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Review

A review on postharvest handling of avocado fruit

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This paper reviews the literature on the effect of pre- and postharvest treatment effects on the postharvest quality of avocado fruit. It is evident from literature that pre-harvest factors such as ambient field temperature and water stress affects the postharvest physiology of avocado fruit. The postharvest handling treatments and environmental conditions identified were pre-packaging treatments, different density packaging films, storage conditions and cyclic temperature storage environments during the avocado fruit cold chain. Temperature was found to have the greatest influence on the physical, sensory and chemical quality of avocado fruit after harvest. Maintenance of an optimal temperature regime from harvest to final market destination is, therefore, required to maintain fruit quality. The influence of varying temperature and relative humidity with time during the avocado fruit cold chain in South Africa requires further study.

Key words: Pre-packaging, packaging, cyclic storage conditions, quality, cold chain, South Africa.

INTRODUCTION

Shelf life can be defined as the period in which a product should maintain a predetermined level of quality under specified storage conditions (Perez et al., 2004). Avocado (*Persea americana* Miller) is a highly perishable commodity (Yahia and Gonzalez-Aguilar, 1998; Jeong et al., 2002; Yahia, 2002; Perez et al., 2004; Gamble et al., 2010) and yet valued for export. The leading exporter of avocados to Europe is Israel, supplying 29% of imports, followed by South Africa contributing 21% and Spain with 17% (Van Zyl and Ferreira, 1995). In 2008 and 2009, approximately 64% of South African produced avocados were exported (Department of Agriculture Forestry and Fisheries, unpublished, 2010), however, in 2009, South African exported avocados were considered to be of an inferior quality (Nelson, 2010).

Avocado quality at its final destination is a major concern during exportation. Thus, the development of valuable postharvest technologies could improve the quality and consequently extend the shelf life of avocados locally and during export to distant markets. Avocados continue respiring even after harvest, commencing the ripening process almost immediately due to their climacteric characteristic of high respiration rates (Wu et al., 2011). Villa-Rodriguez et al., (2011) states the complete ripening process to be five to seven days at 25°C. Numerous studies have been conducted to exhibit the effect of pre-packaging treatments, packaging materials and storage conditions on the effect of avocados (Meir et al., 1997; Hofman et al., 2003; Woolf et al., 2003; Perez et al., 2004; Wu et al., 2011). Pre-packaging methods such as hot and cold treatments, waxes and 1-Methylcyclopropene (1-MCP) were shown to reduce chilling injury and improve avocado quality. Polyethylene (PE) and biodegradable packaging films can extend the avocado shelf life. Optimal temperature and relative humidity conditions have also proven beneficial in maintaining high quality avocados. Studies by Tefera et al. (2007) demonstrated positive effects on

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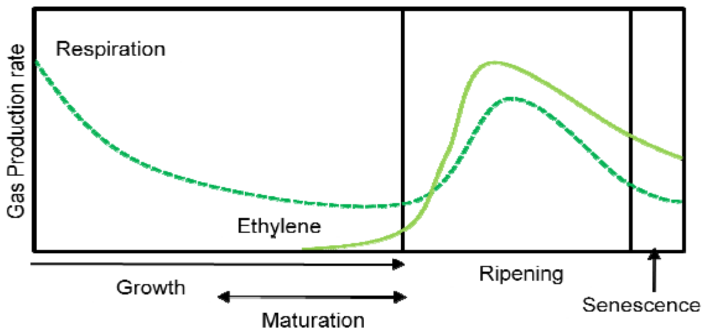

Figure 1. Physiological developmental stages of avocados (Blakey, 2011).

the quality of mangos in Ethiopia by integrating suitable pre-packaging, packaging and storage conditions. Cold chain management is a crucial factor regarding the quality of avocados from harvest till final market destination (Milne, 1998; Blakey and Bower, 2009; Kok et al., 2010). The interplay of time and temperature under cyclic storage conditions are important in maintaining a superior quality product deemed acceptable by both national and international standards.

An overview of the pertinent postharvest handling conditions adopted to enhance the quality of avocados and prolonging their shelf life are presented. An outline of the significant physical, sensory and chemical quality parameters associated with evaluating avocado maturity are provided. Subsequently, the effects of pre-packaging treatments, packaging materials and storage conditions on the quality parameters of avocados are reviewed. Focus was also given to pre-harvest conditions such as exposure of avocados to ambient temperature and water stress as these factors were proven to affect the postharvest behaviour of avocados. Finally the avocado cold chain, regulations, guidelines and recommendations during postharvest handling are identified.

PRE-HARVEST AND HARVESTING FACTORS that AFFECT AVOCADO QUALITY

Understanding avocado postharvest behaviour requires an understanding of the basic physiological principles. Here, some vital pre-harvest and harvesting factors affecting postharvest behaviour of avocados are presented.

Respiration and ripening

Respiration is described as a natural process occurring within all living organisms whereby organic materials are broken down into simpler end products. During respiration oxygen is expended and carbon dioxide liberated accompanied by the production of energy in the form of heat (Workneh and Osthoff, 2010). This process is predominantly responsible for the ripening of avocados. Starrett and Laties (1991), Jeong et al. (2002), Yahia (2002), Jeong et al. (2003) and Wu et al. (2011) described avocados as being climacteric, characterised by a surge in ethylene production and respiration at the start of the climacteric ripening (Figure 1).

The respiration of avocados follows three characteristic climacteric stages viz. preclimacteric minimum of least respiration, climacteric maximum of highest respiration and a postclimacteric stage synonymous with a decline in respiration. It is during the preclimacteric and climacteric stages where much of the changes associated with ripening occur (Perez et al., 2004). The shelf life of fresh commodities is inversely related to respiration and ethylene rates as stated by Perez et al. (2004). An increase in the respiration rate hastens senescence contributing to poor fruit quality (Maftoonazad and Ramaswamy, 2008). Therefore, to improve handling of avocados once harvested it is essential to lower the respiration rates by reducing the temperature, increasing carbon dioxide and reducing oxygen concentrations within limits.

Pre-harvest factors

Here, the significant interaction and impact of pre-harvest factors on postharvest requirements, development and inherent quality characteristics of avocados are highlighted.

Ambient heat exposure

Ferguson et al. (1999) observed the predominant pre-harvest factor influencing postharvest quality of avocados to be ambient temperature during growth. This was confirmed by Woolf et al. (1999) who demonstrated that the side of the avocado exposed directly to sunlight while still on the tree was able to withstand higher temperatures during postharvest treatments of approximately 50°C compared to the shaded side. Avocados exposed to high ambient temperature on the field also demonstrated a tolerance to low postharvest temperatures and external chilling injury (Woolf and Ferguson, 2000). This, however, does not apply to already harvested avocados as it is imperative that they be protected against direct sunlight to elude overheating and subsequent early postharvest deterioration (Milne, 1998; Yahia, 2002).

Results obtained by Woolf et al. (2000), further, confirmed that avocados exposed to direct sunlight were capable of tolerating postharvest hot water treatments of 50 and 55°C and were found to be firmer. Sun exposed fruit showed a higher endurance to chilling injury when stored at 0°C for periods between three to six weeks. The ethylene peak of sun exposed fruit was delayed by two to five days during ripening at 20ºC. Postharvest heat treatments are based on a similar principle of exposing avocados to high temperatures, however, for predetermined periods of time in order to stimulate the production of heat-shock proteins (Florissen et al., 1996; Woolf et al., 1999; Woolf and Ferguson, 2000; Woolf et al., 2000; Fallik, 2004; Wu et al., 2011).

