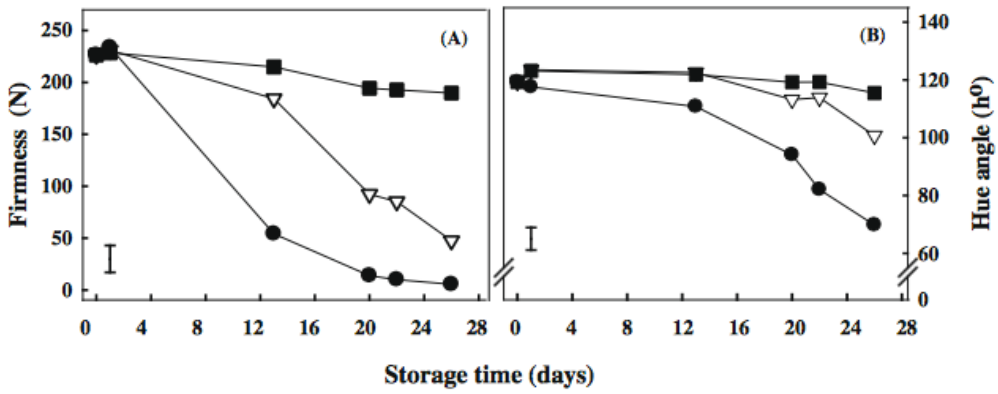

Figure 28. Effect on softening (left) and green colour retention (right) of storing Hass with an ethylene remover (△) compared to air alone (●) or treatment with 1-MCP (■), all stored at 5°C for 4 weeks. From Meyer and Terry, 2010.

[181] Wills RBH, Gibbons SL. 1998. Use of very low ethylene levels to extend the postharvest life of Hass avocado fruit. Int. J. Food Prop. 1:71-76.

[182] Meyer MD, Terry LA. 2010. Fatty acid and sugar composition of avocado cv. Hass in response to treatment with an ethylene scavenger or 1-methylcyclopropene to extend storage life. Food Chem. 121:1203-1210.

[183] Elmi F, Meyer MD, Terry LA. 2012. Extension of avocado storability using e plus (R) ethylene remover coated sheets in sea containers. Acta Hort. 945:325-330.

Controlled atmosphere storage

Key findings

Controlled atmosphere (CA) storage has been demonstrated to be effective at increasing avocado storage life at low temperatures. CA reduces sensitivity to ethylene and prevents initiation of ripening in storage. New systems use the physiological responses of the fruit to minimize oxygen levels without damaging the fruit. Ripening is relatively unaffected and shelf life may be extended.

Although there are many reports of positive outcomes, cost and availability remain barriers to use of CA technology.

- Modifying the storage atmosphere by reducing oxygen (O_2) and/or increasing carbon dioxide (CO_2) provides another way to reduce both ethylene production and ethylene response[184]. Controlled atmospheres (CA) are known to extend storage life and reduce chilling sensitivity in avocados. However, it is important that O_2 does not fall too low or CO_2 rise too high, as this can damage fruit.
- The general recommendation is for atmospheres in the range of 2-5% O_2 and 3-10% CO_2[185]. Examples of specific atmospheres and their benefits include;
    - Meir et al[186] tested a range of atmospheres for storage of Hass. They determined that an atmosphere containing 3% O_2 and 8% CO_2 was the best combination, extending storage life at 5°C up to 9 weeks.
    - Faubion et al[187] also achieved 9 weeks storage life, in this case with an atmosphere containing 2% O_2 and 5% CO_2 at 5.5°C. In this case CO_2 concentrations over 5% increased flesh discolouration, particularly in early season fruit.
    - Storage time of Australian Hass was increased to 10 weeks at 7°C with an atmosphere of 2% O_2 and 4% CO_2[188].
    - Similar results were reported by Marques et al[135]. Avocados stored for 42 days at 5°C in 2% O2 and 5% CO2 were better quality after ripening than fruit stored in air, at 1°C after low temperature conditioning, or treated with 1-MCP. These fruit were even better than those ripened immediately after harvest. Moreover, 98% of CA stored fruit were assessed as 'sound' after 42 days in CA, then 7 days at 5°C in air, then ripening at 18°C.
- The benefits of controlled atmospheres may be further increased using a dynamic system. Whereas a static controlled atmosphere (SCA) system is set at the start of storage, a dynamic controlled atmosphere (DCA) system uses stress responses from the fruit itself to control O_2 level. In the case of avocados, chlorophyll fluorescence has been shown to be a suitable mechanism. Oxygen is reduced until the fruit shows signs of stress, then increased

