

# **Avocado fruit quality management during the postharvest supply chain**

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*Avocados are a popular subtropical fruit of high economic importance and the European Union is the biggest importer of the bulk of the fruit coming from countries like South Africa, Chile and Israel. The fruit is highly nutritious being rich in vitamins A, B, C, minerals, potassium, phosphorus, magnesium, iron and antioxidants. The biggest challenge is that the fruit is highly susceptible to qualitative and quantitative postharvest losses. Successful maintenance of avocado fruit quality during the supply chain depends on many aspects including adequate orchard management practices, harvesting practices, packing operations, postharvest treatments, temperature management, transportation and storage conditions, and ripening at destination. Postharvest losses are mostly attributed to flesh softening, decay, physiological disorders and improper temperature management. Management of the supply chain is solely done to provide the fruit with the most favourable conditions to extend storage life, retain quality and nutritional attributes of the fruit. The focus of this review is therefore to study the findings that have*

*emanated from research done to retain overall avocado fruit quality and to reduce postharvest losses during the supply chain through the adoption of appropriate and novel postharvest technologies.*

**Keywords** *Persea Americana*, Fruit softening, Postharvest diseases, Packaging, Atmosphere modification

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## **Introduction**

### ***Avocado origin, races and cultivars***

Avocado (*Persea americana* Mill.), belongs to the family Lauraceae. It is synonymous with *P. gratissima* Gaertn. There are three races: Mexican, Guatemalen and West Indian and some authorities considered the Mexican race a separate species *P. drymifolia* Cham. & Schlecht. or a separate variety *P. americana* var. *drymifolia* Mex. Morton<sup>(1)</sup> gave the following classification: West Indian as *P. americana* Mill. var. *americana* (*P. gratissima* Gaertn.), Mexican as *P. americana* Mill. var. *drymifolia* Blake (*P. drymifolia* Schlecht. & Cham.) and Guatemalan as *P. nubigena* var. *guatemalensis* L. Wms. The West Indian race is a native of the Central American lowlands and is essentially tropical and produces large fruit with low oil content of only 3 to

10%. The Guatemalan is native to the Guatemalan highland and has medium round fruit with an oil content of 8 to 15% and a leathery, pliable and non-granular skin. The tree is less cold tolerant than the Mexican. The Mexican race thrives best in the subtropics and has the smallest fruit of the three races, with a thin skin and the highest oil of up to 30%.<sup>(2)</sup> The tree is most tolerant of cold growing conditions. Chen *et al.*<sup>(3)</sup> confirmed that the substantial genetic differentiation among the three ecological races corresponded to the defined horticultural races, but they also reported that the previously undetected genetic differentiation has two sub-populations from Central Mexico. Many cultivars are hybrids between the races. ‘Hass’ (a Guatemalan x Mexican hybrid) is considered to be the most dominantly grown cultivar in the subtropics<sup>(4)</sup> and is recognised as the best overall quality avocado available. The fruit weighs between 140 to 400 g with medium to thick skin, leathery, coarse corky in texture and it turns purplish black when ripe. Other popular cultivars include ‘Fuerte’ (a Mexican x Guatemalan hybrid), ‘Bacon’ (a Mexican x Guatemalan hybrid), Pinkerton (a Guatemala hybrid), ‘Edranol’ (a Guatemala hybrid), ‘Ryan’ (a Mexican x Guatemalan hybrid), ‘Ettinger’ (predominantly Mexican) and ‘Fuchs’ (West Indian).<sup>(4)</sup> The fruit characteristics of the above mentioned cultivars are shown in Table 1.

### ***Physical properties of avocado***

The fruit (berry) is pear-shaped, oval or round with a short neck. Fruit length can vary from 7.7 cm to 33 cm and its width can be up to 15 cm. The skin color of the fruit can vary from yellowish green, dark green or reddish-purple, to dark purple (almost black). The edible portion of the fruit, that is, its flesh or pulp can be pale to bright yellow in color and the fruit flavor is described as a buttery or nut-like flavor. Its single seed is situated at the center of the fruit and

**Table 1**

Fruit characteristics of different avocado cultivars<sup>a</sup>

Cultivar	Fruit shape	Skin color	Flesh color	Fruit weight
Hass	Ovate	Purplish black	Creamy yellow	140 to 400 g
Fuerte	Pyriiform	Green	Pale yellow	170 to 500 g
Edranol	Pyriiform	Dark green	Buttery yellow	255 to 500 g
Ryan	Pyriiform	Green	Golden yellow	225 to 420
Pinkerton	Prominantly pebbled	Dark green	Cream-colored	230 to 425 g
Ettinger	Pyriiform	Bright green	Light cream to yellow	170 to 570 g
Bacon	Ovate	Green	Very pale yellow to green	170 to 510 g

<sup>a</sup>Source: Whiley et al. <sup>(4)</sup>

the shape of the seed can be oval, round or oblong and generally the length of the seed is around 5 to 6.5 cm long, but may be smaller. The seed is covered by a thin brown seed coat that adheres to the seed cavity.<sup>(4)</sup>

### ***Avocado production and trade***

Avocados originated in Mexico and Latin America. They have been cultivated in a varying range of habitats including tropical and subtropical regions.<sup>(5)</sup> Avocados are commercially produced in

Mexico, Chile, Israel, Spain, South Africa, Peru, Kenya, USA and the Dominican Republic among others.<sup>(6)</sup> At present, Mexico is the leading producer of avocados in the world followed by Chile and the United States.<sup>(4)</sup> The majority of avocados produced in Mexico are used domestically as they are a staple food in most Mexican households.<sup>(7)</sup> In 2011, avocado production in Mexico was reported to be 337 977 t which was approximately 47% of the world's total quantity.<sup>(4)</sup> According to the FAO<sup>(8)</sup> reports, 13% of the avocados produced in Mexico are traded internationally. In Chile, South Africa, Israel and Spain, the avocado production is mainly aimed at exporting the fruit to the overseas markets. The world avocado trade is focused on two major markets, namely the European Union (EU), which imports 150,000 to 160,000 t per year including imports from Spain, and the United States, which imports 140,000 t per year. The United Kingdom is the third largest importer of avocados in the EU and it is reported to have imported 11,753 t from South Africa in 2008.<sup>(9)</sup> Canada and Japan imported about 30,000 t and 15,000 t respectively and the Asian, Middle East and Eastern European markets imported less than 20,000 t per year.<sup>(10)</sup> Peru, South Africa and Israel are the major avocado exporters to the European markets. In the EU, the Netherlands and France as well as the UK are the major avocado importing countries. Although the 'Fuerte' cultivar displays a green skin color after ripening and is well known in the European markets, the 'Hass' cultivar currently dominates the international trade market due to its longer shelf life, large fruit size and its higher consumer acceptance due to its rich nut-like flavor.<sup>(11,12)</sup> 'Hass' is the dominant and most popular type grown in the USA for export. The avocado export markets are segmented according to cultivars. Hass differs significantly from other cultivars including Fuerte, Etinger and Pinkerton, which have a green skin.

### ***Fruit nutritional composition and aroma volatiles***

Avocado is nutrient rich fruit with the composition depending on ecotype, cultivar, degree of maturity, and growing conditions.<sup>(13)</sup> The mesocarp consists of parenchymatous cells with idioblasts containing oil <sup>(14)</sup> and when ripe the flesh is greenish yellow to bright yellow and buttery in consistency, but inferior varieties may be fibrous. Carotenoids (70% lutein) and chlorophyll are responsible for the greenish yellow to bright yellow color of the mesocarp.<sup>(15)</sup> Carotenoids, including lutein ( $2.93 \mu\text{g g}^{-1}$ ), zeaxanthin ( $0.11 \mu\text{g g}^{-1}$ ),  $\alpha$ -cryptoxanthin ( $0.25 \mu\text{g g}^{-1}$ ),  $\beta$ -carotene ( $0.60 \mu\text{g g}^{-1}$ ) and  $\alpha$ -carotene ( $0.25 \mu\text{g g}^{-1}$ ) are reported in the mesocarp of ripened Hass.<sup>(16)</sup> The ripe fruit contains vitamin A, B, C, minerals, potassium, phosphorus, magnesium and iron. The fruit also contains high levels of lipophilic, bioactive phytochemicals including vitamin E, carotenoids and sterols that display antioxidant and radical scavenging activities.<sup>(17)</sup>

**Table 2**  
Chemical compositions of avocado fruit (per 100g of edible portion) <sup>a</sup>

Chemical compositions of avocado fruit			
Energy value (Cal)	245.00	K (mg)	368.00
Protein(g)	1.70	P (mg)	38.00
Fat (g)	26.40	Mg (mg)	35.00
Total carbohydrate (g)	5.10	S (mg)	28.50
Crude fibre (g)	1.80	Sulphur	11.00
$\beta$ -carotone	0.17	Chlorine (mg)	10.00
Ascorbic acid (mg)	16.00	Ca (mg)	4.21
Niacin (mg)	1.01	Mn (mg)	3.00
Riboflavin (mg)	0.13	Na (mg)	0.60
Thiamine (mg)	0.06	Fe (mg)	0.45

<sup>a</sup>Source: FAO <sup>(18)</sup>

The chemical composition of the edible portion of the fruit is presented in Table 2. The edible portion of the fruit is high in lipid, which varies from 3% to 30% of its fresh weight and it is also rich in oleic, palmitic, linoleic, and palmitoleic acids, as well as stearic acid in trace amounts.<sup>(19)</sup> The fatty acid composition in avocado mesocarp is as follows: oleic acid (86 mg g<sup>-1</sup> oil), palmitic acid (32 mg g<sup>-1</sup> oil), linolenic acid (19 mg g<sup>-1</sup> oil) and palmitoleic acid (14 mg g<sup>-1</sup> oil).<sup>(19)</sup> Ozdemir and Topuz<sup>(20)</sup> indicated that in ‘Fuerte’ oleic acid is the only fatty acid that increased continuously during the season and during ripening at 20 °C for 1 week with percentages ranging from 65.5 to 71.21% while palmitic acid decreased from 18.5 to 16.0% during maturation on the tree and from 16.0 to 14.5% during ripening at 20 °C for 1 week. Similarly, linolenic acid showed a regular decrease as the season progressed from 4.54 to 2% and from 3.0 to 1.4% in ripening at 20 °C for 1 week. The phenolic content of fruits was also shown to be affected by the degree of maturity. The phenolics found were *p*-hydroxybenzoic, protocatechuic, βresorcylic, γ-resorcylic, α-resorcylic, gallic, isovanillic, vanillic, syringic, *o*-coumaric, *m*-coumaric, *p*-coumaric, caffeic, ferulic, and sinapic acids.<sup>(21)</sup> Work by Golukcu1 and Feramuz Ozdemir<sup>(22)</sup> on ‘Bacon’, ‘Zutano’, ‘Fuerte’, and ‘Hass’ indicated that protocatechuic acid, caffeic acid, (-)-epicatechin, and rutin were the main phenolic compounds. Although differences were noted in the phenolic composition of the fruit the general trend was that *o*-coumaric acid and rutin contents increased from the first to the second harvesting period (between January and February) and decreased from the second to the third harvesting period (between February and March). In contrast, the quercetin content of all of the cultivars increased steadily during the harvesting period. They concluded that the total phenolic content of avocados increases at the beginning of

the harvesting period up to the second harvesting time, and it decreases at the end of the harvesting time.