Water stress

Adato and Gazit (1974) found that pre-harvest water stress resulted in premature fruit abscission and an increase in ethylene production leading to accelerated ripening by 40 and 25% depending on the degree of water stress. Both Kaluwa (2010) and Blakey (2011) confirm that water stress decreased the normal avocado ripening time hence reducing the shelf life accompanied by an increased risk of physiological disorders. The effect of water stress on avocados can further be linked to temperature. When a plant is water stressed, the temperature of the fruit rises. Cooling is as a result of evaporative water loss from the plant tissue (Woolf and Ferguson, 2000). Once the fruit is harvested this cooling effect is halted and the rise in temperature is further exacerbated by exposure to the sun. Water stressed 'Hass' avocado trees were found to bear more elongated fruit (Yahia, 2002). The reason for this is unknown and further studies are required to investigate this phenomenon. Water stress reduces the internal quality of avocados due to the increased activity in polyphenol oxidase leading to browning of the flesh. Lower concentrations of calcium were found in water stressed fruit resulting in high incidence of physiological disorders.

Harvesting techniques

Avocados unlike other fruit do not ripen on the tree, but only once harvested (Lee et al., 1983; Hopkirk et al., 1994; Baryeh, 2000; Ozdemir and Topuz, 2004; Perez et al., 2004; Gamble et al., 2010; Osuna-Garcia et al., 2010). The time at which avocados are harvested plays an important role in maturation and the expected shelf life. Harvesting too early in the season contributes to low pulp dry matter. This is associated with irregular ripening, watery texture, flavourless, shriveled, blackened fruit (Gamble et al., 2010; Osuna-Garcia et al., 2010) and a low oil concentration (Blakey, 2011). Perez et al. (2004) reported that harvesting prior to physiological maturity results in irregular softening, a poor taste and higher susceptibility to decay. Generally if the fruit are not harvested at the correct time the quality becomes compromised and the shelf life shortened (Wu et al., 2011).

The time of harvesting among other factors depends on the avocado cultivar. Whiley et al. (1996a) showed that early harvesting at 21 and 24% dry matter lead to a higher cumulative and average yield on the early-maturing 'Fuerte'. However, delaying harvesting till a value of 30% dry matter was attained, reduced yields by 26% and lead to alternate bearing. Similar studies by Whiley et al. (1996b) indicated that early harvesting of late-maturing 'Hass' at 25 to 30% dry matter resulted in high productivity whereas delayed harvesting at 35% dry matter reduced yields also leading to alternate bearing. Chen et al. (2009) observed that late season 'Sharwil' were smaller in size, had higher oil content and dry matter and demonstrated a shorter shelf life than early and mid-season fruit.

Hofman et al. (2002a) recommended that picking avocados when wet should be avoided as this increases the incidence of cold injury, pulp spot and lenticel damage. Fruit harvested in the morning or late afternoon tend to have less field heat. Colour, size or oil content, generally serve as indications as to the most appropriate time for harvesting (Ozdemir and Topuz, 2004).

Harvesting is mainly accomplished by manual techniques such as clipping and snapping. Eaks (1973) investigated the influence of these two methods on the postharvest development of avocados and found no significant difference in terms of weight loss and the rate of ripening. Yahia (2002) found that clipping helped reduce bruising and puncturing of adjacent fruit while in containers as well as reduce the onset of stem end rot. Hofshi and Witney (2002) referring to studies that indicated snapped avocados ripened at a faster rate than those that were clipped. Further studies are required to establish the effect of snapping and clipping on the consequent quality of avocados.

AVOCADO QUALITY CHARACTERISTICS

The quality of horticultural produce are composed of sensory attributes, nutritive attributes, chemical constituents, mechanical properties, functional properties and defects (Abbott, 1999; Yahia, 2002; Forero, 2007). Colour, texture, flavour and aroma have been found to be essential in determining the eating quality of avocados and are the main characteristics to which consumers refer to when purchasing (Lee et al., 1983; Forero, 2007). In order to investigate and maintain the quality of avocados it is essential to be aware of the quality related attributes which are outlined here.

Physical properties

Physical properties are mainly related to the appearance and aesthetic appeal of avocados to which consumers are initially exposed influencing their decision to purchase. The physical quality parameters of avocados include skin colour, firmness, texture, and physiological disorders.

Skin colour

Avocado skin colour is an important indication of the stage of ripening for industry and consumers (Cox et al., 2004; Arzate-Vázquez et al., 2011). Skin colour can be measured either objectively, commonly using a chroma meter or colorimeter or alternatively using subjective means by experienced sensory panellists using eye colour rating. Skin colour is found to vary among different avocado cultivars. The 'Hass' variety is characteristic of a colour change from green to purple and eventually black (Cox et al., 2004; Forero, 2007; Arzate-Vazquez et al., 2011). However, Chen et al. (2009) revealed that the skin colour of the 'Sharwil' variety does not darken with maturity, therefore, other methods must be utilised to distinguish the various stages of maturity. The parameters relating to colour measurement are (Maftoonazad and Ramaswamy, 2008):

L = Lightness or brightness,
a* = Redness or greenness and
b* = Yellowness or blueness.

From these parameters the chroma (C) and hue angle can be determined as follows (Maftoonazad and Ramaswamy, 2008):

$$C = \sqrt{a^2 + b^2} \quad (1)$$

$$hue\ angle = \tan^{-1}\left(\frac{a}{b}\right) \quad (2)$$

where a and b are as described previously. Cox et al. (2004) found that 'Hass' stored at 15°C did not exhibit a fully black colouration as compared to when stored at temperatures of 20 and 25°C despite the fruit being considered as ripe. This demonstrated the dependence of colour change on storage temperature. The change in colour influenced by the ripening process in 'Hass' was attributed to a decrease in chlorophyll, L, C and hue of the skin and an increase in cyanidin 3-O-glucoside. Ashton et al. (2006) found comparable results by observing a decline in the chlorophyll of the skin during ripening but at a faster rate as compared to Cox et al. (2004).

Firmness

The firmness of avocados is a vital determinant in assessing the degree of ripening (Mizrach and Flitsanov, 1999; Flitsanov et al., 2000; Arzate-Vazquez et al., 2011). Firmness can be described as the resistance to penetration (Mizrach and Flitsanov, 1999) determined by employing invasive, such as hand tactile methods, destructive methods such as the Magness-Taylor puncture test (M-T), or non-destructive methods such as impulse response and ultrasonic methods. Destructive techniques do not allow for continuity in monitoring on a commercial basis but is, rather, well suited for laboratory analysis. Mizrach and Flitsanov (1999); Flitsanov et al. (2000) and Mizrach et al. (2000) employed ultrasonic techniques to evaluate the firmness in a non-destructive manner which rendered comparable results to that of destructive methods. Gomez et al. (2005) found that impulse response techniques were more sensitive to firmness changes in pear fruit as compared to the M-T tests and has the potential to replace destructive testing methods in determining fruit firmness and shelf life. A stiffness coefficient to determine the firmness of spherical fruit can be calculated using Equation 1 (Gomez et al., 2005).

$$S = f^2\, m^{2/3} \quad (3)$$

where, S = stiffness coefficient ($kg^{2/3}\ s^{-2}$); f = dominant frequency where response magnitude is the greatest (Hz), and m = fruit mass (g).

Previous studies by Mizrach et al. (2000), demonstrated a strong correlation between fruit firmness, maturity stage and expected storage time. Storage temperature is fundamental in the diminution of firmness as avocados subjected to low temperatures exhibited reduced rates of softening (Paull, 1999; Flitsanov et al., 2000; Mizrach et al., 2000). Villa-Rodriguez et al. (2011) discovered that at storage day 0, 4, 8 and 12 the firmness diminished from approximately 130.51 N to 54.62 N, 19.92 N and 7.37 N, respectively, when stored at 15°C. Arzate-Vazquez et al. (2011) also observed a reduction in the firmness from 75.43 to 2.63 N over a period of 12 days at 20°C and 75% relative humidity.