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[184] Bill M et al. 2014. Avocado fruit quality management during the postharvest supply chain. Food Rev. Int. 30:169-202.
[185] Burdon J et al. 2008. The effect of delays in establishment of a static or dynamic controlled atmosphere on the quality of Hass avocado fruit. Postharvest Biol. Technol. 49:61-68.
[186] Meir S et al. 1995. Further studies on the controlled atmosphere storage of avocado. Postharvest Biol. Technol. 5:323-330.
[187] Faubion DF et al. 1992. Response of Hass avocado to postharvest storage in controlled atmosphere conditions. Proc. 2nd World Avocado Congress, California 1992. pp 467-472.
[188] Smith TE et al. 1992. Long term storage of avocados. In "Proceedings of Conference '97, Searching for Quality, Australian Avocado Growers Federation'. QDPI Brisbane

to avoid damage to the fruit. The system is controlled using HarvestWatch® chlorophyll fluorescence sensors placed over a group of 8-9 avocados[189].

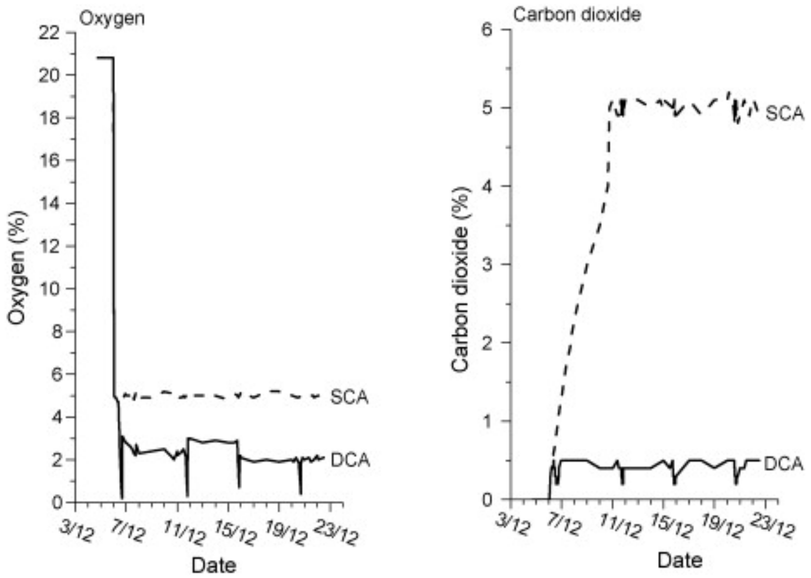

Figure 29. Oxygen and carbon dioxide concentrations inside chambers with a static controlled atmosphere (SCA) or dynamic controlled atmosphere (DCA). From Burdon et al., 2008.

- Burdon et al[190] compared the effects of a DCA system (<3% O_2 + 0.5% or 5% CO_2) to a SCA system (5% O_2 + 5% CO_2). Both DCA and SCA resulted in better outturn quality than air storage after 6 weeks at 5°C. Adding 5% CO_2 to the DCA atmosphere retarded ripening but also increased rots.
- From 1996 onwards, CA shipping containers have been used to export fruit from South Africa to Europe. Use of CA during shipping greatly reduced issues due to fruit softening in transit. During the 2000 export season the majority of fruit was exported in CA, which almost eliminated softening in transit, and resulted in at least one additional week of shelf life, even where fruit age was greater than 30 days[191]. CA has also proven beneficial in managing some, but not all, physiological disorders[192]. However, lack of available containers and the advent of 1-MCP have reduced this method of shipping in recent years.

Modified atmosphere storage

Key findings

Unlike CA, modified atmospheres (MA) use the respiration of the product to reduce O_2 and increase CO_2 in the storage environment. MA packaging has been shown to be effective in the laboratory as it can retain moisture and reduce chilling sensitivity. However, packages designed for storage need to be opened before fruit is warmed and ripened. This requirement has limited commercial adoption of MA packaging.

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[189] Yearsley C et al. 2003. Can dynamic controlled atmosphere storage be used for Hass avocados. Proc. 5th World Avocado Congress, Spain, 2003. pp 665-670.
[190] Burdon J et al. 2008. The effect of delays in establishment of a static or dynamic controlled atmosphere on the quality of Hass avocado fruit. Postharvest Biol. Technol. 49:61-68.
[191] Nelson RM, Bezuidenhout JJ, Donkin DJ. 2000. An overview of the export market situation and fruit quality during the 2000 avocado season. SAAGA Yearbook 24:5-12.
[192] Kruger FJ, Truter AB. 2003. Relationship between preharvest quality determining factors and controlled atmosphere storage in South African export avocados. Acta Hort. 600:109-113.

