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Research article

Influence of postharvest treatments and storage conditions on the quality of Hass avocados

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ABSTRACT

The purpose of this study was to investigate the influence of postharvest treatments on the shelf life of avocado. The experimental design consists of pre-packaging (hot water and wax), packaging (low-density polyethylene and biodegradable films), and storage temperatures (ambient and cold storage), which was arranged in a randomized complete block design with three replications. The effects of combined postharvest treatments on the changes in the physical, chemical, and sensory quality of 'Hass' avocados during a 28-day cold chain simulation were evaluated. The quality parameters evaluated included puree viscosity, moisture content, dry matter, pH, total soluble solids, total titratable acid and subjective quality attributes. Storage conditions significantly ($P \leq 0.05$) affected the measured parameters. Cold chain conditions (5.5 °C for two days, 5 °C for six days and 4.5 °C for 20 days at 95% relative humidity) offered the most significant benefit in maintaining higher fruit quality. The combination of a wax coating, low-density polyethylene packaging, and cold chain conditions was beneficial in delaying ripening by approximately two weeks with minimum changes in moisture content (9.5%) and TSS (19.0%) and viscosity. Cold storage is essential in improving the shelf life and maintaining the quality of avocado fruits during export.

1. Introduction

Perishable commodities such as the avocado (*Persea americana* Mill.) pose a challenge in their supply chain concerning their qualitative and quantitative perishability. This is of great ethical, environmental, and financial concern. The deterioration of perishable commodities, therefore, warrants the complexity of the cold chain management, with great emphasis being placed on controlling and regulating the desired storage conditions (Aiello et al., 2011). The South African avocado industry is primarily based on export, making fruit quality an essential factor (Vorster et al.,1990). Approximately 40% of the South African avocado market is export-orientated (Blakey et al., 2015). Due to the distant export markets, proper postharvest handling must be implemented so as to maintain the avocado quality throughout the export process.

Low temperature is fundamental in extending the shelf life of avocados by retarding the metabolism through reduced respiration rates, ethylene evolution, softening, and colour change (Perez et al., 2004). A deviation of 1 °C in the holding temperature can adversely affect the avocado quality (Milne, 1998). Therefore, strict adherence to the specified cold chain management regime is crucial to maintain an acceptable quality of avocados. The application of a step-down temperature regime, which exposes the avocado to a series of temperatures in decreasing order, has also proven to be beneficial (Milne, 1998). This is often practiced in industry. The interaction of time and temperature is a vital aspect in the quality control of avocados (Vorster et al., 1990). The type of packaging that is used also contributes to the final fruit quality, as efficient packaging will allow for cold air to move uniformly around the fruit horizontally and vertically (Dodd et al., 2007). Studies have shown that the use of low-temperature storage, the application of wax, 1-methylcyclopropene and preventing breaks in the cold chain, were all beneficial in postharvest handling of avocados (Lutge et al., 2012). Based on the literature, it is apparent that numerous studies have been conducted in determining the quality of avocados during the supply chain, with a focus on storage temperature. However, a comparison of the integration of pre-packaging, packaging and storage conditions on the physical, chemical and sensory quality of avocados is deficient. The aim of this experiment is, therefore, to investigate the combined effect of postharvest treatments on the quality of avocados and to provide practical recommendations during avocado postharvest handling in South Africa.

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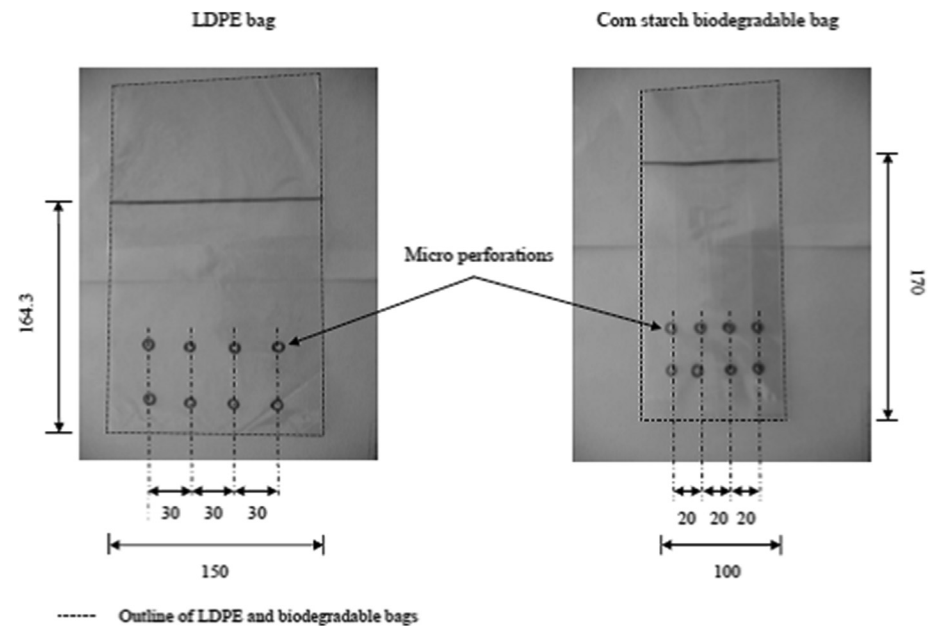