Texture

Texture is a significant indicator of avocado quality and of concern to the consumer (Maftoonazad and Ramaswamy, 2008; Toivonen and Brummell, 2008; Landahl et al., 2009). Avocados undergo drastic changes in texture (Landahl et al., 2009; Li et al., 2010). Chen et al. (2009) stated that the oil content is a key component in the texture of avocados and which Hofman et al. (2002a) identified as contributing to the 'smoothness'. Despite the relation between texture and oil content, it was discovered by Chen et al (2009) that an increase in the oil content over the harvest period did not manifest into any change in the texture. Storage temperature, oxygen and carbon dioxide concentrations and wounding directly affect the texture (Maftoonazad and Ramaswamy, 2008). The relationship between texture and firmness can be extended to the strength of avocados and the ability of the fruit to withstand loading during storage. Firmness can be described as the force necessary to attain a previously defined deformation during textural evaluation (Landahl et al., 2009). It was found that as the avocados ripened the texture, firmness and strength were reduced.

Physiological disorders

Every biological system operates optimally within specific limits. If these limits are significantly reduced or increased, physiological disorders are likely to ensue. Storage at low temperature is commonly used to extend the shelf life of fresh commodities, however, this results in chilling injury of avocados (Eaks, 1976; Florissen et al., 1996; Yahia and Gonzalez-Aguilar, 1998; Woolf et al., 2003; Hershkovitz et al., 2005; Woolf et al., 2005; Adams and Brown, 2007). The main symptoms associated with chilling injury are black spots on the peel or gray or dark-brown discolouration of the mesocarp (Pesis et al., 1994, 2002; Meir et al., 1995; Florissen et al., 1996; Hershkovitz et al., 2005). Florissen et al. (1996), Hofman et al. (2002b) and Hofman et al. (2003) found that employing hot water treatments prior to storage were effective in reducing the effects of chilling injury. Exposing avocados to low temperature storage conditions just above those at which chilling injury is likely to occur prior to storage have been proven to alleviate the effects of chilling injury (Woolf et al., 2003). The optimum low temperature was found to be 6 or 8°C for three to five days. However, Sanxter et al. (1994) and Woolf et al. (2003) found the minimum temperature to be 4°C. Hopkirk et al. (1994) experimented on the 'Hass' variety to demonstrate that postharvest disorders increase with the increase in storage time and temperature.

Other disorders include sunburn leading to development of symptoms which emerge as yellowing or bleaching or a roughened skin (Woolf and Ferguson, 2000). On the other hand controlled or modified atmospheres that expose avocados to too low of oxygen or too high carbon dioxide concentrations can lead to disorders (Ferguson et al., 1999). Application of exogenous ethylene was also found to contribute to mesocarp discolouration (Pesis et al., 2002).

Sensory properties

One of the main sensory properties of avocados is flavour which encompasses both aroma and taste and forms an important component of the eating quality of the fruit (Abbott, 1999).

Flavour

Paull (1999), Workneh and Osthoff (2010) and Paull and Duarte (2011) defined flavor as the ratio of sugar to acid influenced by temperature as in the case of grapefruit held at 8ºC resulting in a sugar and acid decline as compared to those stored at 12ºC. Premature harvesting can lead to an undesirable taste (Brown, 1972; Perez et al., 2004 and Wu et al., 2011) or lack of flavour thereof (Gamble et al., 2010; Osuna-Garcia et al., 2010). The off flavour can be ascribed to increased levels of ethanol and acetaldehyde (Thompson, 2010; Paull and Duarte, 2011). Treatment with 0.25% oxygen and 80% carbon dioxide causes an increase in ethanol and acetaldehyde (Ke et al., 1995). Burdon et al. (2007) observed that exposure of 'Hass' to oxygen and carbon dioxide concentrations of less than 0.5% and up to 20%, respectively, resulted in increased levels of acetaldehyde and ethanol which is in accordance with that found by Ke et al. (1995). As with texture, the oil content also forms a key component of flavour (Chen et al., 2009) and, hence, it can be deduced that a positive correlation exists between texture and taste.

Chemical properties

Identification of horticultural maturity is often difficult to determine in avocados as changes in external appearance are sometimes not easily distinguishable (Lee et al., 1983). Other techniques of determining maturity and that employ chemical properties are therefore required. The chemical properties of avocados discussed here are total soluble sugar, pH, total titratable acid, moisture content, dry matter and oil content.

Total soluble sugars

Carbohydrates are an essential source of energy for growth, development and maintenance in avocados (Liu et al., 1999a, b; Tesfay et al., 2012). Five major soluble sugars were identified within the avocado include the rare seven carbon (C7) reducing sugar mannoheptulose, its reduced polyol form, perseitol, the common disaccharide sucrose, and its component hexoses, fructose and glucose (Liu et al., 1999b). These constituted approximately 98% of the total soluble sugars (TSS). Liu et al. (1999b) demonstrated that ripening of avocados at 20°C resulted in a considerable decline in the TSS in the peel and flesh, particularly the C7 sugars, and that a decrease in the TSS was concomitant with an increase in the oil content. During storage at 1 and 5°C a decrease in the TSS was observed but at a slower rate. Similarly Liu et al. (2002) found a decrease in the C7 sugars during the progression of the ripening process. During avocado growth, carbohydrates are stored, however, once the fruit is harvested these carbohydrates are consumed for postharvest physiological processes such as respiration via enzymatic mechanisms that metabolize the C7 sugars (Liu et al., 1999b). This suggests that the C7 sugars play an important role in the respiration of the avocado during the ripening process.

pH

Avocado pH lies in the range of 6 to 6.5 (Soliva-Fortuny et al., 2004). Maftoonazad and Ramaswamy (2008) observed

Table 1. Maximum moisture content of avocados.

Cultivar	Fuerte	Pinkerton	Ryan	Hass	Lamb Hass	Maluma Hass	Nature's Hass	Other
Moisture content (%)	80	80	80	77	73	78	77	75

that the pH decreased with time during storage. Avocados treated with pectin based coatings illustrated a slower rate of decrease in pH values compared to untreated fruit and those exposed to higher temperatures. Exposure to low oxygen and/or high carbon dioxide for short periods of time has been used as a pretreatment to alleviate physiological disorders and for enhanced storage atmospheres. These conditions can also lead to a decrease in the intracellular pH thereby altering the various physiological processes that are dependent upon pH (Ke et al., 1995). Avocados subjected to (a) 0.25% oxygen, (b) 20% oxygen in combination with 80% carbon dioxide or (c) 0.25% oxygen and 80% carbon dioxide reduced the pH value from 6.9 to 6.7, 6.3, and 6.3, respectively, at 20°C (Ke et al., 1995). Similarly Lange and Kader (1997) stored avocados at 20°C in atmospheres of varying concentrations of oxygen and carbon dioxide and found that concentrations of (a) 21% oxygen, (b) 20% carbon dioxide (17% oxygen and the remainder Nitrogen) and (c) 40% carbon dioxide (13% oxygen and the remainder Nitrogen) produced pH values of 7.0, 6.6 and 6.4 respectively. These show that the lowest concentration of oxygen and highest concentration of carbon dioxide results in a reduction of pH to form an acidic medium.

Total titratable acid

Acidity is associated with both sweetness and sourness of fruit. The method used to measure acidity is titratable acidity (Lobit et al., 2002). Maftoonazad and Ramaswamy (2008) observed an increase in the titratable acid at higher storage temperatures in both pectin-based coated and non-coated avocados. Holcroft and Kader (1999) showed that strawberries exposed to higher concentrations of carbon dioxide at 5°C exhibited increased pH and decreased levels of titratable acidity. Mangoes subjected to postharvest treatments, packaging and storage for 28 days resulted in a decrease in the titratable acidity from 3.42 to 0.2% (Tefera et al., 2007). It can thus be deduced that the postharvest changes in strawberries and mangos differ to that of avocados in terms of total titratable acidity.