- Modified atmosphere (MA) storage relies on the respiration of the fruit to change the atmosphere inside a permeable package. Improvements in plastic technology, particularly the ability to increase or decrease the permeability of different films to O_2 and CO_2, has increased attention on this method in recent years[91].
- One advantage of MA is that humidity is kept high around the product, avoiding moisture loss. This may be part of the reason MA has been shown to reduce chilling sensitivity[193]. For example, Meir et al showed that MA packaging of Fuerte fruit inhibited moisture loss, reducing total weight loss in ripe fruit from 11% to 5%. Packaged fruit could be stored for eight weeks at 5°C without any significant chilling injury[194].
- A combination of MA packaging, low temperature conditioning and dipping in methyl jasmonate is proposed by Sivankalyani et al[195] as a way to protect avocados from chilling damage during cold disinfestation treatment (14 days at 1°C). In this case, perforated plastic bags provided an atmosphere of approximately 13–15% O_2 and 3-5% CO_2.

Figure 30. Condition of Hass avocados following 3 weeks at 5°C in air, 1°C in air, or 1°C in MA packaging combined with methyl jasmonate dip and low temperature conditioning. From Sivankalyani et al., 2015.

- A significant disadvantage of MA is that fluctuations in temperature or changes in respiration rate during ripening can lead to damaging gas concentrations developing inside the bag. Packaging therefore needs to be designed either to extend storage life of unripe fruit OR for packaging fruit which has already been triggered and is in the process of softening. If the purpose is long-term cold storage, fruit must be removed from packaging to allow ripening.
- Although MA packaging has been shown successful in the laboratory, commercial use has been limited[91].

[193] Scott KJ, Chaplin GR. 1978. Reduction of chilling injury in avocados stored in sealed polyethylene bags. Trop. Agric. 55:87-90.
[194] Meir S et al. 1998. Modified atmosphere packaging enables prolonged storage of Fuerte avocado fruit. Acta Hort. 464:397-402.
[195] Sivankalyani V et al. 2015. Combined treatments reduce chilling injury and maintain fruit quality in avocado fruit during cold quarantine. PLoS ONE 10:e0140522

5.4 Changes in storage

Key findings

Both pathogens and avocados continue to develop during cold storage, albeit slowly. As anti-fungal compounds in fruit decline, pathogens such as stem end rots can penetrate the fruit flesh. Rots, as well as some physiological disorders, are closely linked with fruit age – the number of days from harvest. It is generally recommended that fruit should be no more than 30 days old when ripe. Fruit age is particularly critical in late season fruit, where deterioration may accelerate after more than ~25 days in storage.

- Pathogens continue to grow during storage, even if it is at a greatly reduced rate. Everett and Pak demonstrated that growth of stem-end rot organisms at 5°C increases with time in storage, presumably as anti-fungal compounds inside the fruit decline. So, it took 35 days for fungi to grow through the remnant stem and penetrate 1–3mm into fruit. Growth was then faster, as they spread through the flesh, so after 42 days the infected area had increased to 3–11mm. In this case, there was a major increase in the number of infected fruit when storage time increased past 28 days (Figure 31).
- This is similar to the results reported by Dixon, who found a sharp increase in rots after 34 days for New Zealand fruit exported to the USA[196].

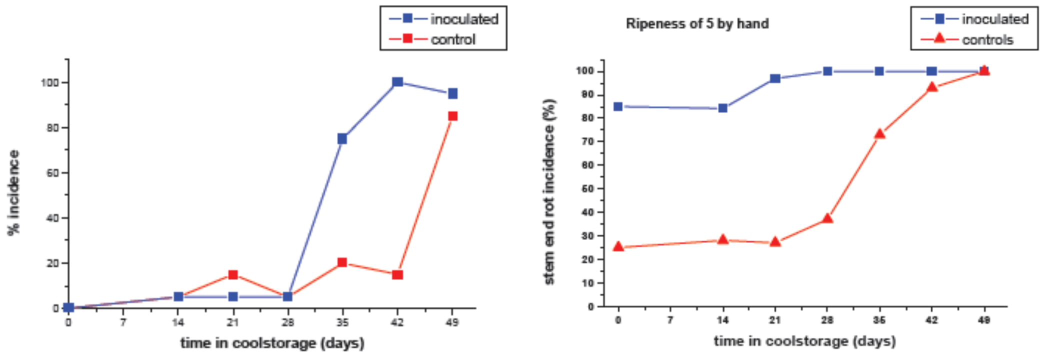

Figure 31. Incidence of stem-end rots, assessed for hard fruit on removal from storage (left) and after ripening (right). Half of the fruit were inoculated with stem-end rot organisms before storage (blue), remainder left untreated (red).