Ethanol, (Z)-3-hexanol and (E)-2-hexenal were reported as the abundant volatiles in whole green and ripe 'Fuerte' avocados by El-Mageed.<sup>(23)</sup> Sesquiterpenes and hexanal were reported as the most abundant volatiles in the headspace of unripe, diced 'Simmonds' avocado; however, the concentrations of these compounds were noted to decrease during ripening.<sup>(24)</sup> Obenland *et al.*<sup>(25)</sup> reported 25 aroma volatiles, including aldehydes, alcohols, esters, ketones and terpenes and 12 of these aroma volatiles were noted to change in concentration during maturation in 'Hass' avocado from California USA. Of these, 1-penten-3-one, hexanal, (E)-2-hexenal, 2,4-hexadienal, benzaldehyde decreased while acetaldehyde, methyl acetate, pentanal,  $\beta$ -myrcene, 2,4-heptadienal and nonanal increased as the season progressed (increasing harvest dates). 1-penten-3-ol and 1-penten-3-one were reported to increase during ripening in avocado.<sup>(26)</sup> El-Mageed<sup>(23)</sup> also reported a decline in hexanal (grassy note) in avocados during ripening.

### ***Fruit respiration and ethylene production***

Avocado is classified as a climacteric fruit and it is extremely unusual since the fruit does not ripen while on the tree. Avocado fruit produces higher concentrations of ethylene (80-100  $\mu\text{L L}^{-1}$ ) in comparison to other climacteric fruits such as mangoes (3  $\mu\text{L L}^{-1}$ ) and bananas (40  $\mu\text{L L}^{-1}$ ).<sup>(27)</sup> Mature fruit displays a characteristic respiratory pattern that coincides with increased ethylene production. This increase in respiration rate and ethylene biosynthesis is accompanied by a complex of biochemical changes including an increased cellulose activity resulting in fruit softening,<sup>(28)</sup> flesh color changes and synthesis of flavor and aroma chemicals.<sup>(29)</sup> The increase in the  $\text{CO}_2$  and ethylene ( $\text{C}_2\text{H}_4$ ) production rate coincides with ripening, resulting in the amino acid



methionine being converted to S-adenosyl methionine, the precursor of 1-aminocyclopropane-1-carboxylic acid, which is the immediate precursor of C<sub>2</sub>H<sub>4</sub>. The 1-aminocyclopropane-1-carboxylic acid synthase converts S-adenosyl methionine to 1-aminocyclopropane-1-carboxylic acid and 1-aminocyclopropane-1-carboxylic acid oxidase; that is, the ethylene-forming enzyme that is membrane bound, participates in the conversion of 1-aminocyclopropane-1-carboxylic acid to C<sub>2</sub>H<sub>4</sub>. The function of 1-aminocyclopropane-1-carboxylic acid synthase and 1-aminocyclopropane-1-carboxylic acid oxidase is influenced by storage temperatures and gas compositions surrounding the fruit.<sup>(30)</sup> The temperature during the ripening phase is important with temperatures above 30 °C causing adverse effects on avocados during ripening.<sup>(31,32)</sup> Temperatures between 20 °C and 25 °C are favorable to ripening avocado cultivars. During ripening, a loss of firmness (texture) takes place due to rapid changes that occur in the ultra-structure of the cell wall and its components.<sup>(14)</sup> These cell wall structural changes are due to the activities of degrading cellulase enzymes in the cell wall<sup>(28,33)</sup> and polygalacturonase that result in decreased tissue cohesiveness resulting from the degradation of pectin and cell disarrangement.<sup>(34)</sup> The mesocarp of an avocado contains common heptoses (C7) sugar, mannoheptulose<sup>(35)</sup> and its corresponding sugar alcohol, perseitol.<sup>(36)</sup> A decrease in the C7 sugar content of avocados during ripening has been reported by Bertling and Bower<sup>(37)</sup>, Liu *et al.*<sup>(38)</sup> and Meyer and Terry.<sup>(39)</sup> However, despite C7 carbohydrates playing a major role in the carbon balance, sucrose has not been considered as an indicator to determine postharvest quality.<sup>(37,38)</sup> Nonetheless, C7 sugars were reported to decrease with fruit maturity.<sup>(37)</sup> It was suggested that the differences in sugar content between the cultivars and growing regions could affect the postharvest fruit quality.<sup>(40)</sup>

### ***Maturity indices for harvesting avocados***

Maturity indices for harvesting avocados are important in order to prevent harvesting of immature or over mature fruit and to reduce postharvest losses. Harvesting immature fruit can result in inadequate ripening, resulting in an inferior fruit quality. Blakey *et al.*<sup>(41)</sup> commented that “avocado fruit are highly variable, and even those graded for similar size and appearance do not behave in the same manner after harvest. This is particularly problematical for those involved in sales to the “ready-ripe” market. These operations are faced with a high variation in the rate of ripening within a consignment, causing logistical difficulties. Pearson<sup>(42)</sup> reported that with increasing maturity the avocado oil content in the fruit increases while the water content or dry matter decreases. Landahl *et al.*<sup>(40)</sup> stated that the oil content in the mesocarp and its composition vary within the fruit. On the other hand, their oil content is also influenced by cultivar type, cultural practices and environmental conditions. However, generally the oil content in the mesocarp is used as an indicator to harvest avocados. The presence of a minimum of 8% oil is used as a suitable maturity index value or indicator to harvest avocados.<sup>(43,44)</sup> In many countries, traditionally, the oil content or dry matter of the mesocarp is used as a maturity indicator in avocados.<sup>(45)</sup> The most accurate method adopted for oil determination was to dry the pulp (mesocarp) and then to employ the solvent extraction method to measure the oil content.<sup>(46)</sup> However, this is a laborious method and it may take as long as 12 h or more to obtain the final results. Therefore, the avocado industry generally adopts two quantitative indices to harvest their fruit for export or domestic markets; the oil and moisture content indices.<sup>(47,48)</sup> It was also asserted that the moisture content of the cultivar Pinkerton exported from South Africa must be between 80%<sup>(49)</sup> and 73% (Table 3).<sup>(50)</sup> Wedding *et al.*<sup>(52)</sup> described the potential of Fourier Transform-near infra-red spectroscopy in diffuse reflectance mode for non-invasive prediction of

**Table 3**Maximum moisture content of different avocado cultivars<sup>a</sup>

Cultivar	Moisture content (%)
Fuerte	80
Hass	77
Pinkerton	80
Ryan	80
Lamb Hass	73
Maluma Hass	78
Nature's Hass	77

<sup>a</sup>Source: Kassim et al. <sup>(51)</sup>

the dry matter of whole 'Hass' fruit. Blakey *et al.*<sup>(41)</sup> also used near infrared spectroscopy to measure mesocarp water content and postulated that on-line sorting of fruit using near infrared spectroscopy, based on time to ripen, would result in consignments of fruit with less ripening variation.

Lee *et al.*<sup>(55)</sup> reported that the oil content is related to the taste of the fruit. However, according to Landahl *et al.*<sup>(40)</sup>, the dry matter and the oil content of the mesocarp do not always correlate and Landahl *et al.*<sup>(40)</sup> and Woolf *et al.*<sup>(54, 45)</sup> argued that depending on the growing areas, the dry matter within the fruit can vary. Furthermore, Hofman *et al.*<sup>(55)</sup> maintained that there are no correlations between the dry matter content, the oil content and the fruit quality. The oil content

in avocado fruit commonly ranges from 15 to 30% depending on the cultivar, and oleic acid was found to be the predominant monounsaturated fatty acid contained therein.<sup>(56)</sup> Oil content is therefore recommended as a suitable maturity index for cultivars that are rich in oil content whereas dry matter is also used for specific cultivars. For cultivars grown in California, the percentage dry matter in the fruit was used commercially as a maturity index for harvesting avocados.<sup>(58)</sup> The maturity standards were related to the percentage dry matter and were developed for cultivars grown in California such as ‘Bacon’ (18.5%), ‘Fuerte’ (19.9%), ‘Gwen’ (25.9%), ‘Hass’ (21.6%), ‘Pinkerton’ (23.0%), ‘Reed’ (19.8%), ‘Zutano’ (18.8%).<sup>(57)</sup> For ‘Hass’, complementary indices such as flesh softening, which is related to skin color changes, are also included in the maturity index. For example, the green skin color (immature stage) changes to purple at the most suitable mature stage.

#### ***Pre-harvest factors that affect postharvest quality of avocados***

Postharvest quality of the fruit develops during growth and maturation and is maintained, not improved, by postharvest conditions. There are several pre-harvest factors which if not well managed can severely affect the quality of the fruit. Understanding these factors and how they can be managed can help minimize postharvest losses of avocado fruit. A summary of the pre-harvest factors that have an inherent effect on the postharvest quality of the fruit is shown in Table 4.