Figure 1. LDPE and corn starch biodegradable flexible films with micro-perforations.

2. Material and methods

2.1. Growing site description

Avocados (*Persea americana* Mill.), belonging to the 'Hass' cultivar, were obtained from the Everdon Estate located in the Karkloof Valley in Howick, KwaZulu-Natal (29°27′S, 30°16′E). The orchard is located in the Phillips' Bioclimatic Group 3, characteristic of cold mesic conditions typical of 'mist belt' areas (Moore-Gordon et al., 1995; Moore-Gordon and Wolstenholme, 1996). The orchard experiences mean minimum temperatures of approximately 15 °C in January and approximately 6.7 °C in July, with corresponding mean maximum temperatures of approximately 26.1 °C and 19.4 °C (Moore-Gordon and Wolstenholme, 1996; Mazhawu et al., 2018). The area receives an average annual rainfall of 1 052 mm. Micro-jet irrigation systems supply water to the scheme that has been installed with tensiometers (Moore-Gordon and Wolstenholme, 1996). The predominant soil is a well-drained Hutton prepared by deep-ripping only once. Two mulch dressings are placed around trees annually, which have resulted in a marked improvement to the fruit. Due to the colder subtropical climate in Howick, the avocados grown in these orchards mature at a later stage compared to those grown in the Limpopo province. This enables the Everdon Estate to lengthen its export season, particularly in the case of 'Hass' which has a harvest season starting from early July and extending into October or early November each year.

2.2. Plant material

Green mature 'Hass' avocados were manually harvested by expert harvesters early in the morning to reduce field heat and minimise mechanical injury. Avocados within a mass range of 203–243 g were selected and packed into single layer standard count 18 corrugated cardboard boxes (18 avocados per box) with ventilation. A total of 222 avocados, amounting to approximately 50 kg, were acquired for this experiment. From the commercially harvested avocados, samples were selected based on their uniformity of weight, shape, colour, size and whether they were bruised and blemish-free to be used in the experiment (Mohammed et al., 1999; Maftoonazad and Ramaswamy, 2008; Getinet et al., 2011; Hassan and Dann, 2019). The selected samples were immediately transported to the University of KwaZulu-Natal Food Science and Agricultural Engineering laboratory, which is located 37 km from the packhouse, where sample preparation, treatment, and storage trials were carried out.

2.3. Experimental design

A factorial design consisting of three pre-packaging treatments (Avoshine® wax, hot water immersion, and no pre-packaging treatment), three packaging treatments (low-density polyethylene (LDPE), corn starch biodegradable films and no packaging), two temperature and relative humidity (RH) storage regimes (cold chain and ambient) and three replications were arranged in a randomised complete block design (Mohammed et al., 1999; Getinet et al., 2011). The samples were randomly treated and evaluated for their quality immediately after harvest.

2.4. Sample preparation and treatments

The avocado samples were visually inspected at the laboratory to ensure that they were not subjected to any damage during transportation and, if they were, the damaged avocados were excluded from the samples (Getinet et al., 2011). All work surfaces, tools, and utensils were cleaned and disinfected. Avocados were treated and tested for each of the two storage regimes on Days 0, 7, 14, 21, and 28.

2.5. Pre-packaging treatments

The use of wax (Kremer-Kohne and Duvenhage, 1997) and hot water pre-packaging treatments (Wu et al., 2011) were selected, as these are extensively used for avocados.

2.5.1. Wax coating

The liquid polyethylene wax emulsion, Avoshine®, was used to evenly coat the avocados as described by Hall (2011). Approximately 0.4 ml of Avoshine® wax was used per 250 g of avocado fruit (Blakey, 2012).