- Both the South African[197] and the New Zealand industry consider fruit age – the number of days from harvest until ripeness – as critical to maintaining quality. Maximum age, or storage life, changes with fruit maturity at harvest. As harvest continues during the season, incidence and severity of rots increases at shorter storage times (Figure 32). So, the maximum storage times that result in good-quality fruit after ripening are reduced as the harvest period continues[198].
- Mandemaker[199] confirmed this effect for NZ avocados exported to Australia. Fruit that was older than 30 days when ripe had a greatly increased percentage of unsound fruit. This

[196] Dixon J. 2001. Development of fruit quality disorders in NZ avocados at outturn in the USA for the 2000-2001 and 2001-2002 seasons. NZ AGA Ann. Res. Rep. 1:31-40.
[197] Bezuidenhout JJ. 1992. Analysis of transit temperature and fruit condition of South African export avocados. SAAGA 15:39-40.
[198] Dixon J et al., 2003. Fruit age management: The key to successful long distance export of New Zealand avocados. NZ AGA Ann. Res. Rep. 3:60-65.
[199] Mandemaker AJ. 2004. The quality of New Zealand avocados in the Australian market. NZ AGA Ann. Res. Rep. 4:61-69.

included fruit affected by stem-end and body rots, but also vascular browning, uneven ripening and flesh discolouration.

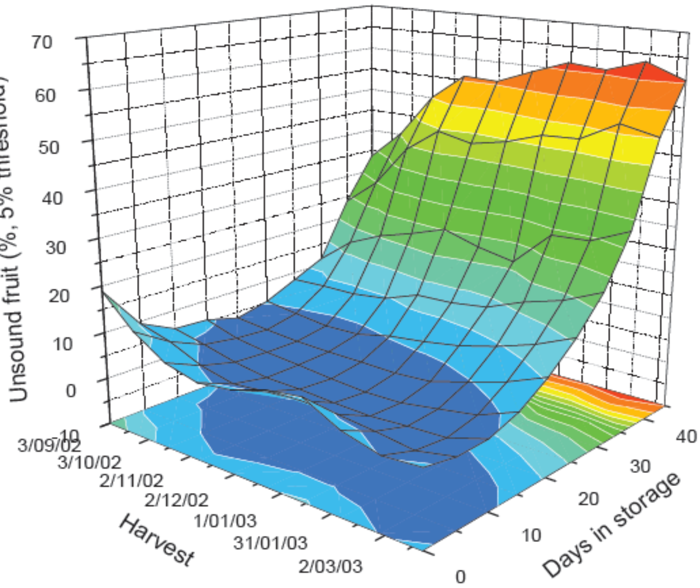

Figure 32. Unsound fruit (using a 5% threshold for disorder severity) for NZ fruit harvested from September to March and removed weekly from 4°C storage. From Dixon et al., 2003.

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6 Ripening

6.1 The ripening process

Key findings

Ripening in avocados is a complex but unstoppable process. Ripening on the tree, and during the first 24 to 72 hours after harvest, is inhibited by an unknown "tree factor". Once this factor declines, fruit enters a pre-climacteric phase where ripening can be induced by ethylene. Ripening occurs coincident with large increases in ethylene production and respiration rate. After the climacteric, respiration and ethylene production fall and the fruit softens to edibility.

- Once ripening has started, it cannot be stopped or reversed, only slowed. Ripening is a complex but ordered process within the fruit, requiring large amounts of energy. As the fruit softens it also becomes more susceptible to pathological and physiological disorders[33], making maintenance of good quality ever more challenging.
- As previously stated, avocados are a highly unusual fruit in that they do not ripen while attached to the tree, even if they are physiologically mature. This is due to unidentified substances released by the tree itself, the so-called "tree factor". A freshly harvested avocado cannot be ripened immediately even if exogenous ethylene is applied, but must wait until the tree factor declines below a critical level[200]. The effects of harvest can be mimicked by girdling the plant stems; presumably this also cuts off supply of the tree factor, thus allowing the fruit to ripen[103].
- The inhibition phase lasts for around 24 to 72 hours after harvest. Fruit then enters the pre-climacteric, where fruit are sensitive to ethylene but not producing ethylene. This is followed by the climacteric, which includes the rise in ethylene production. This phase usually lasts 2–4 days. The final phase is the post-climacteric, where ethylene returns to base levels[201].