**Table 4**Pre-harvest factors that affects the postharvest quality of avocados<sup>a</sup>

Pre-harvest factor	Postharvest effect on fruit quality	Management
Climate or environment: temperature, wind and rainfall	Increased disease incidence, chilling injury	Pruning to expose the fruit to direct sunlight
Rootstock or scion	Susceptibility to physiological disorders during the cold chain, postharvest decay	Choose less susceptible rootstock or scion
Pruning practices	Poor fruit storability	Strike a balance between vegetative and reproductive growth and correct timing is important
Pest and disease management	Changes in fruit composition, influences the ripening behaviour and decay development (anthracnose),	Maintain a clean orchard and correct application of chemicals is important
Plant nutrition (N/Ca)	Development of physiological disorders (mesocarp discoloration or grey pulp) and rots	Manage vegetative growth and avoid excessive nitrogen during fruit development
Plant growth regulators	Poor storability	Manage vegetative growth
Irrigation	Influences polyphenol oxidase levels thus mesocarp discoloration	Avoid water stress during fruit growth and development

<sup>a</sup>Source: Lu Arpaia et al. <sup>(61)</sup>

## **Avocado postharvest chain management**

### ***Harvesting***

Fruit must be harvested without mechanical damage (cuts, scratches and abrasions), which can affect the cosmetic appearance of the fruit and act as an entry point for postharvest pathogens that cause decay during storage and transportation.<sup>(59)</sup> Bruising can also cause localised softening. The usual method of harvesting involves the fruit being placed either into a soft picking bag attached to a harvesting pole or directly into a plastic crate to prevent damage to the fruit. For tall trees, hand picking poles or ladders are used for fruit that cannot be reached easily from the ground. Picking poles must have a clipper or knife attached to the end, with a catching or collection bag made of cloth. Directly after harvesting, the fruit must be moved to the shade in order to reduce weight loss due to moisture loss that will occur rapidly when they are exposed to the sun. It is usually recommended that avocado fruit should reach the packhouse within two hours of picking. The use of clippers is suitable for removing fruit from trees; however, it is recommended that about 1 cm of the pedicel should be left attached to the fruit. Harvesting methods were shown to affect the postharvest fruit quality of ‘Fuerte’ for which pedicels must be manually clipped. On the other hand ‘Hass’ can be snap-picked without causing an undesirable effect on their fruit quality.<sup>(59)</sup> It is, however, well established that fruit cannot be harvested during wet weather conditions because the presence of water droplets on the fruit surface can favor the incidence of postharvest diseases during distribution and storage<sup>(60)</sup> and ‘Fuerte’ and ‘Hass’ harvested during wet conditions exhibited significant lenticels damage in comparison to fruit picked in dry weather. However, lenticels damage does not affect ‘Hass’ fruit quality because the fruit turns dark purple in color during ripening and the lenticels damage cannot be seen clearly in purple background. Generally, the occurrence of lenticels damage is higher for all

the fruit picked early in the season.<sup>(59)</sup> Incidences of vascular browning were also reported to be higher in fruit harvested when they are wet.<sup>(59)</sup> For example, the incidences of vascular browning increased significantly in ‘Hass’ picked during wet conditions and late in the season when compared to the fruit picked during dry weather conditions or early in the season.<sup>(56,61)</sup> Furthermore, fruit picked late was reported to ripen much faster, particularly when grown in warmer areas.<sup>(62)</sup>

### ***Field handling***

After harvesting, the avocado fruit must be carefully transferred from the picking bag into the field crates in order to avoid mechanical injuries, especially bruising.<sup>(63)</sup> The fruit should not be placed on the ground so as to avoid any contact with the soil. This will help to prevent contamination by foodborne pathogens that can survive in the soil such as *Listeria monocytogenes*.<sup>(64)</sup> Generally, PH Bulletin No. 18<sup>(63)</sup> commented that large wooden crates that hold approximately 11 kg of fruit were the preferred type of field container. These containers should not be overfilled and must be placed in a shaded area and protected from direct sun.<sup>(65)</sup> Exposure to the sun will tend to increase the pulp temperature, which accelerates ripening and shortens the shelf life of the fruit.<sup>(62, 63, 65)</sup>

### ***Sorting and grading***

At the packhouse, fruit from the orchard is sorted and graded according to the following commonly used quality criteria for grading avocados: size, skin color, and the absence of cuts or wounds, blemishes, insect damage and spray residue. Moreover, after ripening, the fruit must be free from diseases (anthracnose and stem-end rot), physiological disorders (grey pulp, vascular browning) and bruising.<sup>(67)</sup>

### ***Pre-cooling***

It is highly recommended that fruit be cooled as soon as possible after harvesting in order to delay ripening and related softening. Pre-cooling is very important, especially when the field temperatures are high (>25 °C). On arrival, the fruit must be pre-cooled to about 16 °C in order to remove the field heat. Commercially, hydro cooling is the most common method used.

### ***Fungicide treatment and waxing***

At the packhouse and after cooling, the fruit is commonly treated with a fungicide. For example, diseases of avocados that can occur are controlled by Sportak (prochloraz 450 g a.i. L<sup>-1</sup>)<sup>(68)</sup>, especially in the commercial packhouse of South Africa, New Zealand and Australia.<sup>(69-71)</sup> Prochloraz, a nonsystemic fungicide, is used as a first defense mechanism in the packing line to control postharvest diseases such as anthracnose and stem-end rot in avocados. It affects the mycelial growth of the pathogens and acts as a sterol inhibitor impeding the ergosterol (fatty acid) synthesis, which is an important component of the fungal cell wall. Prochloraz ultra-volume spray applications followed by a polyethylene wax coating were reported to reduce postharvest rots in avocados.<sup>(72)</sup>



Prochloraz is the only fungicide registered in South Africa for postharvest applications. At present, a dip of 200 ppm prochloraz + 50 mM HCl is recommended and adopted by the Westfalia Technological Services to control anthracnose (this disease control is similar to the commercially applied prochloraz concentration, 810 ppm).<sup>(73)</sup>

Waxing reduces moisture loss, may retard fruit softening and may also help to improve the surface appearance of fruit by adding shine and luster (e.g. in 'Fuerte')<sup>(74)</sup>; therefore, waxing is widely used in the South African avocado industry. According to Johnston and Banks<sup>(75)</sup>, waxes provide a surface barrier which hinders the movement of gases that can modify the internal atmosphere in the fruit. However, it has been demonstrated that waxing has some disadvantages including increased incidences of mesocarp discoloration<sup>(76)</sup> and extended delays in fruit ripening associated with softening after cold storage<sup>(77)</sup> in avocados. Commercially, Avoshine<sup>®</sup> carnauba wax coating is used for avocados.<sup>(78-80)</sup> Green-skinned cultivars may develop surface discoloration if the proper wax formulation and application methods are not employed. A shellac or carnauba-based food-grade wax works well and has been applied mechanically by roller brushes in the past.<sup>(63)</sup> However, the effectiveness of a wax application depends on many factors, for example, the concentration strength of the wax formulation; method of application, spraying or dipping; and the duration of the application. Avocados that have been waxed, which slowed ripening have been shown to develop more ripe rots than non-waxed fruit that ripened quicker. Biocoat<sup>™</sup> (a suspension mixture of beeswax and olive oil) extended the shelf life of avocado fruit<sup>(81)</sup> but was ineffective in reducing ripe rots to commercially acceptable levels in late season 'Hass' avocado fruit.<sup>(82)</sup> It also is essential that the applied wax coating must not leave any deleterious residues or affect the natural glossiness of the fruit, the eating quality or alter the characteristic fruit flavor. On the other hand, it has been reported that the managers of ripening

facilities prefer fruit that are not waxed because waxing may result in “checkerboard ripening” (Personal communication van Rooyan Westfalia Technological Services, SA). The EU does not allow morpholine, a synthetic compound used as a solvent for resins and dyes in wax emulsions. <sup>(83)</sup> There is some resistance to waxing of fruits including avocados in the EU due to consumer pressure.

### ***1-methylcyclopropene (1-MCP) treatment***

1-MCP is an ethylene inhibitor that has been approved in many countries as a postharvest treatment to delay ripening and ensure that fruit are less susceptible to extraneous accidental exposure to ethylene. In South Africa, 1-MCP treatment is used for late season fruits (personal communication Van Rooyan Westfalia Estates). Treatment of the avocado cultivars Gold Nijisseiki and Hosui with 1-MCP was effective in prolonging long term cold storage.<sup>(84)</sup> Preclimacteric ‘Booth 7’ fruit were treated for 1 minute with aqueous 1-MCP at 1.86 and 9.3 mmol m<sup>-3</sup> one day after harvest when their ethylene production was less than 0.05 ng kg<sup>-1</sup> second<sup>-1</sup>. Both concentrations strongly suppressed softening, delayed ethylene production and delayed the climacteric peak. Seven days after harvest, when the ethylene production was 65% of maximum and the fruit were considered mid-climacteric, there was a complete loss of sensitivity to 1-MCP at 1.86 mmol m<sup>-3</sup> or at 9.3 mmol m<sup>-3</sup>.<sup>(85)</sup> There was improved efficacy of 1-MCP at elevated doses and following reduction of internal ethylene concentration in suppressing ripening of mid-climacteric fruit. They considered that this was consistent with ethylene strongly influencing 1-MCP sensitivity in climacteric fruit that have been initiated to ripen. Zhang *et al.*<sup>(86)</sup> found that treatment of the cultivar ‘Booth 7’ with 1-MCP resulted in delayed

accumulation of antioxidant chemicals and enzymes and that increasing doses of 1-MCP (over the range of 0.93 and 9.3 mmol m<sup>-3</sup>) increasingly delayed ripening at 20 °C.

Interactions between 1-MCP and waxing have been observed. For example, preclimacteric ‘Tower II’ and ‘Booth 7’ cultivars were treated with 1-MCP for 12 hours at 20 °C and then half of the fruit were waxed with Sta-Fresh 819F<sup>®</sup> (FMC Company, USA) after 1-MCP treatment.<sup>(87)</sup>

The fruit were subsequently stored at 13 °C or 20 °C at 85% RH. 1-MCP and waxing delayed the ripening of ‘Tower II’ stored at 20 °C. Fruit treated with both 1-MCP and wax had better retention of green peel color and fruit firmness, and the treatments delayed the climacteric pattern of ethylene evolution and respiration rates. Waxing reduced weight loss and retarded softening, but did not delay climacteric patterns of ethylene evolution and respiration rates. Firmness of untreated fruit decreased from >100 N to 20 N in as few as 7 days at 20 °C, whereas fruit treated with both 1-MCP and wax reached 20 N only after 11 days at 20 °C. The firmness of ‘Booth 7’ treated with both 1-MCP and wax decreased from >170 N to 20 N over a 5-week period at 13 °C.