2.5.2. Hot water dipping

A hot water bath containing water was initially heated to 80 °C for 30 min to destroy most heat-sensitive micro-organisms and, after that, reduced to 38 °C. The avocado samples were immersed in hot water for five minutes, then removed and dried.

2.5.3. Control

Avocado samples were not subjected to any pre-packaging treatments.

2.6. Packaging treatments

The selection of the packaging materials, LDPE, and biodegradable packaging films, were made based on previous findings, which showed their beneficial effects for avocados (Xiao and Kiyoto, 2001; Aguilar-Mendez et al., 2008).

2.6.1. LDPE bag

Soft, flexible, and strong LDPE bags with 20 μm thickness and 250 × 150 mm, high water vapour transmission rate (375–500 g μm m^{-2}.day^{-1}) and high ratio of CO_2 to O_2 permeability were used (Mangaraj et al., 2009). Micro-perforations (n = 4) at 30 mm intervals were made along the bottom of each bag in two rows, using a 1.13×10^{-3} m diameter needle to allow for the movement of gases and moisture between the micro-environment inside the bag and the surroundings.

2.6.2. Biodegradable cornstarch cellulose bag

Transparent biodegradable corn starch cellulose bags (30 μm thickness, 240 × 100 mm and 45 mm gussets) were used. These bags have a high barrier to air and micro-organisms, which is ideal for the packaging of food (Aguilar-Mendez et al., 2008). Two rows containing four micro-perforations ($\varnothing = 1.13 \times 10^{-3}$ m) at 20 mm intervals were made along the bottom of each bag. The interval spacing of the micro-perforations was smaller compared to the LDPE bags, due to the difference in width of the bags. Nine avocados from each of the pre-packaging treatments were each placed in a single LDPE bag and sealed at 164.3 mm from the base, to ensure that the volume within the both the LDPE and biodegradable bags had a similar volume. The individually sealed fruits were then placed in the respective storage temperature environment. Figure 1 represents the LDPE and corn starch packaging treatments.

2.7. Temperature and relative humidity

A total of 108 avocado samples were stored at 5.5 °C ± 0.01 °C for two days, then at 5 °C ± 0.01 °C for six days and then 4.5 °C ± 0.01 °C for 20 days, allat 95% relative humidity based on a typical Everdon Estate packhouse regime to depict a realistic cold chain. These conditions were controlled in a CTS Climate Test Chamber (Model C-40/100) with a temperature range of -40 °C to +180 °C and a humidity range of 10%–98%. Theoretical temperature and relative humidity fluctuations of the chamber for climatic testing are ± 0.3K and 1.5%, respectively. The total capacity of the testing chamber is 100 L (500 × 500 × 400 mm). Control samples were placed in six corrugated cardboard boxes in a single layer and exposed to ambient temperature (±25.14 °C) and relative humidity (±52.67%) conditions. Two HOBO data loggers (BoxCar® Pro 4.3 software) were used to record the control conditions.

2.8. Parameters analysed

Data were collected on Days 0, 7, 14, 21, and 28 during storage. The quality parameters that were analyzed included moisture content, dry matter, total titratable acid, total soluble solids, pH, puree viscosity, and, subjective quality attributes.

2.9. Puree preparation

A Braun 300 W MR 400 hand blender was used to blend the diced avocados for two to three minutes until a fine paste was formed as described by Jacobo-Velazquez and Hernandez-Brenes (2011). The puree was sampled for moisture content, dry matter, total titratable acid, total soluble solids, pH, and viscosity.

2.10. Moisture content and dry matter

Moisture content (wet basis) and dry matter were determined using 3 g of avocado puree. The samples were dried in an oven at 70 °C for 48 h or until constant weight as described by (Chen et al., 2009).

2.11. Total titratable acid, total soluble solids and pH

Approximately 25 g of the avocado puree was added to a beaker containing 25 g (25 ml) of distilled water. The samples were homogenized and filtered through muslin to collect the juice (Maftoonazad and Ramaswamy, 2008). An aliquot of 3 ml of juice was pipetted to a 50 ml beaker, into which two drops of phenolphthalein indicator solution was added. The juice aliquot was titrated with 0.1 N sodium hydroxide (NaOH) till a pink colour was formed and persisted for five seconds while the solution was being stirred, using a magnetic stirrer. Titratable acidity was calculated as the number of milliliters of 0.1 M sodium hydroxide multiplied by an appropriate conversion factor (Equation (1)). A conversion factor of 0.28 was selected, based on linoleic acid, a predominant acid in avocados, as used by Maftoonazad and Ramaswamy (2008).

$$\mathrm{TTA} = (0.1 \times NaOH \times 0.28 \times 1000)/\,(S) \tag{1}$$

where *TTA* is the total titratable acid, 0.1 is 0.1 mol of NaOH [N], NaOH is the amount of NaOH added [ml], 0.28 is the conversion factor, and S is the juice sample [ml].