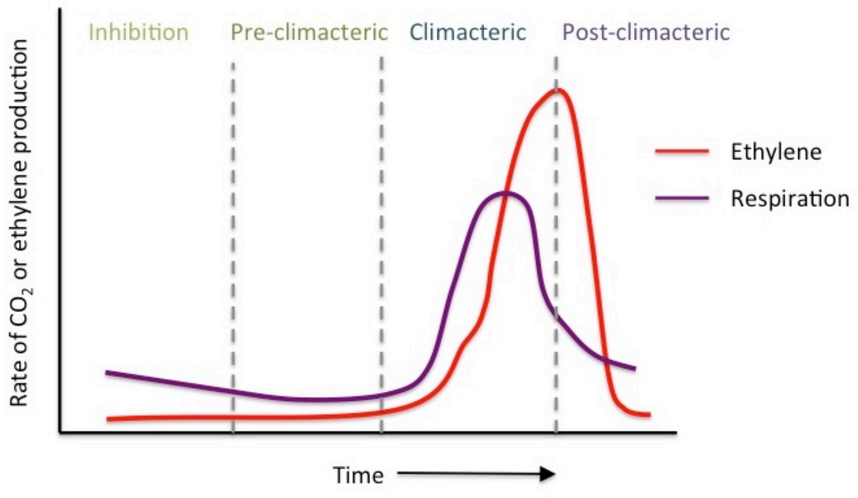

Figure 33. Typical patterns of ethylene production and respiration during the 4 phases of avocado ripening. Derived from Lallu et al., 2004.

[200] Gazit S, Blumenfeld A. 1970. Response of mature avocado fruits to ethylene treatments before and after harvest. J. Amer. Soc. Hort. Sci. 95:229-231.
[201] Lallu N et al. 2004. Role of water loss in ripening of Hass avocados. NZ AGA Ann. Res. Rep. 4:70-79.

6.2 Application of ethylene

Key findings

Induction of ripening with ethylene can reduce variability, shorten the time to edible ripe and restrict disease development. However, if fruit has been stored for a long period or at high temperature, ethylene may not be needed. Ethylene is usually applied at 10ppm or higher using a range of methods. However, ventilation is needed, as high CO_2 in the ripening room can inhibit ripening.

- Commercial ripeners generally trigger ripening with exogenous ethylene. This reduces the time to ripe, increases uniformity among the batch, and can improve outturn quality[33]. Application of ethylene may have fewer benefits if fruit has not been properly cooled during storage and transport, or has been stored for an extended period already[202].
- Ethylene treatment with 50 or 100ppm for 24 to 36 hours at 17°C is sufficient to stimulate rapid ripening. This may be reduced to 12 hours in late harvested fruit, and 3–6 hours if fruit has been previously stored for 10 days at 5°C[203].
- Treatment with 10ppm ethylene has slightly less effect than higher concentrations, indicating the ethylene receptors are not fully saturated at this concentration. Exposure to 1ppm ethylene resulted in very slow ripening rates[204].
- The effects of ethylene on ripening are reduced if CO_2 inside the ripening room increases, as can occur in a sealed chamber with limited headspace and ventilation. As little as 2.5% CO_2 can significantly reduce ripening rate[204].
- Ethylene can be applied using different methods. These are summarised in Hofman et al., 2013, and reproduced in Table 1.

Table 1. Systems for applying ethylene. From Hofman et al., 2013.

Process	Comments	Advantages / disadvantages
Trickle	Constant trickle from gas bottle to maintain around 10ppm ethylene	Good control, convenient. Can be expensive to set up. Requires room ventilation to prevent CO_2 accumulation.
Shot	Ethylene gas injected every 6–8 hours at 100ppm. Room door opened for 15 minutes every 8 hours before ethylene re-injected.	Cheaper to set up. Less control. Risk of CO_2 build-up.
Ethylene generator	Generates ethylene by catalytic breakdown of ethanol.	Dosing can be automated. Removes OH&S issues and costs associated with bottled ethylene.
Ethephon dip	Applied as a solution, ethephon converts to ethylene inside the fruit.	Cheap for small batches. Not practical for large volumes. Not registered in all countries. Classified as hazardous to users.