### ***Packing and palletization***

It is essential for the packhouse to conduct fruit maturity tests. According to the South African Avocado Growers Association (SAAGA)<sup>(46)</sup>, fruit maturity needs to be tested by taking ten randomly harvested fruit from an orchard. The fruit is then categorised according to different grades according to size and appearance and packed into 4 kg cartons in a single layer. Avocado fruit is also packed for the domestic markets in pre-packed units; in plastic bags and in tray packs over-wrapped with cling film. Packhouse workers must wear gloves in order to prevent contamination by foodborne pathogens and mechanical damage (bruising or scratches) that are

likely to occur during handling. The packhouse sorting or grading tables must be clean and smooth. The fruit stem of each fruit must be trimmed with the help of a sharp knife to a length of 6 mm to 12 mm.

### ***Quality assurance in relation to packaging and transportation***

In South Africa, export fruit must be graded according to the quality criteria of the Perishable Products Export Control Board (PPECB).<sup>(88)</sup> Quality standards for exports are determined by the Department of Agriculture, Forestry and Fisheries (DAFF) in conjunction with SAAGA. Quality inspections are carried out by the PPECB prior to shipping of the exports. One of the primary functions of the PPECB is to ensure that standards for refrigerated road transport and refrigerated containers adhere to the prescribed regulations and standards. In addition, growers of avocados have to comply with Good Agricultural Practice (GAP) standards. The SAAGA reports indicate that 95% of the industry is Europe Gap accredited. Other accreditations in the industry include BRC, LEAF, Fair-trade and Tesco's Nature's Choice.<sup>(89)</sup> Packaging cartons must include information cultivar, exporter, and locality of origin, average fruit weight. The packaging should also include grower codes for traceability in case of problems such as dirt discards and quality defects, Packer codes (to monitor productivity and accuracy) and data codes are important to monitor the time and temperature chain involved in the fruit export. Packing is in 370 x 285 mm area top (outside diameter) cartons.<sup>(46)</sup> Adequate ventilation during palletization is also recommended. Palletization is carried out on a pallet with dimensions of 1114 x 1110 mm, and the cultivar 'Fuerte' is generally packed with 252 boxes on each pallet pallet.<sup>(46)</sup>

### ***Temperature and relative humidity management***

The postharvest life of avocados is extended in cold storage by maintaining the overall quality parameters such as texture, taste and nutritional composition during the supply chain. A low temperature has a direct effect on their respiration rate, which is an indication of the rate of perishability. For every 10 °C increase in temperature the respiration rate approximately doubles and the primary metabolic substrates (sugars and organic acids) are depleted at an increasingly faster rate. Storage life varies inversely with respiration rate; therefore, the shelf life of avocados is shortened at higher temperatures. Low temperature storage slows the climacteric increase in CO<sub>2</sub> and C<sub>2</sub>H<sub>4</sub> production that occurs with ripening. Multiple enzymes that are involved in the synthesis of C<sub>2</sub>H<sub>4</sub>, carbohydrates, organic acids and volatile compounds are inhibited at lower temperatures, and consequently, ripening-related changes in color, flavor, texture and aroma are delayed. Various temperatures are recommended to extend the shelf life of avocados varying from about 5 to 13 °C.<sup>(90)</sup> It is also important to maintain the packhouse temperature and therefore, the PPECB applies a grading system for cooling facilities in packhouse. The recommended fruit pulp temperature is above 3 °C and the recommended shipping temperature is achieved 24 hours after harvesting.

Temperature recommendations for cold storage vary with race, cultivar, maturity or ripeness and harvest season but generally include 5 to 10 °C and 90% RH for 2 to 4 weeks <sup>(91)</sup>, Therefore, avocados should be stored at 8 °C to extend their shelf life. Alternatively avocados can be stored at 8 to 12 °C and 85 to 90% RH for 2 to 4 weeks for unripe fruit and 5 to 8 °C and 85 to 90% RH for 1 to 2 weeks for ripe fruit (Table 5). <sup>(92)</sup> Saucedo Veloz *et al.*<sup>(96)</sup> reported that storage at 5 °C for 6 weeks followed by 4 days at 20 °C resulted in excessive softening, browning and storage rots while 2 °C for 6 weeks followed by 4 days at 20 °C resulted in fruit of better quality.

**Table 5**

Recommended storage conditions for specific avocado cultivars

<b>Cultivar</b>	<b>Ripe or unripe</b>	<b>Temperature</b>	<b>Relative humidity</b>	<b>Duration</b>	<b>Source</b>
'Booth 1' (Guatemalan x West Indian hybrid)	Unripe	4.5 °C	85 to 90%	2 to 4 weeks	(93)
'Booth 1'	Unripe	4 °C	90 to 95%	4 to 8 weeks	(94)
'Fuchs' (West Indian)	Unripe	12.8 °C	85 to 90%	2 weeks	(95)
'Fuchs'	Unripe	10 to 13 °C	85 to 90%	2 weeks	(93)
'Fuerte' (Mexican x Guatemalan hybrid)	Unripe	5.5 to 8 °C	85 to 90%	3 to 4 weeks	(93)
'Fuerte'	Ripe	2 to 5 °C	85 to 90%	1 to 2 weeks	(93)
'Fuerte'	Ripe	3 to 7 °C	85 to 90%	2 to 4 weeks	(94)
'Hass' (Guatemalan x Mexican hybrid)	Unripe	5.5 to 8 °C	85 to 90%	3 to 4 weeks	(93)
'Hass'	Ripe	2 to 5 °C	85 to 90%	1 to 2 weeks	(94)
'Hass'	Ripe	3 to 7 °C	85 to 90%	2 to 4 weeks	(96)

<sup>a</sup>Source: Kader<sup>(92)</sup>

Certain avocado cultivars were reported to be susceptible to chilling injury when stored below 13 °C.<sup>(97)</sup> Fruit stored below 8 °C may develop chilling injury and ‘Hass’ stored at 5 °C for 4 weeks had uneven ripening, distorted respiratory patterns and reduced ethylene peaks during subsequent ripening at 20 °C.<sup>(98)</sup> Symptoms of chilling injury include pitting, browning of pulp near the seed or in the tissue midway between the seed and the skin, failure to soften when transferred to a higher temperature, off flavor, vascular strands and development of a brownish appearance. In other work, chilling injury was shown to occur at 10 to 11.1 °C for cultivars of the West Indian race and 4.4 to 6.1 °C for the Mexican and Guatemalan races.<sup>(99)</sup> In a study of avocados from trees propagated from seed in Grenada, Thompson *et al.*<sup>(100)</sup> showed that there was considerable variation in storage life and chilling injury symptoms between fruit from different trees. It meant that even at 7 °C some 77% of the fruit ripened without showing symptoms of chilling injury and at 13 °C some 27% actually suffered from chilling injury. However, it does seem clear that the Mexican and Guatemalan races are less susceptible to chilling injury than the West Indian race. Controlled atmosphere storage can affect susceptibility to chilling injury. There were less chilling injury symptoms in ‘Booth 8’, ‘Lula’ and ‘Taylor’ after refrigerated storage in controlled atmospheres than in refrigerated storage in air.<sup>(94,96,99,101)</sup> Corrales-Garcia<sup>(102)</sup> found that ‘Hass’ stored at 2 or 5 °C for 30 days in air, 5% CO<sub>2</sub> with 5% O<sub>2</sub> or 15% CO<sub>2</sub> with 2% O<sub>2</sub> had higher chilling injury for fruits stored in air than the fruits in controlled atmosphere storage, especially those stored in 15% CO<sub>2</sub> with 2% O<sub>2</sub>. Spalding and Reeder<sup>(103)</sup> showed that storage of fruits at either 0% CO<sub>2</sub> with 2% O<sub>2</sub> or 10% CO<sub>2</sub> with 21% O<sub>2</sub> fruit had less chilling injury and less anthracnose during storage at 7 °C than fruits stored in air. Intermittent exposure of the cultivar ‘Hass’ to 20% CO<sub>2</sub> increased their storage life at 12°C and reduced chilling injury during storage at 4 °C compared to those stored in air at the same temperatures.<sup>(104)</sup>

Fuerte avocados will ripen normally at temperatures between 9 and 24 °C, but in the presence of 100  $\mu\text{L L}^{-1}$  ethylene, chilling injury occurred at 12 °C.<sup>(105)</sup> Application of calcium to avocados could reduce their susceptibility to chilling injury during subsequent storage.<sup>(106)</sup> Fruits stored for 4 to 10 weeks at 2 °C had reduced severity of chilling injury symptoms and percentage of injured fruits after they had been dipped for 30 seconds in methyl jasmonate at 2.5  $\mu\text{M}$  for ‘Fuerte’ and ‘Hass’ and 10  $\mu\text{M}$  for ‘Etinger’.<sup>(107)</sup>

Heat treatments (hot air or hot water) have been shown to reduce the chilling injury in some tropical fruits. Hot air treatments at 38 °C for up to 10 h or hot water treatments from 39 to 42 °C prevented chilling injury in avocados.<sup>(108-110)</sup> Heat treatments also helped to reduce chilling injury by stimulating the development of heat shock proteins, which play a major role in protecting cell integrity and provide thermo-tolerance to many horticultural commodities.<sup>(111-113)</sup> It has been demonstrated that heat shock protein production prevented irreversible protein denaturation in fruit in response to high temperature exposure, but presented a temporary resistance to sub-lethal temperatures. Hot air treatments were reported to increase the expression of heat shock protein genes and protein accumulation in avocados.<sup>(114)</sup> As observed by Ouma<sup>(115)</sup>, heating avocados to 38 °C for periods of 24, 48 or 72 h improved their appearance and reduced the effects of chilling injury as opposed to untreated fruit. Ouma<sup>(115)</sup> also showed that ethylene production was delayed, the rate of respiration remained unchanged, and the weight loss was reduced as the number of days of heating increased. This in turn improved the shelf life of the fruit. The polygalacturonase and  $\beta$ -galactosidase activities were reduced by heat treatments, whereas an enhanced pectin methyl esterase activity was observed.<sup>(116)</sup>