Moisture content

Moisture content is the preferred indicator of maturity in South Africa with the recommended moisture content in the range of 69 to 75% depending on the cultivar (Mans et al., 1995). Export of early season 'Fuerte' commences once the moisture content has reached 78 to 80% equivalent to an oil content of 9 to 11 standards of moisture percent (Dodd et al., 2008). The current determination (Table 1) and the specified limits of avocado moisture content in South Africa are according to the Standards and Requirements Regarding Control of the Export of Avocados (1998-1999). Studies are, however, ongoing to establish more accurate means of measurement (Retief, 2012).

Oil content

Avocado is considered to be an important oil fruit and oil content serves as a significant indicator of fruit maturity (Hofman et al., 2002a; Ozdemir and Topuz, 2004; Gamble et al., 2010; Blakey, 2011). As the fruit matures, the concentration of oil within the mesocarp increases as described by Hofman et al. (2002a), Ozdemir and Topuz (2004) and Chen et al. (2009). This increase in oil results in a reduction in the water by the same amount within the fruit implying that the percentage of total water plus oil remains constant throughout the avocado life (Hofman et al., 2002a; Ozdemir and Topuz, 2004). Lee et al. (1983) and Chen et al. (2009) observed a close correlation between the percentage oil content and percentage dry matter. The maturity index could then be calculated by either the oil content or dry matter.

Dry matter

Hofman et al. (2002a) and Gamble et al. (2010) referred to percentage dry matter determination as an alternative to oil content determination in assessing the maturity. Extending the maturation stage of the avocado allows for more oil accumulation and dry matter however the risk of increased disease is introduced. Maturity standards are being used by avocado producing countries to avoid marketing of low quality immature fruit. The standards adopted are the Californian minimum dry matter of 20.8% for 'Hass' or a slightly higher minimum dry matter content of approximately 25% to decrease disorders during storage (Gamble et al., 2010). An oil content of 8% has been reported by Ozdemir and Topuz (2004) to be acceptable for marketing of avocados.

Villa-Rodriguez et al. (2011) found that the dry matter had increased from 31.65 to 36.52% over eight days at 15°C and thereafter decreased to 32.91 on the day 12. Zauberman and Jobin-Decor (1995) found that as the dry matter increased the time to ripen decreased implying that the more mature the fruit the less time required to ripen.

Table 2. Heat treatment regimes of avocados.

Temperature (°C)	Heating media	Exposure time	Effects	Reference
37 - 38	Air	17-18 h	Reduced chilling injury	Sanxter et al. (1994)
38	Air	6-12 h	Reduced chilling injury and reduction in ripening time and flesh injury after ripening	Florissen et al. (1996)
38	Water	2 h	Reduced chilling injury	Woolf and Lay-Yee (1997)
40 and 41	Water	30 min	Reduced body rots and decreased vascular browning	Hofman et al. (2002b)
38	Water	30 min	Good appearance and internal quality	Wu et al. (2011)
38	Air	6 h	Reduced chilling injury	Wu et al. (2011)

Hofman et al. (2000) suggested that the percentage oil content and dry matter are not suitable indicators of avocado maturity in late-harvested 'Hass' due to late harvested fruit having inconsistent changes. No distinct correlation could be drawn between the effect of varying temperature and relative humidity on the percentage dry matter and oil content of avocados during storage, thus, motivating research to be conducted in this field.

PRE-PACKAGING TREATMENTS

Treatments prior to packaging have the added benefit of prolonging the shelf life and enhancing the quality of avocados when combined with suitable packaging and storage conditions (Tefera et al., 2007). Here, some common pre-packaging techniques and technologies applied to avocados are presented.

Heat treatments

In Kenya, Ouma (2001) observed that heating avocados at 38°C for periods of 24, 48 and 72 h improved the appearance and reduced the effects of chilling injury as opposed to untreated fruit. The maximum ethylene evolution was delayed; however, the rate of respiration was unchanged. Furthermore, weight loss was reduced as the number of days of heating increased leading to an improved shelf life.

To address the attack of insect pests in avocados, cold disinfestation is often used (Florissen et al., 1996; Hofman et al., 2002b; Hofman et al., 2003; Wu et al., 2011). This treatment requires exposing the fruit to a temperature of 1°C for 16 days but this induces chilling injury. To alleviate the onset of chilling injury, heating the avocados for various duration and temperature regimes are applied (Table 2).

Water is the preferred medium for most thermal applications as it is more efficient in transferring heat than air (Fallik, 2004). Heat treatment using air requires a longer heating time than with water. The variation in temperature and associated treatment times differs among the studies depending on the cultivar as well as pre-harvest environmental conditions such as sun exposure (Woolf et al., 1999). Such heat treatments are associated with the induction of heat shock proteins responsible for protecting the fruit against heat injury (Florissen et al., 1996).

Low temperature conditioning

Low temperature conditioning is based on the principal of holding the avocado at temperatures just above those at which it is susceptible to induce tolerance to low temperatures (Woolf et al., 2003). Low temperature conditioning between 4 to 8°C for a period of four days provided substantial protection against chilling injury (Hofman et al. (2003); similar to the results found by Woolf et al. (2003) of 6 or 8°C for three to five days. Hard skin, tissue breakdown and incidence of rot were reduced and even eliminated (Woolf et al., 2003); skin damage and internal quality were improved (Hofman et al., 2003). In both these studies, the researchers deduced that hot water treatments do not prove to be as successful in alleviating external chilling injury and improving the overall quality of the avocado when compared to low temperature conditioning.

Heat shock proteins can also be stimulated by near chilling temperatures to reduce chilling injury (Florissen et al., 1996). This can be attributed to heat shock proteins inhibiting the ethylene production rates associated with increased levels of chilling injury.

Surface coating and wax treatments

Postharvest water loss has a detrimental effect on avocados. Weight (water) loss leads to accelerated ripening and a higher degree of physiological disorders (Johnston and Banks, 1998). Waxes were found to address the challenge of water loss due to their impermeability characteristic. This allows for water retention, increasing turgidity and maintaining fruit weight for longer periods. Hagenmaier and Shaw (1992), Banks et al. (1997), Johnston and Banks (1998) and Maftoonazad and Ranaswamy (2008) describe waxes as providing a surface barrier, thus hindering the movement of gases. This creates an internal modified atmosphere resulting in lowered rates of respiration and delayed ripening. A PE based wax of concentration 11% visibly improved the exterior sheen and reduced mass loss (Johnston and Banks, 1998). Waxes are able to contribute to both the physiological characteristics of avocados and in enhancing the exterior aesthetic appeal by imparting a sheen and gloss to the exterior of the fruit (Hagenmaier and Shaw, 1992; Johnston and Banks 1998; Yahia, 2002; Maffoonazad and Ramaswamy 2008). The use of pectin-based waxes by Maftoonazad and Ramaswamy (2008) demonstrated improved results when compared to their earlier work of using methyl cellulose coatings in reducing respiration rates. In South Africa, the use of waxes is recommended prior to packaging provided that no more than 140 mg of the compound adheres per kg of avocados (Standards and Requirements Regarding Control of the Export of Avocados, 1998-9). 'StaFresh', a natural wax emulsion produced equivalent and enhanced results in physiological disorders, external appearance and shelf life when compared to a PE wax on South African avocados stored at 5.5°C for four weeks and ripened at 18°C (Kremer-Kohne and Duvenhage, 1997).