[202] Arpaia ML et al. 2006. Avocado postharvest quality. Proc. Calif. Avocado Res. Symposium. Irvine, CA pp 143-155.
[203] Woolf A et al. 1997. Ethylene ripening protocols for local and export market avocados. Proc. "Searching for Quality" ed. JG Cutting, pp 38-45.
[204] Arpaia ML, Woolf A, White A. 2004. Avocado postharvest quality. Proc. Calif. Res. Symposium. UC Riverside, October 2004.

6.3 Maturity effects

Key findings

Fruit must be of minimum maturity to ripen normally. As maturity increases during the harvest season, ripening becomes faster. Despite this, new evidence suggests that ripening is associated with accumulation of certain key metabolites, dry matter being a relatively crude indicator of readiness to ripen.

- Normal ripening only occurs if a certain level of maturity has been reached. Attempts to ripen immature fruit result only in slight softening due to water loss, with fruit having poor texture and watery flavour[107].
- There is some evidence that the 7-carbon sugars mannoheptulose and perseitol are key to this process. Liu et al[103] found that ripening could not occur until these declined below a threshold limit of approximately 20mg.g^{-1} fresh weight.
- However, Pedreschi et al[205] have challenged this theory. They found that neither mennoheptulose, perseitol, calcium or even DM correlated with variable ripening rates in Hass avocados. Instead they demonstrate that ripening rate is better correlated with changes in a number of key metabolites, including amino acids and fatty acids.
- The authors suggest that non-destructive measurements of DM – such as NIRS – may still prove inadequate for ensuring homogeneous ripening. Instead, it may be possible to develop a test for specific metabolomic markers for maturity and ripening.
- Despite this, it is clear from numerous reports that as DM increases during the harvest season, time to ripen decreases[206]. For example, Hass avocados harvested at Nambour, Qld, in June took 13 days to ripen (DM = 23.3%), reducing to eight days in July (DM = 27.9%) and six days in August (DM = 35.1%)[207].
- However, the relationship between fruit maturity and ripening rate is often less clear in cold-stored fruit. In this case, accumulation of metabolites, water stress and increases in abscisic acid concentration may also play a role[208].

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[205] Pedreschi R et al. 2014. Metabolomics analysis of postharvest ripening heterogeneity of Hass avocados. Postharvest Biol. Technol. 92:172-179.
[206] Cutting JGM, Wolsterholme BN. 1992. Maturity and water loss effects on avocado postharvest physiology in cool environments. J. Hort. Sci. 67:569-575.
[207] Zauberman G, Jobin-Décor MP. 1995. Avocado quality changes in response to low-temperature storage. Postharvest Biol. Technol. 5:235-243.
[208] Cutting JGM, Wolstenholme BN. 1992. Maturity and water loss effects on avocado postharvest physiology in cool environments. J. hort. Sci. 67:569-575.

6.4 Moisture content

Key findings

There is abundant evidence that moisture loss is associated with ripening. Although the mechanism by which this occurs is less clear, it may be due to water stress stimulating abscisic acid, which in turn increases ethylene production. Water stress soon after harvest can advance ripening, whereas results from infusing water into fruit have been mixed.

- Numerous authors have commented that moisture content, and water loss during storage, are critical in terms of speed of ripening and the end quality of fruit[206]. Bower et al[209] suggest that water is the most important factor in variability of ripening in avocado fruit.
- To test the effect of moisture content on ripening, Adato and Gazit[210] induced different rates of water loss in Fuerte and Hass avocados. They demonstrated that the rate of water loss was closely correlated with time taken for fruit to ripen. An increase in water loss of approximately 1%.day^{-1} reduced days to ripe by approximately 1 day. Conversely, supplying water to the fruit through the pedicel tissue increased the time taken to ripen by several days.
- Similar tests have been conducted on New Zealand Hass. Increasing water loss by 2.5–3.0% during the inhibition phase not only advanced ripening by two days, but also reduced the incidence of stem end rots from 50% to 19%. Inducing water loss during later stages also reduced stem end rots, but did not affect the number of days to ripe[201].
- Blakey et al[162] also found that infusing Hass avocados with 1.5ml of water reduced variability during ripening. The effects were greatest in late harvested fruit, which naturally has a lower moisture content. The authors suggest that moisture loss initiates a number of changes within the fruit, including stimulation of abscisic acid, which in turn increases ethylene production. A water infusion of only 1% of the fruit mass altered ripening behaviour. In contrast, DM can vary by 10% within a consignment.
- In contrast, Cutting and Wolstenholme did not find any effect on ripening of passive water infusion into the fruit, although they did also report that this treatment improved quality after ripening[208].
- A certain threshold of water stress may therefore be a key factor in initiating ripening. This may explain why:
    - Fruit from water stressed trees ripens faster[107]
    - Fruit that has a high DM content, and therefore lower water content at harvest, ripens sooner than less mature fruit
    - Fruit that has been stored for an extended period (potentially losing moisture) ripens faster than non-stored fruit; in general, the longer the storage period, and the higher the temperature, the faster fruit will ripen[211].