The optimum storage temperature is also a function of fruit maturity and the physiological stage of fruit development. Mature fruit picked early in the season is much more susceptible to low



storage temperatures and more likely to suffer from chilling injury<sup>(117,118)</sup> and were observed to store best at 7.5 °C. Swarts<sup>(119)</sup> concluded that the effects of chilling injury in early season fruit is not due to fruit maturity but rather to a decrease in orchard temperature to below 17 °C. Storage at 5 to 6 °C for 28 days was recommended for ‘Fuerte’ and ‘Hass’, both non-West Indian cultivars, before the onset of physiological disorders.<sup>(120)</sup> They also reported that lowering the storage temperature may increase the incidence of external chilling injury but can help to reduce the discoloration of the edible portion. Van Rooyen and Bower<sup>(121)</sup> and Van Rooyen<sup>(122)</sup> showed that mesocarp discoloration was reduced in green cultivars at 2 °C and in a purple cultivar (Hass) at 1 °C. According to Swartz<sup>(119)</sup>, a proposal was made to store early season fruit at higher temperatures (7.5 °C) and the mid and late season fruit at 5.5 °C or even lower.<sup>(123)</sup>

The maintenance of a high humidity is also important because avocados, like other fruit, are susceptible to shrivelling. Therefore, it is recommended that avocados be stored at 90 to 95% RH to prevent weight loss and skin desiccation. Weight loss is directly related to water loss, which takes place through the stomata, stem scar and cuticle; the amount of water loss depends on cuticle composition and thickness, which varies for cultivars and maturity stage. However, a high humidity may promote decay development, especially if moisture condenses on the fruit (sweating) over long periods of time when temperatures fluctuate during transportation. Therefore, for the efficient marketing of avocados the participants in the supply chain need to understand and maintain optimum temperatures and humidity in order to retain the overall fruit quality.

### ***Fruit ripening***

Unlike probably all other climacteric fruit, avocados do not ripen until they have fallen naturally from the tree or have been harvested. They can remain in a mature but unripe condition on the tree for considerable periods.<sup>(23)</sup> Ripening involves softening of the flesh and a change in skin color for certain cultivars. The rate of ripening after harvesting is determined by the harvest maturity of the fruit, the temperature and exposure to ethylene. West Indian avocado cultivars ripen best at temperatures between 16 °C and 24 °C. At higher temperatures, fruit ripens unevenly, develops off-flavors and influences the development of postharvest decay. In fact, Biale and Young<sup>(124)</sup> showed that at both 5 °C and 30 °C no climacteric rise in respiration occurred in a Mexican and Guatemalan hybrid, but a climacteric occurred at all the intervening temperatures. General recommendations include 18 to 21°C with exposure to 10  $\mu\text{L L}^{-1}$  of ethylene for 24 to 72 hours<sup>(125)</sup> and 15.5 °C as the optimum temperature for ripening Florida avocados.<sup>(121,126)</sup> Ripening fruit at lower temperatures, for example 15 to 20 °C, can lead to significant reduction in rots compared with ripening at higher temperatures.<sup>(127)</sup> Treatment with 100 ppm ethylene at 20 °C for 24 to 48 h was shown to initiate avocados to ripen within three to six days. Early season mature fruit may take 10 to 12 days to ripen at 20 °C, whereas mature fruit harvested late in the season may ripen within five to six days in the same conditions. Unripe avocados must not be stored with ethylene-producing crops if required to be in a firm unripe condition. Soft ripe fruit has a shelf life of only 3 days.<sup>(128)</sup> Optimum ripening conditions may also vary with cultivars and harvest season. For example Yahia<sup>(94)</sup> reported that for the cultivar 'Hass' in New Zealand ripening at 17 to 20 °C with 10 to 100  $\mu\text{L L}^{-1}$  of ethylene was optimum, but for early season fruits, 2 to 3 days exposure time was required but only 1 to 2 days for late season fruit. In South Africa, according to the Westfalia Technological Services, fruit are ripened

at 18 to 20 °C, >90% RH with 100 ppm ethylene for 24 h cycles. Every 24 hours the rooms are ventilated and the progress of ripening is monitored. Generally, under these conditions, fruit ripens after 4 to 7 days (Personal communication van Rooyan Westfalia Technological Services, SA). During ripening, the air flow and CO<sub>2</sub> are monitored. The ripened fruit is then stored at 5 °C overnight before dispatch.

### **Postharvest quality loss and management**

The major causes of postharvest quality losses along the marketing chain are due to mechanical injury that occur during harvesting, field handling or transportation, as well as over-ripe fruit, desiccated fruit, postharvest diseases (anthracnose and stem-end rots), and chilling injury as a result of improper storage temperatures, pest damage, and physiological disorders. These factors affect the appearance, texture, taste, and nutritional value of the fruit; for example, loss of firmness and chilling injury were the main limitations in the retail quality for avocados subjected to fluctuating temperatures (too cold or too warm) during a simulation of the shipping and handling of the fruit. <sup>(28)</sup>

### ***Postharvest diseases***

The postharvest life of avocados is affected by fungal pathogens; therefore, postharvest diseases become a major constraint for successful storage and shipments. Anthracnose and stem-end rot are two major postharvest diseases that cause serious losses during exports. <sup>(129)</sup> Diseases of avocado fruit that have been reported are shown in Table 6. Five fungi have been identified as being important pathogens of avocado in New Zealand. <sup>(131)</sup> These are *Colletotrichum acutatum*,

**Table 6**Postharvest diseases of avocado fruit<sup>a</sup>

Common name	Causal agent
Anthracnose	<i>Colletotrichum gloeosporioides</i> .(the conidial stage of <i>Glomerella cingulata</i> (Stonem.) Spauld & Schrenk)
Stem end rot	<i>Botryodiplodia theobromae</i> Pat, <i>Dothiorella</i> spp. <i>Thyronectria pseudotrichia</i> (Schw.) Seeler
Alternaria rot	<i>Alternaria</i> sp
Rhizopus rot	<i>Rhizopus stolonifer</i> (Ehrenb. Ex Fr.) Lind
Rusty blight	<i>Colletotrichum gloeosporioides</i> (Penz.) Penz. & Sacc. in Penz., <i>C. nigrum</i> Ellis & Halst.
Scab	<i>Sphaceloma perseae</i> Jenkins
Sooty blotch	<i>Akaropeltopsis</i> sp.
Fusarium rot	<i>Fusarium</i> spp.
Pestaloptiopsis rot	<i>Pestaloptiopsis versicolor</i> (Spreg.) Steyart
Phytophthora rot	<i>Phytophthora citricola</i> Sawada
Pink mould, pink rot	<i>Trichothecium roseum</i> Link. synonymous with <i>Cephalothecium roseum</i> Corda.
Botryodiplodia rot	<i>Botryodiplodia</i> sp. <i>Botryosphaeria obtusa</i> (Schwein.) Shoemaker <i>B. quercuum</i> (Schwein.) Sacc. <i>B. rhodina</i> (Cooke) Arx. <i>Botrytis cinerea</i> Pers.:Fr. synonymous with <i>B. vulgaris</i> Link:Fr. <i>Botryotinia fuckeliana</i> (de Bary) Whetzel [teleomorph].
Cercospora spot or blotch	<i>Pseudocercospora purpurea</i> (Cooke) Deighton
Dothiorella rot	<i>Botryosphaeria ribis</i> Grossenb. & Duggar conidial stage <i>Dothiorella gregaria</i> Sacc.
Bacterial soft rot	<i>Erwinia carotovora</i> Jones <i>Pseudomonas syringae</i> pv <i>syringae</i> van Hall.
Blue mould	<i>Penicillium expansum</i> Link.

<sup>a</sup>Source: Manicom<sup>(129)</sup> and Smilanick<sup>(130)</sup>

*C. gloeosporioides*, *Botryosphaeria parva*, *B. dothidea* and *Phomopsis* sp. Each of these fungi can cause postharvest diseases of avocado, infecting either through the side of the fruit (body rots) or through the picking wound (stem-end rots). Hartill<sup>(131)</sup> reported two major post-harvest diseases have been found in New Zealand avocados: anthracnose, associated with *Colletotrichum* spp., and stem-end rots, associated with *Botryosphaeria* and *Phomopsis* species. Several *Fusarium* species have been also isolated from fruit rots. Scab (*Sphaceloma perseae* Jenkins) was recorded for the first time on New Zealand avocados<sup>(68)</sup>

#### *The susceptibility of the fruit to disease development*

The cultivar Hass grafted onto Duke 6 rootstock and ‘Hass’ fruit with low calcium concentrations are more susceptible to anthracnose development with the result that the postharvest fungicide treatment may not be effective.<sup>(125,130)</sup> In order of frequency, *Colletotrichum*, *Dothiorella*, *Alternaria* and *Phomopsis* spp. were isolated from decayed California avocados.<sup>(136)</sup> The most prevalent fungi responsible for postharvest diseases in New Zealand were reported to be *Colletotrichum acutatum*, *C. gloeosporioides*, *Botryosphaeria parva*, *B. dothidea* and *Phomopsis*.<sup>(131)</sup> Anthracnose caused by *C. gloeosporioides*, and a lenticular rot caused by *Dothiorella gregaria* can infect the fruit in the field and develop during postharvest storage.<sup>99)</sup> However, fungal infections were found to be associated only with area of primary damage, except where fruits were overripe where the most common organism was *B. theobromae*.<sup>(100)</sup> Infections can also occur postharvest through the cut stalk<sup>(99)</sup> and in the past some exporters dabbed a blob of candle wax on the cut stalk, but no objective studies have been found that confirm its effectiveness.

## ***Post harvest diseases control***

### *Fungicide application and related issues*

For control of anthracnose and stem-end rot diseases, fruit should be treated with prochloraz (an amide fungicide) within 24 h of harvest applied as a nonrecirculated spray over fruit on rollers or brushes. Both field spraying and postharvest treatments are necessary to achieve high quality fruit. Copper sprays are used in the orchard and prochloraz is applied postharvest.<sup>(69)</sup> Limited control of the anthracnose disease can be achieved with an application of pre-harvest copper oxychloride. The latter application leaves undesirable patches on the fruit surface and it is a time-consuming process to remove them manually in the packhouse prior to packing.<sup>(132)</sup> Currently, the only fungicides registered for use on avocados in New Zealand are various copper formulations (e.g., copper hydroxide, copper oxychloride and copper sulphate) and prochloraz. Copper hydroxide inhibited spore germination on all the fungi they tested but only at high concentrations (2.4 to 11.6  $\mu\text{g mL}^{-1}$ ). Benomyl did not inhibit spore germination of *Botryosphaeria* spp. Prochloraz and pyrimethanil (an anilinopyrimidine fungicide) were only effective against the *Botryosphaeria* spp. at the highest concentration tested (369.6, 913.1, 562.3 and 1147.2  $\text{g mL}^{-1}$ ).<sup>(69)</sup> Of the fungicides tested, prochloraz was the most effective inhibitor of mycelial growth of four of the five fungi tested (*C. acutatum*, *C. gloeosporioides*, *B. dothidea* and *Phomopsis*) at concentrations ranging from 0.29 to 0.36  $\text{g mL}^{-1}$ . Fluazinam was next most effective against *C. acutatum* and *C. gloeosporioides* at levels of 7.8 and 1.7  $\text{g mL}^{-1}$ , respectively.