The pH was measured using a standard pH meter, which was calibrated using pH 4 and pH 7 buffer solutions. The pH was determined according to methods by Getinet et al. (2008), Maftoonazad and Ramaswamy (2008), and Jacobo-Velazquez and Hernandez-Brenes (2011).

The total soluble solids were determined using an ATAGO digital portable palette style refractometer (±0.1 % Brix) by placing one to two drops of the juice on the prism (Getinet et al., 2008; Maftoonazad and Ramaswamy, 2008).

2.12. Puree viscosity

Puree viscosity was measured using the Anton Paar Rheolab QC Rheometer basic unit (Model 13000) with Rheoplus V3.40 software. The viscosity was measured as a function of shear rate on approximately 16 g of puree samples, which was ramped from 0.01 s^{-1} to 100 s^{-1} for 250 s (Tabilo-Minizaga et al., 2005). A graphical representation of the shear stress (pa) and shear rate (s^{-1}) was plotted using the software. The experiment was carried out using the concentric cylinder and cup accessory. The puree samples were filled to the level mark inside the cup. All measurements were carried out at a room temperature of approximately 24 °C.

2.13. Subjective quality attributes

Once the avocados were removed from storage, they were inspected and examined visually for mould development or decay. The skin colour was perceived by the human eye in terms of green, purple or black, synonymous to degree of ripening (Hassan and Dann, 2019). Changes in the firmness was inspected by hand-feel for any soft spots (Hassan and Dann, 2019) Any other variances concerning the physical appearance were also observed and recorded such as dark spots or bruises. Based on this each fruit was assigned an overall rating of either 'good', 'fair' or 'poor'.

Table 1. Changes in the moisture content (%) of avocados subjected to pre-packaging, packaging and different storage conditions for 28 days.

Treatment			Storage Period (Days)				
Pre-packaging	Packaging	Storage Conditions	0	7	14	21	28
	LDPE	CC	54.05^{a}	52.88^{cd}	51.00^{ef}	48.91^{f}	48.18^{gh}
		AT, ARH	55.00^{a}	52.24^{de}	48.02^{gh}	-	-
HWT	Bio	CC	54.05^{a}	53.58^{ab}	50.00^{f}	48.09^{gh}	46.04^{hij}
		AT, ARH	55.00^{a}	51.00^{ef}	48.51^{fg}	-	-
	NP	CC	54.05^{a}	53.10^{abc}	51.15^{ef}	48.28^{gh}	45.40^{j}
		AT, ARH	55.00^{a}	47.02^{h}	43.78^{lm}	-	-
	LDPE	CC	54.05^{a}	54.80^{a}	50.12^{f}	49.85^{f}	48.92^{f}
		AT, ARH	55.00^{a}	50.74^{ef}	47.74^{gh}	-	-
Avoshine®	Bio	CC	54.05^{a}	50.75^{ef}	50.81^{ef}	49.24^{f}	47.79^{gh}
		AT, ARH	55.00^{a}	49.55^{f}	49.23^{f}	-	-
	NP	CC	54.05^{a}	51.62^{ef}	49.02^{f}	48.51^{fg}	45.23^{jk}
		AT, ARH	55.00^{a}	50.83^{ef}	47.21^{gh}	-	-
	LDPE	CC	54.05^{a}	51.04^{ef}	48.47^{fg}	48.48^{fg}	45.74^{ij}
		AT, ARH	55.00^{a}	48.59^{fg}	45.00^{kl}	-	-
NPP	Bio	CC	54.05^{a}	50.43^{f}	49.77^{f}	48.57^{fg}	45.79^{ij}
		AT, ARH	55.00^{a}	51.47^{ef}	48.67^{fg}	-	-
	NP	CC	54.05^{a}	46.76^{h}	46.42^{h}	41.79^{no}	39.00^{op}
		AT, ARH	55.00^{a}	52.48^{cde}	42.00^{mn}	-	-

Means within a column followed by the same letter/s are not significantly different from each other, according to Duncan's Multiple Range Test ($P \leq 0.05$). HWT, hot water treatment; NPP, no pre-packaging; Bio, biodegradable corn starch packaging; LDPE, low-density polyethylene packaging; NP, no packaging; CC, cold chain; AT, ambient temperature; ARH, ambient relative humidity.