[209] Bower JP et al. 2007. Variable ripening of fruit in avocado consignments. VI Avocado Congress.
[210] Adato I, Gazit S. 1974. Water-deficit stress, ethylene production and ripening in avocado fruits. Plant Physiol. 53:45-46.
[211] Marques J et al. 2011. How to store partially ripened Hass avocado fruit. Conference Proceedings.

6.5 Temperature

Temperature management before and during ripening

Key findings

Although higher temperatures can increase ripening rates, this is at the expense of postharvest quality. Avocados are normally ripened at between 15°C and 20°C, with the lower temperature potentially providing the best outturn quality.

Once fruit are partially ripened, they may need to be held for a period to meet supply chain requirements. If fruit are only just "sprung", they are best stored at 2°C.

- Temperature is critical in both preventing initiation of ripening in storage, and in inducing ripening after storage.
- At 5°C, mature avocados can commence ripening during storage. As previously noted, Hass avocados can start ripening after three weeks during storage at 5°C and after only two weeks during storage at 8°C. Fruit that starts to ripen during cold storage has poor internal quality, being more likely to have vascular browning, discoloured flesh and increased rots[207]. This is because fruit undergoing the climacteric peak in respiration and ethylene production has increased sensitivity to chilling[191], perhaps due to the stress of increased metabolic demands at low temperatures.
- Higher temperatures result in faster ripening. However, this can have negative effects. Hopkirk[212] found that increasing the ripening temperature from 15 to 20°C significantly increased stem-end rots and reduced shelf life from 16 to 9 days at 20°C. Ripening fruit at 25 or 30°C not only resulted in uneven ripening, but increased the incidence of body rots to 96% and stem end rots to 66 or 80%.
- During ripening, the skin of Hass avocados changes from green to black. This is due initially to breakdown of chlorophyll, then accumulation of the anthocyanin cyanidin-O-glucoside. When Hass fruit are ripened at 15°C, chlorophyll still breaks down, but less anthocyanin accumulates compared to fruit ripened at 20 or 25°C. The result is a fruit which is soft and ripe, but with less of the purpling that indicates ripeness to consumers[213].
- Ripening at 15°C or 20°C, with or without 100ppm exogenously applied ethylene, does not affect oil content or fatty acid profiles in the ripe fruit, suggesting either strategy can result in fruit with good eating quality[214].
- Ripening at lower temperatures is recommended if the risk of disease is high, whereas higher temperatures can be used if disease risk is lower[96]. This may be why Australian industry recommendations are for lower ripening temperatures for late season fruit.

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[212] Hopkirk G et al. 2010. Influence of postharvest temperatures and the rate of fruit ripening on internal postharvest rots and disorders for New Zealand Hass avocado fruit. NZ J. Crop hort. Sci. 22:3005-311.
[213] Cox K et al. 2004. Skin colour and pigment changes during ripening of Hass avocado fruit. Postharvest Biol. Technol. 31:287-294.
[214] Pedreschi R et al. 2016. Impact of postharvest ripening strategies on Hass avocado fatty acid profiles. South African J. Botany. 103:32-35.

Temperature management after ripening

Key findings

Once fruit are partially ripened, they may need to be held for a period to meet supply chain requirements. If avocados are still rubbery, they are best stored at 2°C. If fruit are starting to soften, even slightly, then they should be stored at 5 to 8°C. Storage times of up to two weeks are possible, but periods longer than this are likely to increase the number of unacceptable fruit.

- Once fruit have been sprung, they are generally cooled for transport to retail stores or held for a period to meet supply chain requirements.
- Marques et al[211] investigated the effect of holding time and temperature on avocados ripened to various stages of firmness. These were defined as “rubbery-sprung”, “sprung-softening” and “softening firm”, corresponding to Firmometer values of 10–25, 30–40 and 45–65 respectively[215]. Findings from this work (Figure 34) include:
    - ✦ Fruit ripened to “rubbery sprung” can be stored at 2°C, especially if storage time is short (Figure 35).
    - ✦ Fruit ripened to “sprung-softening” can be stored at 5 or 8°C for up to two weeks and still have >85% acceptable fruit.
    - ✦ Fruit ripened to “softening-ripe” has reduced life. It is best stored at 5°C, but only around 80% of fruit may still be acceptable after two weeks.