The strobilurins were the next most effective fungicide group, and of these fungicides, kresoxim-methyl (a methoxyiminoacetate strobilurin fungicide) was the most effective, at concentrations ranging from 0.1 to 1.9  $\mu\text{g mL}^{-1}$ . Strobilurin fungicides were extracted from the fungus and were

first launched in 1996. They are mostly contact fungicides with a long half-life as they are largely only absorbed into the cuticle and not transported any further, although some of them have a low uptake in the leaves (e.g., azoxystrobin). Strobilurins inhibit respiration and inhibit a specific enzyme – succinate dehydrogenase. The best time to apply strobilurins is prior to infection or at very early stages of disease development.<sup>(133)</sup> Willingham *et al.*<sup>(1)</sup> reported that strobilurin fungicides were effective in controlling postharvest diseases of ‘Hass’ avocado. Of the three strobilurin formulations tested in the field, the Amistar<sup>®</sup> and Flint<sup>®</sup> (both methoxyiminoacetamide strobilurin fungicides) fungicides were found to be superior to the Strobry<sup>®</sup> (a methoxyiminoacetate strobilurin fungicide) formulation. When Amistar<sup>®</sup> or Flint<sup>®</sup> were sprayed on the trees the incidence of anthracnose was significantly reduced by 66% and 74%, respectively. Working with the cultivar Hass, Willingham *et al.*<sup>(134)</sup> found that the variety of rootstock had a significant impact on postharvest anthracnose susceptibility. The incidence of anthracnose was on average 34 to 35% lower for ‘Hass’ grafted on the Guatemalan Velvick rootstock as compared with the Mexican Duke 6 rootstock. They claimed that this was the first record of such an effect for avocado.

Consumers prefer purchasing fruit that is not treated with pesticides and that are free from defects, disease free and safe for consumption. On the other hand, the importing countries have enforced strict import regulations regarding the maximum residue limits (MRL) of chemicals in the edible portion of the fruit. The disposal of fungicide solutions used in large volumes can also affect the environment, especially the soil and water resources, and there is evidence of the development of resistant strains of pathogenic organisms to these chemicals.<sup>(132,135)</sup> Due to green consumerism and an increasing demand for organically produced fruit and vegetables, the horticultural industry needs to find an alternative solution to postharvest fungicide applications.

According to the food quality and safety report of the South African National Department of Agriculture and Fisheries (DAFF), the permissible MRL for prochloraz in South African avocados is 2 mg kg<sup>-1</sup>.<sup>(136)</sup> Therefore, research has focused on finding alternatives to replace the currently used prochloraz fungicide postharvest application in packhouse and this literature includes some important developments regarding this research. Also, postharvest chemical fungicide treatment is not permitted in some countries.

#### *Bio-control application*

*Bacillus* spp. on their own or combined with a fungicide could be used to control postharvest diseases of avocados.<sup>(137)</sup> *Bacillus* spp. isolated from leaves and fruit of avocados were more effective in controlling anthracnose and stem end rot of avocados when applied as a postharvest dip than prochloraz applied in the same way and *B. subtilis* was just as efficient as prochloraz in controlling anthracnose postharvest.<sup>(137,138)</sup> Microbial antagonist or bio-control agents are used on their own or in combination with a reduced concentration of synthetic fungicides.<sup>139)</sup> For example, the combination of *B. subtilis* and prochloraz was more effective than when they were applied separately. The use of antagonistic microorganisms for bio-control purposes has emerged as a viable disease management strategy<sup>(140)</sup>. In South Africa, biological control research programs on avocado commenced in 1987 and the bio-control agent (*Bacillus subtilis* B246, Avogreen<sup>®</sup>)<sup>(141)</sup> was introduced to commercial avocado growers and is still being used by organic avocado growers. Enhanced disease control is achieved by incorporating *B. subtilis* in wax. However, the biggest challenge facing companies marketing bio-control products in South Africa is severe lack of technical knowledge regarding their handling and use.



## Plant extracts and essential oils

Regnier *et al.*<sup>(142)</sup> tested *Lippia scaberrima* essential oil and three of the major oil components, (d)-limonene, R-(–)-carvone, and 1,8-cineole, as well as that of S-(+)-carvone *in vitro* against *C. gloeosporioides*, *Lasiodiplodia theobromae*, and an *Alternaria* isolate. They found significant inhibition of the mycelial growth of all the pathogens when applied at a concentration of 2000  $\mu\text{L L}^{-1}$ . They subsequently carried out a simulated export trial using *L. scaberrima* essential oil, in addition to *Mentha spicata* (spearmint) essential oil and concluded that they could be alternatives to synthetic fungicides for the postharvest management of avocado fruit that would be acceptable to the organic market. Combined application of modified atmosphere packaging (~8% CO<sub>2</sub>, 2% O<sub>2</sub>) and sachets containing thyme oil significantly reduced the incidence and severity of anthracnose, grey pulp, vascular browning, weight loss and loss of fruit firmness. These combination treatments also exhibited an acceptable taste, flavor, and texture, and a higher overall acceptance of the cultivars ‘Fuerte,’ ‘Hass’ and ‘Ryan’ after ripening at 25 °C followed by cold storage at 10 °C. The combination treatment MAP and thyme oil sachets was reported to delay ripening in avocados; with respect to the skin color, it clearly indicated changes in cv. ‘Hass’<sup>(143)</sup>. Thyme oil (66.7  $\mu\text{L L}^{-1}$ ) treatment was reported to enhance the activities of defense enzymes including chitinase, 1, 3- $\beta$ -glucanase, peroxidase and phenylalanine ammonia-lyase resulting in an increase in the total phenolics content. The thyme oil (66.7  $\mu\text{L L}^{-1}$ ) treatment also improved the activities of antioxidant enzymes (superoxide dismutase and catalase) and based on these findings, Sellamuttu *et al.*<sup>(144)</sup> suggested that the effects of thyme oil on anthracnose in the avocado fruit is due to the elicitation of biochemical defence responses in the fruit and inducing the activities of antioxidant enzymes.

### *Hot water treatment*

Postharvest heat treatments are recommended as nonpolluting, safe, physical treatments in order to control disease during storage and the marketing of fresh fruit. Heat treatments possess many advantages over chemical treatments: they do not leave any residue on or in the fruit, they can be implemented within a short duration, they are easily monitored, and the pathogens can be controlled even after gaining entry into the fruit.<sup>(139)</sup> The use of postharvest heat treatments to control decay during storage needs to be applied within a short period after harvesting in order to prevent the entry or further penetration of the target pathogens found on the surface or in the first few cell layers under the skin of the fruit. Treatment temperatures and duration can be cultivar specific. Improper heat treatments in terms of unfavorable higher temperatures or increasing time of exposure could result in undesirable effects on the quality of the fresh produce. Hot water treatment is widely utilized in many countries for decay control because it is relatively easy to use and is usually cost-effective.<sup>(145)</sup>

Heat treatments control decay by directly inhibiting spore germination and mycelial growth, thereby inhibiting pathogen development. Heat treatments further induce defense responses such as increased biosynthesis and an accumulation of phytoalexins (specific plant antimicrobial compounds) via the activation of phenylalanine ammonia lyase (PAL EC 4.3.1.5.), the key enzyme of the phenylpropanoid pathway.<sup>(146)</sup> Furthermore, heat treatments can increase the lignifications of cell walls in wound sites in order to provide physical barriers against invading pathogens. Heat treatments have also been shown to induce the production of pathogenesis-related proteins and the accumulation of enzymes such as chitinase (hot water dip at 53 °C in grapefruit)<sup>(147)</sup> and  $\beta$ -1,3-glucanase to hydrolyse the fungal cell walls in order to inactivate the pathogens.<sup>(148,149)</sup> In avocados, quantitative changes in the phytoalexin (1-acetoxy-2-hydroxy-4-

oxo-heneicosa-12, 15-diene) and the anthracnose symptom development after hot water treatments at 55 °C for 10 min were reported by Plumbley *et al.*<sup>(150)</sup> The concentration of 1-acetoxy-2-hydroxy-4-oxo-heneicosa-12, 15-diene at harvest was 2000 and 2600 µg g<sup>-1</sup> fresh weight in the skin and mesocarp, respectively. The levels of diene were reported to decline rapidly during the first 24 h after harvesting and did not recover until 98 h in the skin. When hot water treated fruit was inoculated, the symptoms occurred after 2 days, whereas in untreated fruit relatively minor symptoms were noted after 6 days. However, when there was a delay in inoculation after hot water treatment the symptoms appeared only after 6 days. Based on these observations, Plumbley *et al.*<sup>(150)</sup> conclude that the quiescence of *C. gloeosporioides* could be maintained by the level of antifungal diene present in the peel at the time of fungal penetration and the formation of subcuticular hyphae. Anthracnose development was also investigated in avocados treated with hot water at 55 °C for 5 min, 50 °C for 10 min and 45 °C for 15 min by Karunaratne and Adikaram<sup>(151)</sup>. These researchers reported that the hot water treatment at 50 °C for 10 min failed to reduce anthracnose development whereas fruit treated at 45 °C for 15 min on the day of harvesting, or 1 to 5 days after harvesting, resulted in a significant reduction in anthracnose symptom development. However, they found no significant difference in the antifungal compound 1-acetoxy-2-hydroxy-4-oxo-heneicosa-12, 15-diene between the hot water treated fruit at 45 °C for 15 min and those of the other treatments tested that could explain the reduction of anthracnose symptoms noted in the fruit subjected to 45 °C for 15 min. Table 7 shows a summary of alternative treatments to replace prochloraz fungicide application to control postharvest diseases in avocados.