Table 2. Changes in the dry matter (%) of avocados subjected to pre-packaging, packaging and different storage conditions for a 28 days.

Treatment			Storage Period (Days)				
Pre-packaging	Packaging	Storage Conditions	0	7	14	21	28
	LDPE	CC	45.95^{no}	47.12^{kl}	49.00^{ij}	51.09^{i}	51.82^{gh}
		AT, ARH	45.00^{no}	47.76^{jk}	51.98^{gh}	-	-
HWT	Bio	CC	45.95^{no}	46.42^{mn}	50.00^{i}	51.91^{gh}	53.96^{efg}
		AT, ARH	45.00^{no}	49.00^{ij}	51.49^{hi}	-	-
	NP	CC	45.95^{no}	46.90^{lm}	48.85^{ij}	51.72^{gh}	54.60^{e}
		AT, ARH	45.00^{no}	52.98^{g}	56.22^{bc}	-	-
	LDPE	CC	45.95^{no}	45.20^{no}	49.88^{i}	50.15^{i}	51.08^{i}
		AT, ARH	45.00^{no}	49.26^{ij}	52.26^{gh}	-	-
Avoshine®	Bio	CC	45.95^{no}	49.25^{ij}	49.19^{ij}	50.76^{i}	52.21^{gh}
		AT, ARH	45.00^{no}	50.45^{i}	50.77^{i}	-	-
	NP	CC	45.95^{no}	48.38^{ij}	50.98^{i}	51.49h^{i}	54.77^{de}
		AT, ARH	45.00^{no}	47.52^{jkl}	52.79^{gh}	-	-
	LDPE	CC	45.95^{no}	48.96^{ij}	51.53^{hi}	51.51^{hi}	54.26^{ef}
		AT, ARH	45.00^{no}	51.41^{hi}	53.58^{fg}	-	-
NPP	Bio	CC	45.95^{no}	49.57^{i}	50.23^{i}	51.43^{hi}	54.21^{ef}
		AT, ARH	45.00^{no}	48.53^{ij}	51.33^{hi}	-	-
	NP	CC	45.95^{no}	53.24^{g}	55.00^{cd}	58.21^{ab}	61.00^{a}
		AT, ARH	45.00^{no}	49.17^{ij}	58.00^{abc}	-	-

Means within a column followed by the same letter/s are not significantly different from each other, according to Duncan's Multiple Range Test ($P \leq 0.05$). HWT, hot water treatment; NPP, no pre-packaging; Bio, biodegradable corn starch packaging; LDPE, low-density polyethylene packaging; NP, no packaging; CC, cold chain; AT, ambient temperature; ARH, ambient relative humidity.

2.14. Statistical analysis

The differences between treatments were determined by an analysis of variance (ANOVA) employing the MSTAT-C statistical software, Version 2.10 (MSTAT, Michigan State University). The means were separated using Duncan's Multiple Range Test, with a significance level of 0.05.

3. Results and discussion

3.1. Moisture content and dry matter content

Table 1 displays the changes in the moisture content (MC) of avocados subjected to different pre-packaging, packaging, and storage conditions. The influence of storage conditions and storage period were

Table 3. Changes in the pulp viscosity (pa.s) of avocados subjected to pre-packaging, packaging and different storage conditions for 28 days.

Treatment			Storage Period (Days)				
Pre-packaging	Packaging	Storage Conditions	0	7	14	21	28
	LDPE	CC	0.02^{m}	0.03^{m}	0.03^{m}	0.153^{m}	3.71^{efg}
		AT, ARH	0.03^{m}	0.05^{m}	2.29^{jk}	-	-
HWT	Bio	CC	0.02^{m}	0.06^{m}	0.10^{m}	0.06^{m}	4.68^{cd}
		AT, ARH	0.03^{m}	1.27^{l}	2.66^{ij}	-	-
	NP	CC	0.02^{m}	0.06^{m}	0.02^{m}	0.04^{m}	3.06^{h}
		AT, ARH	0.03^{m}	4.91^{cd}	6.08^{b}	-	-
	LDPE	CC	0.02^{m}	0.06^{m}	0.04^{m}	0.06^{m}	0.02^{m}
		AT, ARH	0.03^{m}	0.01^{m}	2.50^{jk}	-	-
Avoshine®	Bio	CC	0.02^{m}	0.06^{m}	0.05^{m}	0.03^{m}	3.50^{gh}
		AT, ARH	0.03^{m}	0.02^{m}	2.63^{ij}	-	-
	NP	CC	0.02^{m}	0.08^{m}	0.04^{m}	0.04^{m}	2.70^{hi}
		AT, ARH	0.03^{m}	0.03^{m}	4.09^{def}	-	-
	LDPE	CC	0.02^{m}	0.03^{m}	0.04^{m}	0.03^{m}	4.40^{cde}
		AT, ARH	0.03^{m}	0.09^{m}	2.01^{kl}	-	-
NPP	Bio	CC	0.02^{m}	0.03^{m}	0.04^{m}	0.06^{m}	3.62^{fgh}
		AT, ARH	0.03^{m}	3.01^{hi}	2.52^{jk}	-	-
	NP	CC	0.02^{m}	0.06^{m}	0.08^{m}	0.06^{m}	5.15^{cd}
		AT, ARH	0.03^{m}	2.37^{jk}	7.11^{a}	-	-