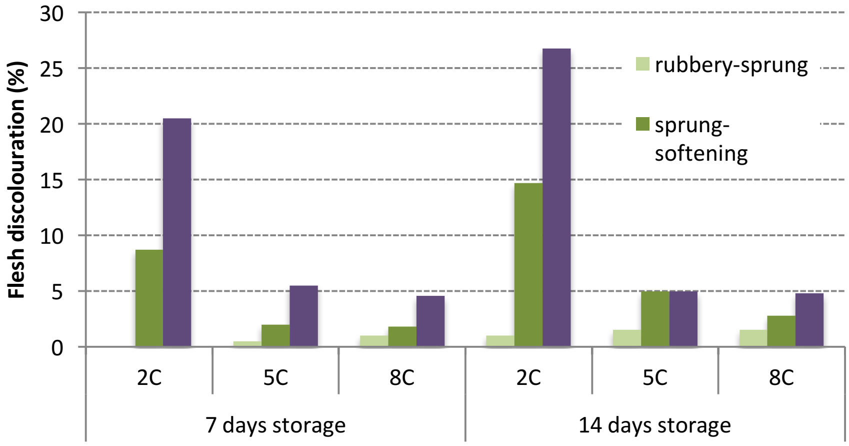

Figure 34. Area of discoloured flesh after 7 or 14 days storage at 2, 5 or 8°C for Hass avocados previously ripened to ‘rubbery-sprung’, ‘sprung-softening’ or ‘softening-firm’. From Marques et al., 2011.

Figure 35. Internal quality of Hass avocados ripened to ‘rubbery-sprung’ (left), ‘sprung-softening’ (centre) or ‘softening-firm’ (right) firmness stages then held for 7 days at 2°C. From Marques et al., 2011.

[215] White A et al. 2009. ‘The international avocado quality manual’. Plant and Food Research, Auckland.

- The researchers also noted the number of days taken for stored fruit to reach the "soft-ripe" stage preferred by consumers. Unsurprisingly, fruit that was ripened to a more advanced stage before storage ripened the most quickly. Storage temperature had little or no effect on fruit held for one week. However, larger differences were found when storage time was extended to two weeks (Figure 36).

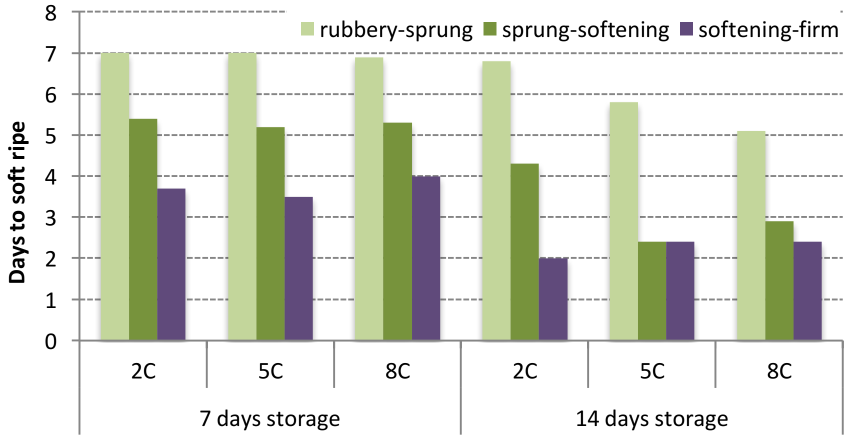

Figure 36. Number of days to reach full, edible softness for Hass avocados previously ripened to 'rubbery-sprung', 'sprung-softening' or 'softening-firm' then stored at 2, 5 or 8°C for 7 or 14 days. From Marques et al., 2011.

- The effect of holding temperature on ripened fruit was also studied by Arpaia et al[216]. They found that partially ripe avocados could be stored at 1, 5 or 12°C for four days without reducing quality or acceptance by consumers. Storage for two weeks was problematic, with increases in stem end rot and flesh discolouration. This was particularly pronounced at 12°C, 5°C still providing acceptable quality.
- Once fruit start ripening, they become more susceptible to bruising. However, bruising is not visible when fruit are held at 2.5 to 5°C post-impact. However, if fruit are held at 15°C or higher damage is soon apparent. Bruises can continue to darken and spread for a week or more in firm-ripe fruit at ambient temperatures[154].

[216] Arpaia ML et al. 2015. Influence of cold storage prior to and after ripening on quality factors and sensory attributes of Hass avocados. Postharvest Biol. Technol. 110:149-157.