**Table 7**

Alternative treatments researched to replace prochloraz fungicide application to control postharvest diseases in avocados

Alternative treatments to control postharvest diseases in avocados	Description of postharvest treatments	Target pathogen and the decay	Source
1. Application of biocontrol agent (Avogreen <sup>(R)</sup> )	<i>Bacillus subtilis</i> B246, Avogreen <sup>(R)</sup> (	<i>C. gloeosporioides</i> (anthracnose)	(134)
2. Hot water treatment	at 55 °C for 10 min at 45 °C for 15 min	<i>C. gloeosporioides</i> (anthracnose) <i>C. gloeosporioides</i> (anthracnose)	(148) (149)
3. Plant extract	1 to 5 days after harvesting <i>Lippia scaberrima</i>  <i>Mentha spicata</i> (spearmint)	<i>C. gloeosporioides</i> (anthracnose) <i>Lasiodiplodia theobromae</i> (stem-end rot) <i>Alternaria</i> spp. <i>C. gloeosporioides</i> (anthracnose) <i>Lasiodiplodia theobromae</i> (stem-end rot) <i>Alternaria</i> spp. <i>C. gloeosporioides</i> (anthracnose)	(140)       (141)
4. Combined applications of essential oil and modified atmosphere packaging (MAP)	Thyme oil and MAP (~8% CO <sub>2</sub> , 2% O <sub>2</sub> ) (	<i>C. gloeosporioides</i> (anthracnose)	(141)
5. Controlled atmosphere storage	Fuchs and Waldin stored at 2% O <sub>2</sub> and 10% CO <sub>2</sub> at 7.2 °C for 3 to 4 weeks	<i>C. gloeosporioides</i> (anthracnose)	(164)
6. Dynamic CA		Fungal decay	(167)
7. Hypobaric storage	91 mm Hg plus 10% CO <sub>2</sub>	<i>C. gloeosporioides</i> (anthracnose) stem end rot ( <i>Diplodia natalensis</i> )	(99)

### ***Physiological disorders***

Different types of physiological disorders were reported in avocado fruit after 2 to 4 weeks' cold storage.<sup>(154)</sup> The major disorders were vascular browning and grey pulp.<sup>(155)</sup> When the fruit was exposed to less than 3 to 5 °C for more than two weeks they developed vascular browning and grey pulp. Vascular browning was described by Florissen *et al.*<sup>(156)</sup> as mesocarp discoloration with a hardening of the vascular strands and an off-flavor development. A chilling injury (internal) symptom can be expressed as a greyish brown discoloration in the mesocarp especially at the basal end of the fruit around the seed and this is referred to as typical vascular browning that is initiated at the base of the fruit. The grey and dark discoloration in the mesocarp is reported as being grey pulp.<sup>(157)</sup> 'Pinkerton' is the most susceptible cultivar to grey pulp and both controlled atmosphere storage and modified atmosphere packaging delayed, but did not prevent its development.<sup>(158)</sup> Kruger *et al.*<sup>(159)</sup> mentioned that avocado fruit grown from different areas differed in their susceptibility to mesocarp discoloration. Season, irrigation regimes<sup>(160)</sup> as well as calcium nutrition<sup>(161)</sup> also contribute to the observed differences in mesocarp discoloration.

Pulp spot, also known as low temperature disorder, is another significant physiological disorder of avocados that can develop during storage. High incidences of pulp spot were commonly observed in the cultivar 'Fuerte' as small dark spots in the mesocarp and a blackening of the vascular bundles. This disorder was reported to be higher in early season than later season fruit.<sup>(162)</sup>

During the browning process in the above mentioned physiological disorders, enzymatic oxidation of phenolic compounds to melanin, which is mediated by poly phenol oxidase (PPO), is responsible for the brown discoloration of the mesocarp.<sup>(123,128)</sup> The activity of PPO was noted to increase due to ethylene production during the ripening of avocados.<sup>(155, 163)</sup> PPO activity takes

place in presence of oxygen. Post-harvest moisture stress was reported to play a role in the initiation of physiological disorders therefore reducing the water loss by applying modified atmosphere packing may reduce flesh discoloration (browning).<sup>(164)</sup> Bower and Cutting<sup>(165)</sup> reported with increase of ABA content during initial stage of ripening and softening increased the PPO activity and residual ABA was negatively correlated with PPO activity. Comparative study on PPO activities in three avocado cultivars, 'Fuerte', 'Horeshim' and 'Lerman' indicated that the 'Fuerte' showed the highest activity where as 'Horeshim' and 'Lerman' showed lower PPO activities at matured stage.<sup>(166)</sup> Moreover the initial PPO activity increased Quintal, Fortuna, cultivars than the 'Choquete'. Reports showed that the PPO activity was affected by cultivation practices and postharvest storage conditions. Peroxidase (POD) activity was shown to decrease with fruit maturation and according to Vanini *et al.*<sup>(167)</sup> in 'Quintal', 'Fortuna' and POD activity was related to the ripening process influencing the change in the fruit flavor, therefore, treatment capable of reducing POD activity will help during processing. In 'Fuerte' fruits and its POD activity declined with ripening and fruit softening and Zauberman *et al.*<sup>(168)</sup> suggested that the POD activity in 'Fuerte' avocado fruit mesocarp has no role in the development of chilling injury or mesocarp browning

## ***Atmosphere modification and fruit quality***

### *Controlled atmosphere*

Controlled atmosphere storage (CA) can be defined as a system where the desirable gas composition of reduced O<sub>2</sub> and/ or increased CO<sub>2</sub> can be regulated and maintained constantly throughout the storage and/ or transportation period.<sup>(169)</sup> CA storage is mostly used for long term storage of fruits such as apples but it is also being increasingly used in transportation of fruit by sea. Generally, CO<sub>2</sub> delays many responses of fruit to ethylene. The higher CO<sub>2</sub> and lower O<sub>2</sub> in CA storage was reported to reduce the rates of respiration and ethylene production.<sup>(170)</sup> Due to this phenomenon, CA can affect the postharvest physiology of the fresh produce depending on the O<sub>2</sub>/CO<sub>2</sub> balance. Fabion *et al.*<sup>(171)</sup> reported that the severity of chilling injury (physiological disorder) in avocados is reduced in low O<sub>2</sub>/elevated CO<sub>2</sub> atmospheres. However, CO<sub>2</sub> levels exceeding 5% may have a detrimental effect on ‘Hass’ avocado fruit quality and therefore specific optimum levels of CO<sub>2</sub> in low O<sub>2</sub> needs to be defined. Fruit maturity was shown to also have an influence on the severity of chilling injury in CA.

Postharvest disease control can also be achieved by controlling host resistance through storing or shipping the fruit in CA conditions.<sup>(152)</sup> The cultivars Fuchs and Waldin stored at 2% O<sub>2</sub> and 10% CO<sub>2</sub> at 7.2 °C for 3 to 4 weeks had reduced anthracnose disease development after fruit softening or ripening at 21.1 °C.<sup>(103)</sup> The use of CA storage in disease control was more aimed at spore germination than controlling the radial mycelial growth of the fungus, but the main objective was to delay fruit softening so that the pathogen (*C. gloeosporioides*) would remain dormant.<sup>(103)</sup> On the other hand, a higher incidence of anthracnose was reported in 'Fuerte' stored at 1% O<sub>2</sub> and 10% CO<sub>2</sub>, which was explained by the low O<sub>2</sub> shock experienced by the fruit tissues resulting in the damaged cells becoming more susceptible to the anthracnose pathogen during ripening at 25 °C.<sup>(161,172)</sup> Generally, O<sub>2</sub> content of 2% to 5% and CO<sub>2</sub> of 3% to 10% are used to store avocados for five to six weeks.<sup>(162,173)</sup> According to Burdon and Lallu<sup>(153)</sup>, CA storage can be maintained by adopting static (SCA) or dynamic (DCA) systems. DCA was defined by Toivonen and DeEll<sup>(174)</sup> as where the gas mixture in the CA store will constantly change due to metabolic activity of the respiring fruits in the store. Where the O<sub>2</sub> level falls below a threshold level several metabolic processes will change, which includes ethanol synthesis, and the chloroplasts will be stressed causing them to fluoresce. DCA uses the measurement of either chlorophyll fluorescence or ethanol production to control the O<sub>2</sub> level in the store. In the SCA system, the O<sub>2</sub> concentration is maintained at a pre-determined concentration until the end of the storage time. Burdon and Lallu<sup>(153)</sup> indicate that DCA stored 'Hass' avocados grown in New Zealand ripened after four days, similar to the fruit that were stored and ripened in air, while the SCA stored fruit took seven days to ripen. DCA-stored avocados ripened more uniformly and had less fungal decay and physiological disorders. DCA was recommended in order to extend the storage time, while maintaining the overall quality of avocado for New Zealand avocado growers and



**Table 8**Controlled atmosphere storage of avocados<sup>a</sup>

CA	Temperature regime	Carbon dioxide/oxygen concentration	Source
1	12°C	3 to 10% CO <sub>2</sub> + 2-5% O <sub>2</sub>	(169)
2	10 to 13°C	3 to 10% CO <sub>2</sub> + 2-5% O <sub>2</sub>	(170)
3	5°C	5% CO <sub>2</sub> + 5% O <sub>2</sub>	(171)
4	2 or 5°C	15% CO <sub>2</sub> + 2% O <sub>2</sub>	(93)
5	10°C	3 to 5% CO <sub>2</sub> + 3-5% O <sub>2</sub>	(152)
6	10°C	9% CO <sub>2</sub> + 1% O <sub>2</sub>	(152)
7	5°C	9% CO <sub>2</sub> + 2% O <sub>2</sub>	(172)
8	6°C	5% CO <sub>2</sub> + 2% O <sub>2</sub>	(172)
9	6°C	5% CO <sub>2</sub> + 2% O <sub>2</sub>	(153)
10	6°C	5% CO <sub>2</sub> + 5% O <sub>2</sub>	(153)
11	6°C	10% CO <sub>2</sub> + 2% O <sub>2</sub>	(153)
12	5°C	8% CO <sub>2</sub> + 3% O <sub>2</sub>	(174)
13	5.5°C	10% CO <sub>2</sub> + 2% O <sub>2</sub> (4 weeks)	(175)

<sup>a</sup>Source: Thompson<sup>(90)</sup>

exporters. As with temperature recommendations, so controlled atmosphere storage recommendations vary and Thompson<sup>(49)</sup> reviewed the recommendations for controlled atmosphere storage of avocados (Table 8).