Means within a column followed by the same letter/s are not significantly different from each other, according to Duncan's Multiple Range Test ($P \leq 0.05$). HWT, hot water treatment; NPP, no pre-packaging; Bio, biodegradable corn starch packaging; LDPE, low-density polyethylene packaging; NP, no packaging; CC, cold chain; AT, ambient temperature; ARH, ambient relative humidity.

found to be significant ($P \leq 0.05$) on the changes in the MC. Under cold chain conditions, the LDPE maintained higher MC, as compared to biodegradable films. Control avocado samples devoid of pre-packaging and packaging treatments resulted in the highest MC loss at both cold chain and ambient storage conditions of 27.8% at Day 28 and 23.6% at Day 14, respectively. Higher temperatures contributed to a more significant loss in MC, as observed in the works of Ozdemir and Topuz (2004). The lowest reduction in the MC throughout the storage period of 9.5% at Day 28 was recorded for avocado samples pre-treated with wax, packaged in LDPE films and stored at cold chain conditions. Analysis of the MC trends emphasises the additional benefit of using pre-packaging and packaging in reducing the MC, under low-temperature storage. Several authors (Hofman and Jobin-Decor, 1999; Ozdemir and Topuz, 2004; Landahl et al., 2009; Obenland et al., 2012) have found the MC, dry matter (DM) and oil content of avocado fruit to be well correlated. These parameters are widely accepted as avocado fruit maturity indexes due to their consistency during fruit development (Shezi et al., 2020). A delay in the loss of the MC, therefore, implies a delay in the accumulation of oil and dry matter within the avocado, and hence, a delay in the ripening process.

The percentage of DM in avocado samples increased in both ambient and cold chain storage conditions (Table 2). Hofman and Jobin-Decor (1999) found that the storage of avocados at lower relative humidities of 40% and 60%, as opposed to 80% and 98%, resulted in an increase in the DM content by approximately 1% towards the end of the storage period at 22 °C. An increase in the dry matter is synonymous with avocado fruit maturation and the ripening process (Zauberman and Jobin-Decor, 1995; Hofman and Jobin-Decor, 1999; Shezi et al., 2020). Similar results have been observed in the present experiment, as the relative humidity (RH) of the cold chain conditions was higher (95%) than at ambient conditions (±52.67%). The lower RH at ambient conditions increased the moisture loss from the fruit, thereby increasing the DM content. This was further exacerbated by the higher temperature under ambient conditions. Packaging films were found to be significant ($P \leq 0.05$) with LDPE and biodegradable packaged avocados having lower DM than unpackaged avocado samples, at both cold chain conditions and ambient conditions. Pre-packaged avocados displayed a lower DM, compared to control avocado samples without any pre-packaging. Control avocado samples devoid of any pre-packaging and packaging treatments resulted in the highest DM accumulation at both cold chain and ambient storage conditions of 32.8% on Day 28 and 28.9% on Day 14, respectively. The least increase in the DM throughout the storage period of 11.2% at Day 28, was observed for samples pre-treated with wax, packaged in LDPE films and stored at cold chain conditions ($P \leq 0.05$). It can be observed that on Day 28 from Tables 1 and 2, samples were no longer viable to be tested as they had long passed their shelf life and decayed.