Low oxygen atmosphere/ hypoxic acclimation

Exposure of fruit to low levels of oxygen has been used as an alternative to chemical fumigation however fruit tissue are sensitive to low oxygen concentrations. Pesis et al. (1994) demonstrated through an experiment using 'Fuerte' that pre-treatment with low oxygen atmospheres inhibited chilling injury and fruit softening. Optimum results were found at 3% oxygen and 97% nitrogen for a period of 24 h at 17°C prior to storage at 2°C with relative humidity of 90% for a period of three weeks. El Mir et al. (2001) investigated the effect of exposing 'Hass' to low oxygen levels in order to acclimatize the fruit tissue to withstand insecticidal low oxygen atmospheres. It was concluded that treating avocados with 3% oxygen for 24 h and thereafter exposing the fruit to insecticidal treatment of 1 and 0.25% oxygen for one to three days at 20ºC produced greater fruit firmness.

1-Methylcyclopropene (1-MCP)

1-MCP is a synthetic cyclopropene used as an ethylene action inhibitor in many perishable fruit (Feng et al., 2000; Jeong et al., 2002, 2003; Hershkovtiz et al., 2005; Zhang et al., 2011). Earlier work by Jeong et al. (2002) indicated that 'Simmonds' avocado treated with 0.45 µl L^{-1} 1-MCP for 24 h at 20°C delayed ripening by four days. However, when compared to the later work by Jeong et al. (2003) which incorporated the use of wax and 1-MCP at a lower storage temperature of 13°C, less weight loss and a greener colour was observed. Weight loss of fruit treated with 1-MCP and wax was found to be 3.8% after 19 days of storage (Jeong et al., 2003) whereas after 8 days fruit treated with only 1-MCP was found to be 3.9% (Jeong et al., 2002). Avocados treated for 24 h with 1 µl L^{-1} 1-MCP at 20°C, followed by 21 days of storage at 4°C and 3.5% oxygen and thereafter transferred to 20°C for 14 days delayed the onset of respiration and climacteric peaks. Oxidation of lipids within the fruit pulp was also effectively controlled resulting in an extended shelf life. Zhang et al. (2011) found comparable results. Mid-climacteric avocados exposed to hypoxia conditions followed by treatment with 18.6 m mol m^{-3} of aqueous 1-MCP (1000 µg L^{-1}) exhibited reduced fruit softening and delays in peak ethylene production and respiration in comparison to those treated with 1-MCP only. The use of 1-MCP has been used with success in South Africa (Lemmer et al., 2002; Vorster, 2004-05). Lemmer et al. (2002) recommended that 500 ppb of 1-MCP be applied to avocados for 12 h at either 5 or 10°C, however he further stated that additional studies may be beneficial to refine this application dosage and exposure time.

PACKAGING AND STORAGE METHODS

The basic functions of food packaging are for storage, preservation and protection for prolonged periods of time (Garlic et al., 2011). A review on the past and current trends related to packaging and storage of avocados is presented here. The two most recognized techniques for avocados are modified atmosphere packaging (MAP) and controlled atmosphere storage (CAS). These methods have been proven to extend the shelf life and maintain the quality of avocados and other fresh fruit (Yahia and Gonzalez-Aguilar, 1998 and Berrios, 2002).

Packaging films

The plastic materials primarily used for MAP of whole fruit and vegetables are, low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP), polyvinylchloride (PVC), polystyrene (PS), ethylene vinyl acetate (VA), ionomer, rubber hydrochloride (pliofilm) and polyvinylidine chloride (PVDC) (Workneh and Osthoff, 2010) (Table 3).

Storage of avocados in PE bags reduced the effects of chilling injury (Pesis et al., 1994; Meir et al., 1997). Thompson (2010) revealed that individually sealed 'Fuerte' in PE bags of 0.025 mm thickness for 23 days at 14 to 17°C ripened normally once removed from the bags. The atmosphere within the bags after storage was found to be 8% carbon dioxide and 5% oxygen. Similarly individually sealed 'Hass' stored at 10°C resulted in

Table 3. Packaging film permeabilities (Workneh and Osthoff, 2010).

Film type	Transmission rate		
	Oxygen*	Carbon dioxide*	Water vapour**
Low density polyethylene (LDPE)	3900 - 13000	7700 - 77000	6 - 23.2
Linear low density polyethylene (LL DPE)	7000 - 9300	-	16 - 31
Medium density polyethylene (MDPE)	2600 - 8293	7700 - 38750	8 - 15
High density polyethylene (HDPE)	52 - 4000	3900 - 10000	4 - 10
Polypropylene (PP)	1300 - 6400	7700 - 21000	4 - 10.8
Polyvinylchloride (PVC)	620 - 2248	4263 - 8138	> 8
Polyvinylchloride (PVC), plasticized	77 - 7750	770 - 55000	> 8
Polystyrene (PS)	2000 - 7700	10000 - 26000	108.5 - 155
Ethylene vinyl acetate copolymer (12% VA)	8000 - 13000	35000 - 53000	60
Ionomer	3500 - 7500	9700 - 17800	22 - 30
Rubber hydrochloride (Pliofilm)	130 - 1300	520 - 5200	> 8
Polyvinylidine chloride (PVDC)	8 - 26	59	1.5 - 5

*Measured in units of $cm^3m^{-2}day^{-1}$ at 1 atm. **Measured in units of g $m^{-2}day^{-1}$ at 37.8°C and 90% relative humidity.

increased storage life (Oudit and Scott, 1973). West Indian avocados stored in PE bags at 13°C exhibited delayed softening and increased shelf life (Thompson et al., 1971). This study further demonstrated perforated bags and unwrapped avocados have a similar effect on the storage life. Low density polyethylene (LDPE) packages displayed more suitable MAP conditions of low oxygen and high carbon dioxide in retaining avocado, papaya and mango freshness as compared to oriented PP and oriented PS films (Xiao and Kiyoto, 2001).

Biodegradable films and coatings are becoming more popular from an environmental perspective as they are easily recyclable (Aguilar-Mendez et al., 2008). The compositions of biodegradable films are essential in determining the postharvest behaviour of avocados and in the performance of the packaging itself. Gelatin-starch films and coatings are used on avocados with positive outcomes of firmer fruit pulps, skin colour retention and lower weight loss. Higher starch concentrations and pH of the biodegradable film causes greater carbon dioxide permeability while lower levels of starch lead to higher film puncture strength (Aguilar-Mendez et al., 2008). Gelatin and starch based films offer the benefit of being inexpensive and manufacturing is possible on a large scale.

Modified atmosphere packaging

There exists a misconception that MAP and CAS is one in the same. However, MAP incorporates a lower degree of control over the concentration of gases as it depends on the interaction between the commodity and the packaging (De Reuck et al., 2010). The aim of MAP is to create a micro environment within the package specific to the avocado requirements to delay ripening and maintain the quality. According to Meir et al. (1997); Mangaraj et al. (2009) and Sandhya (2010), ideally equilibrium is established between the avocado and the packaging based on the following factors:

1. Maturity stage and respiration rate of the commodity,
2. Storage temperature,
3. Film surface area to fruit volume or weight ratio, and
4. Type of film (thickness and permeability to oxygen, carbon dioxide and water vapour).

Equilibrium is assumed to be established once the quantity of gas exchanged through the avocado is equivalent to that through the film (Mangaraj et al., 2009; De Reuck, 2010). MAP is based on the principle of modifying the atmosphere within the package to lower oxygen concentrations and raise carbon dioxide concentrations (Meir et al., 1997; Yahia and Gonzalez-Aguilar, 1998; Berrios, 2002; Hertog et al., 2003; Valle-Guadarrama et al, 2004; Mangaraj et al., 2009). This modified atmosphere suppresses respiration and ethylene formation thereby promoting a longer avocado shelf life. Due to the numerous variations in the factors required to establish equilibrium, it is not possible to reach an ideal equilibrium, however, a reasonable average can be attained.