### *Modified atmosphere packaging*

In modified atmosphere (MA) packaging, the atmospheric composition (mainly moisture O<sub>2</sub> and CO<sub>2</sub>) around the fruit is modified or altered by storing the fruit in plastic films sometimes with microperforations or the addition of chemicals inside the bags to control ethylene, CO<sub>2</sub> and water vapor. In MA, the levels of O<sub>2</sub> and CO<sub>2</sub> cannot be controlled or regulated like in CA. Different atmospheres are achieved by flushing the atmosphere with a predetermined O<sub>2</sub> and CO<sub>2</sub> at the beginning of storage. It can also be modified during storage by varying the film type and its gas permeability as well as the weight or volume of the fruit or vegetables and the storage temperature.<sup>(176)</sup> When the internal atmosphere is modified by the respiration of a commodity, some gas equilibrium concentration will be reached in a few days time. At the equilibrium steady-state, it is assumed that the quantity of gas exchanged through the fruit skin is equivalent to that exchanged through the film. An equilibrium steady state is reached when the gas composition inside the package has stabilized.<sup>(176,177)</sup>

The use of MA packaging to market avocados is practiced in many countries and it is reported to delay ripening and prolong storage. Aharoni *et al.*<sup>(177)</sup> reported that decay was not reported as a major problem, since the fruit was properly sorted, incidences of decay in avocados packed in polyethylene bags. Storage life was extended by 3 to 8 days at various temperatures by sealing individual fruit in polyethylene film bags compared to those stored without packaging.<sup>(101)</sup> ‘Fuerte’ fruit sealed individually in 25 µm thick polyethylene film bags for 23 days at 14 to 17°C

ripened normally on subsequent removal to higher temperatures.<sup>(178)</sup> Levels of gases inside the bags after 23 days storage were 8% CO<sub>2</sub> and 5% O<sub>2</sub>. Thompson *et al.*<sup>(100)</sup> showed that sealing various seedling varieties of West Indian avocados in polyethylene film bags greatly reduced fruit softening during storage at various temperatures. Meir *et al.*<sup>(179)</sup> recommended 5 °C in 30 µm thick polyethylene film bags for 'Hass', Scott and Chaplin<sup>(180)</sup> recommended 4 to 7.5 °C in 50 µm polyethylene bags for 'Fuerte'. Eksteen and Truter<sup>(172)</sup> found that 'Fuerte' packed in polyethylene bags in cartons and stored at 5.5 °C for 33 days and ripened at 20 °C atmosphere prolong their storage life but failed to control the incidence of anthracnose. A similar observation was reported by Oudit and Scott<sup>(181)</sup> for the cultivar Hass. They explained that the higher humidity within the bags during ripening at 20 °C could have been the reason for the high incidence of anthracnose. MA packaging with an ethylene scavenger was also reported to reduce mesocarp discoloration and decay in avocados.<sup>(163)</sup> Modified atmosphere packaging has many advantages, such as its easy implementation at the commercial level, biodegradable films can be used and therefore its application becomes more environmentally friendly.<sup>(182)</sup> For avocados, the MA packaging technology provides many advantages including delaying the climacteric rise in respiration rate, thereby retarding ripening and deterioration processes. MA packaging can also prevent fruit browning by preventing loss of membrane integrity and prevents loss of electrolyte leakage by reducing the polyphenol oxidase activity.<sup>(183)</sup> At the same time, MA packaging has been shown to inhibit the expression of hydrolytic enzymes involved in fruit softening in avocado and as a result it slows softening.<sup>(184)</sup> The high humidity surrounding the fruit during MA packaging helps to reduce the weight loss during the marketing of the fruit.

### *Hypobaric storage*

Hypobaric storage is the storage under pressures of less than one atmosphere (760 mm Hg = 101.32 kPa) and has been used in storage and transport of fruit and vegetables. Burg<sup>(185)</sup> summarised his work over many years on the effects of hypobaric storage on avocados. The cultivar Choquette stored at 14.4 °C under atmospheric pressure started to ripen in 8 to 9 days and they were fully ripe in 14 days. Softening of those under 5.3 to 13.3 kPa began after 25 days and when transferred to 20°C under atmospheric pressure all fruit developed normal taste with no internal blackening or decay. Burg<sup>(185)</sup> subsequently found that in storage at 12.8 °C hypobaric conditions at 13.3 to 20 kPa was better than at 5.3 to 10.7 kPa and in later work he reported that 2.7 kPa was optimal at 10 °C. With the cultivar Waldin, Burg<sup>(185)</sup> reported that in storage at 10 °C their postharvest life was improved as the pressure was lowered from 13.3 to 20 kPa down to 8 to 10.7 kPa with the fruit remaining firm for 30 days at 8 to 10.7 kPa compared to 12 to 16 kPa at atmospheric pressure. Similar results were found in storage at 12 °C but all fruit ripened quicker. Spalding and Reeder<sup>(103)</sup> compared storage of Waldin at 7.2 °C and 98 to 100% RH for 25 days at atmospheric pressure in air with controlled atmosphere storage under 2% O<sub>2</sub> and 10% CO<sub>2</sub> or 2% O<sub>2</sub> and 0% CO<sub>2</sub> and two hypobaric storage conditions in 91 mm Hg, one with added CO<sub>2</sub> at 10%. After storage, all the fruit was ripened at 21.1 °C. They found that 92% of the fruit stored in the controlled atmosphere of 2% O<sub>2</sub> and 10% CO<sub>2</sub> were acceptable and all those in the hypobaric conditions of 91 mm Hg plus 10% CO<sub>2</sub>, while none of the fruit in the other treatments were acceptable. The factors that affected acceptability were anthracnose disease and chilling injury, both of which were completely absent in fruit stored under 91 mm Hg plus 10% CO<sub>2</sub>. They defined acceptable fruit as having good appearance, free of moderate or severe decay and chilling injury, and with no off-flavors. They also found no stem end rot

(*Diplodia natalensis*) directly after storage but after ripening at 21.1 °C. No stem end rot was detected except low levels on those that had been stored under 91 mm Hg and higher levels were observed in the fruit that had been stored under 2% O<sub>2</sub> and 10% CO<sub>2</sub>. Black pitted areas developed in lenticels during softening of avocados stored at atmospheric pressure or hypobaric plus 10% CO<sub>2</sub> <sup>(186)</sup>. However, pitting was slight and was not considered to be objectionable to the average consumer. Tissue from the infected areas contained *Pestalotia* spp. fungus. From this they concluded that high CO<sub>2</sub> was necessary for the successful storage of avocados since the hypobaric system would have reduced the partial pressure of O<sub>2</sub> 91 mm Hg would be about 2.5%.

### ***Edible coatings***

The use of edible coatings or films in preserving fruit quality has of recent attracted the attention of many researchers in the food industry. Edible coatings are made from biopolymers such as carbohydrates, proteins and lipids however are biodegradable and are most importantly they are biodegradable. Edible coatings also act as surface barrier hindering the movement of gases thus creating an internal modified atmosphere in the fruit. However, different edible coatings made from different materials have different properties. Maftoon Azad <sup>(187)</sup> found that the application of methyl cellulose a polysaccharide resulted in lower respiration, reduction in color changes in both skin and flesh as well as softening of the tissue and increased the shelf life in ‘Hass’ avocado with a maximum storage period of 10 days (1.5 times the control treatment) at room temperature. Similarly, the application of gelatine-starch coatings delayed the ripening process which resulted in firmer fruit and lower weight loss in ‘Hass’ <sup>(188)</sup>. In addition a delay in respiratory climacteric pattern by 3 days was noticed in coated fruits stored at 20 °C.

## Conclusions

The critical stage in the life cycle of fruit is during postharvest because after harvest fruit quality can only be maintained and not improved. Avocado production in countries like South Africa, Israel and Chile is export-driven with the European Union being the biggest market and this entails high fruit quality standards. Consequently, stringent quality assurance systems and well managed postharvest management practices are required. The maintenance of fruit quality therefore begins from the point of harvest until it reaches the retailer or the table of the overseas consumer. During transportation, fruit is not only stored for long periods but handled at different transit points. As a result, avocado fruit quality can be lost due to fruit softening that occurs during ripening, the development of physiological disorders and decay development as a result of microorganism infection. Temperature management is one of the critical issues that need to be managed during this period because it is related to several physiological and biochemical processes of the fruit which ultimately affects fruit quality. Most avocado cultivars that enter international trade can be stored between 5 to 7 °C and care should be taken to avoid the development of physiological disorders especially chilling injury. MA, CA and hypobaric storage can be used in combination with low temperature to delay fruit ripening and reduce decay development. However, these technologies are expensive due to the equipment that is required. Application of 1-MCP to delay fruit ripening seemed to be promising in delaying ripening but the biggest challenge is the development of decay associated with the use of this compound. <sup>(189)</sup>.

Decay development mostly due to anthracnose and stem-end is another challenge faced during the supply chain. The use of fungicides such as prochloraz has been one of the traditional methods used to address the issue of postharvest decay development. However, there is a need

for safer methods to control postharvest decay development due to an increase in consumer concern regarding food safety and demand for organically produced fruit. The use of bio-control agents, application of essential oils or plant extracts in combination with modified atmosphere packaging or edible coatings and heat treatment could be possible alternatives to fungicide use. The major limitations are that heat treatment might damage the tissue of the fruit and affect the marketability of the fruit, while on the other hand the use of essential oils and plant extract could have some impact on the sensory properties of the fruit. However, use of essential oils in lower concentration in vapor phase application can minimize the impact on sensory properties of the fruit. Combination of a bio-control agent with lower concentrations of fungicides or GRAS (Generally Regarded As Safe) compounds also reduces the postharvest losses due to postharvest diseases during the supply chain. All the new alternative treatments must be evaluated on different cultivars, at different maturity stages and according to fruit sizes or weights and at different seasons or locations at least over three seasons before they should be adopted commercially. Therefore, to have fruit of good quality either on the shelf of the retailer or on the table of the consumer an effectively managed supply chain is required and a range of technologies are required.

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