3.2. Puree viscosity

The four-way interaction between pre-packaging, packaging, storage conditions, and storage period had a significant ($P \leq 0.05$) influence on the puree viscosity. A substantial increase in the viscosity was observed for avocado samples subjected to ambient storage conditions between Days 7 and 14. In contrast, storage at cold chain conditions maintained the viscosity level as determined at harvest during the first 21 days of storage for all treatments (Table 3). Sakurai and Nevins (1997) explained the decrease in the viscosity and elasticity of avocado tissue as a result of fruit ripening, which is mediated by the action of endo-type hydrolytic enzymes resulting in the breakdown of xyloglucan molecules in the cell wall (Sakurai and Nevins, 1997). This decrease in the elasticity could account for the increase in the viscosity of the puree avocado pulp as the ripening proceeds with time. Control avocado samples devoid of pre-packaging, packaging, and exposed to ambient storage conditions contributed to the greatest increase in the viscosity from 0.03 Pa.s on Day 0–7.11 Pa.s on Day 14. The combination treatment of wax and LDPE films with storage at cold chain conditions maintained the viscosity throughout the storage period. Unripened avocados have high moisture content (Table 1). Therefore, when passing the unripened puree through the muslin, the fluid was more easily separated from the solid components of the puree, which could also be attributed to higher levels of the carbohydrate propectin. Propectin can hold cells together in unripe fruits as determined in unripe guavas (Sanchez et al., 2009). In the present experiment, due to the higher moisture content of the unripe avocado, the puree had larger particles, as opposed to the ripe avocado puree, which had a smooth buttery texture and higher viscosity. A higher

Table 4. Changes in the pH of the pulp of the avocado subjected to pre-packaging, packaging and different storage conditions for 28 days.

Treatment			Storage Period (Days)				
Pre-packaging	Packaging	Storage Conditions	0	7	14	21	28
	LDPE	CC	6.74^{a}	6.60^{cde}	6.58^{de}	6.55^{e}	6.53^{fg}
		AT, ARH	6.76^{a}	6.50^{gh}	6.44^{hi}	-	-
HWT	Bio	CC	6.74^{a}	6.68^{c}	6.62^{cde}	6.59^{cde}	6.46^{h}
		AT, ARH	6.76^{a}	6.52^{g}	6.03^{k}	-	-
	NP	CC	6.74^{a}	6.55^{e}	6.58^{de}	6.54^{ef}	6.58^{de}
		AT, ARH	6.76^{a}	6.60^{cde}	6.19^{j}	-	-
	LDPE	CC	6.74^{a}	6.73^{ab}	6.66^{c}	6.61^{cde}	6.58^{de}
		AT, ARH	6.76^{a}	6.76^{a}	6.59^{cde}	-	-
Avoshine®	Bio	CC	6.74^{a}	6.72^{abc}	6.71^{abc}	6.69^{bc}	6.65^{c}
		AT, ARH	6.76^{a}	6.65^{c}	6.52^{g}	-	-
	NP	CC	6.74^{a}	6.67^{c}	6.69^{bc}	6.66^{c}	6.61^{cde}
		AT, ARH	6.76^{a}	6.69^{bc}	6.61^{cde}	-	-
	LDPE	CC	6.74^{a}	6.63^{cd}	6.58^{de}	6.57^{de}	6.53^{fg}
		AT, ARH	6.76^{a}	6.73^{ab}	6.12^{jk}	-	-
NPP	Bio	CC	6.74^{a}	6.63^{cd}	6.65^{c}	6.63^{cd}	6.60^{cde}
		AT, ARH	6.76^{a}	6.53^{fg}	6.41^{i}	-	-
	NP	CC	6.74^{a}	6.63^{cd}	6.61^{cde}	6.58^{de}	6.58^{de}
		AT, ARH	6.76^{a}	6.61^{cde}	6.09^{jk}	-	-

Means within a column followed by the same letter/s are not significantly different from each other, according to Duncan's Multiple Range Test ($P \leq 0.05$). HWT, hot water treatment; NPP, no pre-packaging; Bio, biodegradable corn starch packaging; LDPE, low-density polyethylene packaging; NP, no packaging; CC, cold chain; AT, ambient temperature; ARH, ambient relative humidity.

Table 5. Changes in the total soluble solids (°brix) of avocados subjected to pre-packaging, packaging and different storage conditions for 28 days.