Gas concentrations for MAP were found to be 2 to 6% oxygen and 3 to 10% carbon dioxide at 5°C and 7°C (Meir et al., 1997). This combination inhibits avocado softening and decreases the effect of chilling injury. Meir et al. (1997) investigated the effect of MAP on the storage of 'Hass'. Optimum results were found when storing 3.2 kg of the avocados in 30 µm PE bags (40 × 70 cm) at 5ºC. The concentration of oxygen and carbon dioxide attained values of approximately 4 and 5%, respectively, at 5 and 7ºC. At 5ºC lower ethylene evolution was detected with firmer fruit. These concentrations are in accordance with those prescribed by Sandhya (2010) of 2 to 5% oxygen, 3-

10% carbon dioxide and 85 to 95% nitrogen. Berrios (2002) recommends similar CAS and MAP conditions of 2 to 5% oxygen and 3 to 10% carbon dioxide at 5 to 13ºC for transportation and storage of avocados. Temperature variation of 7 to 14°C resulted in varying oxygen and carbon dioxide concentrations between 2 to 6 and 3 to 7%, respectively (Meir et al., 1997). The avocados retained a good quality for up to seven weeks. Softening became evident within four weeks of storage as oxygen levels exceeded 9%.

A web-based software tool was developed by the University College Cork in Ireland, 'PACK-in-MAP', assisting in designing optimal modified atmosphere conditions of fresh commodities. This is achieved by user input of the commodity type. The software is then able to define the optimum temperature, range of oxygen and carbon dioxide concentrations and permeability of various packaging materials (Mangaraj et al., 2009).

Modification of the storage environment can be accomplished either through respiration of the commodity identified as natural or passive MAP or by intentionally introducing a gas mixture into the packaging identified as artificial or active MAP (Yahia and Gonzalez-Aguilar, 1998; Mangaraj et al., 2009; De Reuck et al., 2010).

Controlled atmosphere storage

In CAS the headspace gas is more precisely monitored and controlled on a continuous basis to suit the requirements of the fruit (Berrios, 2002; Sandhya, 2010; Workneh and Osthoff, 2010). Oxygen and carbon dioxide concentrations of 2 to 6 and 3 to 10% respectively were recommended by Meir et al. (1997) at 5 and 7°C to reduce chilling injury and inhibit softening of avocados. The most effective results were attained during storage at temperatures between 5 and 7°C accompanied by oxygen and carbon dioxide concentrations of 2 to 3 and 8 to 10%, respectively (Meir et al., 1997). Reduction in mesocarp discolouration in 'Fuerte' was achieved with 2% oxygen and 10% carbon dioxide at 5.5°C for 28 days (Pesis et al., 2002).

CAS is a capital intensive operation as stated by Workneh and Osthoff (2010) and is more suited for bulk storage of commodities and for prolonged storage periods (Sandhya, 2010).

Semi-active and modified atmosphere storage system

Related to MAP and CAS are alternative systems of packaging such as semi-active and modified atmosphere storage system (MASS). Semi-active atmosphere modification is the initial removal or addition of a specified volume of gas from/ to the package (Yahia and Gonzalez-Aguilar, 1998). This technique of packaging proved to reduce the accumulation of ethylene; however, no additional benefits in terms of fruit softening and weight loss were identified over passive MAP.

Berrios (2002) described MASS as a means of eliminating atmospheric air through a gas impermeable packaging containing the commodity in an intermittent mode. The system is composed of a gas impermeable packaging fitted with a positive or negative pressure release valve which enables movement of gases to either enter or exit the system. Avocados subjected to MASS demonstrated a longer shelf life with reduced weight loss as compared to those under MAP conditions. Berrios (2002) stated that MASS could possibly be converted into an inexpensive alternative to CAS in countries which do not have the means of such technology.

STORAGE PARAMETERS

The conditions prevailing within storage facilities are essential in attaining an extended shelf life and enhanced quality of avocados. The essential storage parameters and the subsequent effect on avocado quality is focused on here.

Temperature

Temperature is the single most important factor to consider in storage of fruit due to its involvement in biological processes (Workneh et al., 2011). Low temperature storage reduces the rate of respiration and ethylene production resulting in retarded metabolic rates and an extended shelf life (Hofman et al., 2002a; Perez et al., 2004; Workneh and Osthoff, 2010; Getinet et al., 2011). Theoretically, for every 10°C increase in temperature a resultant doubling in the rate of respiration occurs (Workneh and Osthoff, 2010). Equation 2 demonstrates this concept by determining the temperature quotient, Q_{10} which represents the rate of deterioration for each 10°C rise in temperature above the optimum (Perez et al., 2004).

$$Q_{10} = \frac{SL\ (T-10)}{SL\ x\ T} \tag{4}$$

Where, Q_{10} = temperature quotient, SL = Shelf life, T = storage temperature (°C), andShelf Life is expressed in days. Equation 3 can be used to predict the shelf life of avocados at different temperatures (Perez et al., 2004).

$$Q_{10}^{\Delta/10} = \frac{Shelf\ Life\ (T_1)}{Shelf\ Life\ (T_2)} \tag{5}$$

Where, Δ = Difference between $T_1$and T_2 (°C)

Too low a temperature can result in chilling injury of avocados. Zauberman and Jobin-Decor (1995) found that storage at 5 and 8°C resulted in early ripening and mesocarp discolouration. Perez et al. (2004) reported the

Table 4. Optimum temperature and relative humidity of avocado fruit (Yahia, 2002).

Cultivar	Temperature (°C)	Relative humidity (%)	Postharvest life (weeks)
'Hass'	3 - 7	85 - 90	2 - 4
'Fuerte'	3 - 7	85 - 90	2 - 4
'Fuchs'	13	85 - 90	2
'Pollock'	13	85 - 90	2
'Lula'	4	90 - 95	4 - 8
'Booth I'	4	90 - 95	4 - 8

optimum storage temperature for unripe avocados to be 5 to 13°C and for mature avocados 2 to 4°C resulting in a two to four week shelf life, depending on the cultivar. If, however, mature avocados were to be stored at 5 to 8°C the shelf life would be reduced to one to two weeks. According to Hopkirk et al. (1994) cool stored avocados at 6°C thereafter ripened at 15°C was the most effective in enhancing the fruit quality. This compares with Meir et al. (1995) who reported that temperatures of between 5 and 7°C yielded successful results in prolonging the shelf life of 'Hass' avocados by five to nine weeks. Combining a temperature of 7°C with 2% oxygen and >4% carbon dioxide extended the storage time to 9 weeks (Zauberman and Jobin-Decor, 1995).

Van Rooyen and Bower (2006) discovered that storage of 'Pinkerton' at below the recommended temperature of 5.5°C reduced the severity of mesocarp discolouration which was thought to be due to chilling injury while storage at temperatures above the recommended temperature intensified the disorder. However, cold storage increased the occurrence of mesocarp discolouration in 'Fuerte' and became more pronounced with increasing maturity (Cutting et al., 1992). These two papers demonstrate that the avocado cultivar and time of harvest contribute to the onset of chilling at specified temperatures. Too high temperatures are also undesirable with fruit failing to ripen adequately and proliferation of postharvest disorders at 30 and 25°C as compared to a ripening temperature of 20°C (Eaks, 1978; Hopkirk et al., 1994). Flitsanov et al. (2000) demonstrated the effect of temperature on the firmness of the 'Ettinger' variety. During the first four weeks of storage at 2, 4, 6 and 8°C the firmness decreased to 89.2, 79.2, 12.5 and 10.9 N, respectively indicating that the higher temperature accelerated the ripening process as measured by firmness. Results obtained by Mizrach et al. (2000) are in accordance with those found by Flitsanov et al. (2000).

Relative humidity

Most fresh commodities require high relative humidity conditions during storage (Hofman et al., 2002a; Getinet et al., 2011). By increasing the relative humidity, the vapour pressure deficit is reduced, resulting in less water loss (Blakey, 2011). The negative effect of low relative humidity on texture and appearance can be attributed to water loss (Paull, 1999). Adato and Gazit (1974) demonstrated that avocados at 10 to 20% relative humidity lost water three times faster than those stored at 90 to 95% relative humidity and 21 to 22°C. The ripening process was also hastened by 3.3 days. However, Hofman and Jobin-Decor (1999) discovered that holding avocados at 60% relative humidity or less for four days resulted in an increase in the dry mass by 1.5% and reduced the days to ripen as compared to a 98% relative humidity. Storage conditions of mature avocados at 5°C and a relative humidity of 85 to 90% could result in a shelf life of two to three weeks as compared to a shelf life of one to two weeks at 5 to 8°C (Perez et al., 2004) (Table 4).

Gas concentration

Gases significantly affect the storage of fresh commodities particularly oxygen, carbon dioxide, ethylene and nitrogen (Berrios, 2002). The combination of gas concentrations depend largely on the cultivar and intended use of the avocado.

Oxygen and carbon dioxide

Meir et al. (1995) describes oxygen and carbon dioxide as having a synergistic role in inhibiting the ripening process of avocados through the increase in carbon dioxide and decrease in oxygen. Previous studies have demonstrated that most successful atmospheres were created containing 2% oxygen and 10% carbon dioxide. The study undertaken by Meir et al. (1995) showed that a carbon dioxide concentration in combination with an oxygen concentration of 8 and 3%, respectively, yielded a storage time of nine weeks with marketable fruit and no chilling injury at 5°C. Similarly carbon dioxide concentrations of 5 or 10% delayed the respiratory rise and decreased the respiration rate contributing to a prolonged shelf life (Kosiyachinda and Young, 1976). Exposing 'Fuerte' to 25% carbon dioxide for three days prior to storage at 5°C for 28 days resulted in decreased disorders and lower levels of total phenols (Pesis et al., 1994).

Subjecting avocados to excessively high carbon dioxide and too low oxygen concentrations induced exocarp and mesocarp injury (Ke et al., 1995; Lange and Kader, 1997). Oxygen concentrations of less than 1% are likely to result in anaerobic respiration (Forero, 2007). Oxygen levels below 3% for prolonged periods are not recommended (Valle-Guadarrema et al., 2004). Lange and Kader (1995) showed that avocados stored in 40% carbon dioxide and 12.6% oxygen demonstrated increased respiration rates when compared to 20% carbon dioxide and 16.8% oxygen. Meir et al. (1995) related peel injury with low concentrations of oxygen and slower softening rates of avocados to be associated with higher carbon dioxide levels.

Ethylene

Climacteric fruit produce ethylene just before and during the climacteric rise. Ethylene has the potential to induce over-ripening, accelerate quality loss and increase susceptibility to pathogens during storage of fresh commodities (Martinez-Romero et al., 2007). The effect of ethylene on avocados can be identified as flesh softening, colour change and development of distinct aromas (Gerard and Gouble, 2005; Martinez-Romero et al., 2007). Zauberman and Fuchs (1973) found that treatment of avocados with ethylene at a storage temperature of 6°C contributed to accelerated respiration rates and softening. Fruit treated continuously with exogenous ethylene produced the least amount of ethylene compared to untreated fruit and those treated for 24 h. It is suspected that the ethylene evolved is merely due to the diffusion of the exogenous ethylene that had initially been absorbed rather than production of ethylene by the fruit. Findings by Zauberman and Fuchs (1973) concur with those of Hatton and Reeder (1972) which indicate that the removal of ethylene from storage atmospheres reduced the rate of softening. Eaks (1978) showed that avocados held at 35°C displayed the climacteric pattern and ripened with minute amounts of ethylene being evolved as compared to temperatures of 20 and 25°C. Ethylene formation in avocados have, thus, appeared to be independent at high temperatures of 35°C while at 40°C this process seems to be inhibited. These studies indicate that the storage temperatures and application of exogenous ethylene to the avocados play a vital role in the formation of ethylene. Pesis et al. (2002) suggests absorbent sachets to remove ethylene from the packaging after five weeks storage at 5°C to reduce mesocarp discolouration and decay in 'Hass'.

Nitrogen

Nitrogen is a tasteless, colourless, odourless gas and relatively un-reactive (Sandya, 2010). Nitrogen is commonly used as a filler gas in the gas mixture to prevent collapsing of packages due to its low solubility in food as demonstrated by Ke et al. (1995) and Lange and Kader (1997). Storage of avocados in anoxia conditions of 100% nitrogen resulted in irreparable damage (Moriguchi and Romani, 1995). Gouble et al. (1995) demonstrated that continuous treatment with 80% of the nitrogen composite, nitrous oxide and 20% oxygen inhibited the ethylene production in avocado fruit.

A summary of the pertinent postharvest conditions of avocados that were reviewed are presented in Table 5 including the essential storage parameters as discussed within the scope of this document.

POSTHARVEST MANAGEMENT SUPPLY CHAIN IN SOUTH AFRICA

The South African avocado industry is predominantly export based (Bower and Cutting, 1987) which necessitates the need to ensure that the avocado quality is capable of meeting international standards.

Cold chain

Transportation of avocados from the growing regions in South Africa to the port in Cape Town and eventually, to European supermarkets requires extensive logistical management (Bower and Cutting, 1987). Maintaining the cold chain is essential in avoiding soft fruit with physiological disorders (Nelson, 2006). The Perishable Products Export Control Board works in alliance with the South African Avocado Growers' Association providing recommendations and guidelines for handling of avocados during export (Eksteen, 1995, 1999).

Studies by Blakey and Bower (2009) and Kok et al. (2010) demonstrated a break in the avocado cold chain was detrimental to the quality of the fruit. These investigations indicated that storage of avocados at 1°C for 28 days to simulate shipping regimes reduced the rate of softening and mass loss. However, Kok et al. (2010) states that additional studies are required to confirm these findings. Milne (1998) described the vital role played by the combination of time and temperature during cold chain management of avocados by reporting that a break later in the cold chain lead to greater fruit softening. Bezuidenhout, (1992) conducted an analysis to address the softening of avocados experienced during export to Europe. It was found that an increase in temperature by 1°C during a transit time of 28 days resulted in increased softening.

Step down temperature is a technique adopted which gradually reduces the storage temperature of avocados (Milne, 1998). This was shown to reduce chilling injury and pulp spot symptoms. Early season 'Fuerte' stored at 7.5°C for week one, 5.5°C for weeks two and three followed by 3.5°C for week four resulted in reduced chilling injury compared to 5.5°C for the total four week period. However, Sekhune (2012) advised not to subject avocados to temperatures below 5°C and greater than 10°C after harvest (Table 6). Milne (1998), however,

Table 5. Summary of avocado storage conditions recommended by different authors.

Cultivar/ type	Storage temperature (°C)	Ripening temperature (°C)	Storage/ ripening time	Relative humidity (%)	O_2 (%)	CO_2 (%)	Additional information	Reference
'Hass'	6	15	10 days				Best quality fruit and reduced postharvest rots	Hopkirk et al. (1994)
	5	20	<1 week 1-3 days		0.25	80	Increase in ethanol and acetaldehyde, reduction in pH values from 6.9 to 6.3	Ke et al. (1995)
	5 & 7						Prolong the shelf life to 5-9 weeks	Meir et al. (1995)
	5	20		90-95	3	8	Remained green after 9 weeks and retarding chilling injury	Meir et al. (1995)
	2	22	4 weeks				Remained firm and green for 5 weeks, ripening was delayed	Zauberman and Jobin-Decor (1995)
	5 & 8	22	4 weeks				Development of mesocarp discolouration and vascular browning, fruit ripening commenced during storage	Zauberman and Jobin-Decor (1995)
	7				2	>4	Shelf life of 9 weeks	Zauberman and Jobin-Decor (1995)
					12.6	40	Increased respiration rates	Lang and Kader (1997)
	5 & 7				2-6	3-10	CA and MA - Inhibit softening and chilling injury	Meir et al. (1997)
	7-14				2-6	3-7	MA - Fruit retained good quality for 7 weeks	Meir et al. (1997)
	5 or 7				2-3	8-10	Recommended storage conditions	Meir et al. (1997)
Hass' avocado tree on clonal 'Duke 7' rootstock		20	12 days	85-90			Decline in the TSS content	Liu et al. (2002)
'Hass'	5-13				2-5	3-10	MA - For transport and storage	Berrios (2002)
'Fuerte'	5.5		28 days		2	10	Reduced mesocarp discolouration	Pesis et al. () 2002
'Hass'	4-8		4 days				Reduced chilling injury	Hofman et al. (2003)
'Hass'		16					Reduced tissue breakdown, hard skin and rot	Woolf et al. (2003)
Unripe	6 or 8 5-13		3-5 days				2-4 weeks shelf life	Perez et al. (2004)
Mature	2-4						2-4 weeks shelf life	Perez et al. (2004)
Cultivar/ type	**Storage temperature (°C)**	**Ripening temperature (°C)**	**Storage/ ripening time**	**Relative humidity (%)**	**O_2* (%)**	**CO_2** (%)**	**Additional Information**	**Reference**
Mature	5			85-90			2-3 weeks shelf life	Perez et al. () 2004
Mature	5-8						1-2 weeks shelf life	Perez et al. (2004)
'Pinkerton'	<5.5						Reduced mesocarp discolouration	Van Rooyen and Bower (2006)
'Hass'	6		17 days		0.5	20	Increase in ethanol and acetaldehyde	Burdon et al. (2007)

Table 5. Contd.

			85-95	2-5	3-10	MA - Recommended storage conditions	Sandhya (2010)
'Hass'	20	12 days	75			Reduction in firmness from 75.43 N to 2.63 N	Arzate-Vazquez et al. (2011)
'Hass'	15	12 days				Firmness reduced from 130.51 N to 7.37 N and increase in dry matter from 31.65% to 36.52% and thereafter decrease to 32.91%	Villa-Rodriguez et al. (2011)

Table 6. Moisture content and temperature guidelines for export of avocados.

Moisture content (%)	Cold room (°C)	Road transport (°C)	Port storage (°C)	Vessel - 1st week (°C)	Vessel - last week (°C)
78.5 - 80.0	7.5	7.5	7.5	7.5	5.5
77.5 - 78.4	7.5	7.5	7.5	6.5	5.5
76.5 - 77.4	7.0	7.0	7.0	6.1	5.5
75.5 - 76.4	6.5	6.5	6.5	6.0	5.5
74.5 - 75.4	6.5	6.5	6.5	5.5	5.5
73.5 - 74.4	6.0	6.0	6.0	5.5	5.5
72.5 - 73.4	6.0	6.0	6.0	5.5	5.5
71.5 - 72.4	5.5	5.5	5.5	5.5	5.5
69.5 - 71.4	5.5	5.5	5.5	5.5	4.5
69.4 and less	5.5	5.5	5.5	5.5	3.5

reports that this step down regime was not necessary for ‘Fuerte’ grown in KwaZulu Natal as a continuous storage temperature of 5.5°C was sufficient for both internal and external quality.

A basic avocado cold chain is depicted by Figure 2 where T_X represents the temperature at each stage X in °C. For example T_H represents the temperature at harvest.

DISCUSSION AND CONCLUSION

Pre-harvest factors play a significant role in the postharvest development of avocado fruit. Harvesting methods and time of harvest contribute to the final quality as too early harvesting can lead to low dry matter and flavourless fruit. Exposure to sunlight whilst still on the tree has been found to reduce chilling injury and improving the avocado fruit quality as opposed to shaded fruit. Temperature has the greatest influence on avocado quality both pre-harvest and throughout the postharvest stages. Therefore, suitable temperatures at all stages of avocado handling are essential. The minimum optimum storage temperature was found to be approximately 5°C (Meir et al., 1995; Zauberman and Jobin-Decor, 1995; Meir et al., 1997; Berrios, 2002; Perez et al., 2004) with a maximum of about 13°C (Berrios, 2002; Perez et al., 2004). Atmospheres containing 85 to 90% relative humidity were favourable for avocado quality depending on the cultivar (Yahia, 2002). In South Africa, the use of waxes and 1-MCP pre-treatments and non-perforated PE and biodegradable packaging were used with positive results for avocado quality.

The avocado cold chain is composed of different processes required for minimising quality loss. By maintaining optimum conditions at each stage specifically at suitable optimum temperature and time, the quality and shelf life of the fruit can be of a superior standard. In reality, avocados are subject to conditions that are not optimum due to breaks in the cold chain as a result of logistical problems that might be encountered. Therefore,

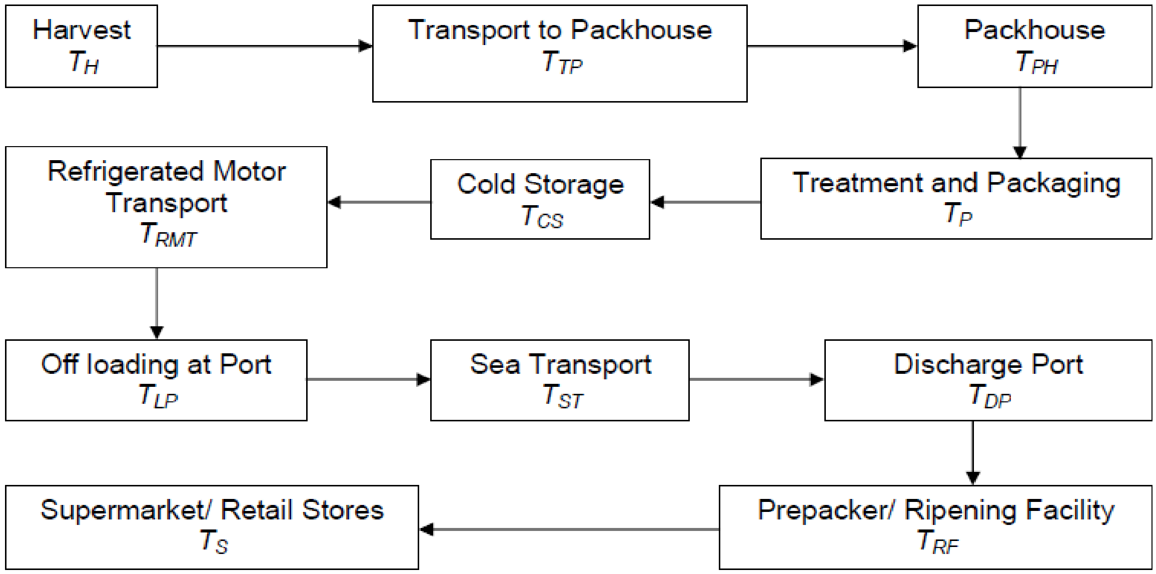

Figure 2. Avocado cold chain (Eksteen, 1999).

studies are needed to evaluate the effect of cyclic storage conditions on the quality of avocados.

Changes in skin colour, firmness, pH, total titratable acid, percent dry matter or oil content, weight loss, flavour and marketable quality are among the most common methods associated with avocado quality assessment.

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