Treatment			Storage Period (Days)				
Pre-packaging	Packaging	Storage Conditions	0	7	14	21	28
	LDPE	CC	2.90^{h}	3.20^{g}	3.27^{fg}	3.20^{g}	4.20^{bcd}
		AT, ARH	2.95^{h}	3.07^{gh}	4.40^{bc}	-	-
HWT	Bio	CC	2.90^{h}	2.95^{h}	3.00^{h}	3.10^{gh}	3.87^{d}
		AT, ARH	2.95^{h}	3.07^{gh}	4.30^{bc}	-	-
	NP	CC	2.90^{h}	3.47^{ef}	3.80^{de}	3.80^{de}	4.47^{bc}
		AT, ARH	2.95^{h}	4.70^{ab}	5.00^{a}	-	-
	LDPE	CC	2.90^{h}	3.00^{h}	3.27^{fg}	3.30^{efg}	3.45^{ef}
		AT, ARH	2.95^{h}	3.10^{gh}	3.95^{d}	-	-
Avoshine®	Bio	CC	2.90^{h}	3.13^{gh}	3.53^{ef}	3.40^{efg}	3.70^{e}
		AT, ARH	2.95^{h}	3.10^{gh}	4.57^{abc}	-	-
	NP	CC	2.90^{h}	3.13^{gh}	3.27^{fg}	3.30^{efg}	3.90^{d}
		AT, ARH	2.95^{h}	2.63^{hi}	$4.30b^{c}$	-	-
	LDPE	CC	2.90^{h}	3.20^{g}	3.45^{ef}	3.50^{ef}	3.50^{ef}
		AT, ARH	2.95^{h}	2.90^{h}	3.70^{e}	-	-
NPP	Bio	CC	2.90^{h}	3.13^{gh}	3.30^{efg}	3.37^{efg}	3.83^{de}
		AT, ARH	2.95^{h}	4.15^{cd}	4.00^{d}	-	-
	NP	CC	2.90^{h}	3.00^{h}	3.10^{gh}	3.27^{fg}	4.30^{bc}
		AT, ARH	2.95^{h}	3.67^{e}	4.80^{ab}	-	-

Means within a column followed by the same letter/s are not significantly different from each other, according to Duncan's Multiple Range Test ($P \leq 0.05$). HWT, hot water treatment; NPP, no pre-packaging; Bio, biodegradable corn starch packaging; LDPE, low-density polyethylene packaging; NP, no packaging; CC, cold chain; AT, ambient temperature; ARH, ambient relative humidity.

viscosity is, therefore, synonymous with fruit ripening, which is accelerated by high ambient temperatures.

3.3. pH value

Aguirre-Joya et al. (2017) stated that Hass avocado fruit have a characteristic pH near neutrality, as can be seen in Table 4. Storage conditions and storage periods significantly ($P \leq 0.05$) influenced the avocado pH value. A general decline in the pH value was observed for avocado samples subjected to the different postharvest treatments, specifically those stored under ambient conditions. This trend is in agreement with the findings of Maftoonazad and Ramaswamy (2008), Jacobo-Velazquez and Hernandez-Brenes (2011) and Aguirre-Joya et al. (2017). Pre-packaging treatments had a higher significance ($P \leq 0.05$) than packaging films. Wax-coated avocado samples had higher pH values when stored under both cold chain and ambient conditions. Jacobo-Velazquez and Hernandez-Brenes (2011) reported the decline in the pH value to be attributed to the movement of organic acids from intercellular

Table 6. Changes in the total titratable acid (mg.ml^{-1}) of avocados subjected to pre-packaging, packaging and different storage conditions for 28 days.

Treatment			Storage Period (Days)				
Pre-packaging	Packaging	Storage Conditions	0	7	14	21	28
	LDPE	CC	1.9^{k}	3.6^{hi}	3.9^{h}	3.7^{h}	5.0^{def}
		AT, ARH	1.7^{k}	4.9^{ef}	8.4^{bc}	-	-
HWT	Bio	CC	1.9^{k}	3.1^{hij}	3.1^{hij}	2.3^{jk}	2.3^{jk}
		AT, ARH	1.7^{k}	3.8^{h}	8.1^{bcd}	-	-
	NP	CC	1.9^{k}	3.4^{hi}	4.1^{gh}	3.6^{hi}	4.2^{fgh}
		AT, ARH	1.7^{k}	2.0^{k}	8.4^{bc}	-	-
	LDPE	CC	1.9^{k}	3.1^{hij}	3.2^{hij}	3.4^{hi}	3.7^{h}
		AT, ARH	1.7^{k}	1.4k^{l}	5.1^{de}	-	-
Avoshine®	Bio	CC	1.9^{k}	3.4^{hi}	3.4^{hi}	4.4^{fg}	7.0^{bcd}
		AT, ARH	1.7^{k}	1.9^{k}	6.2^{d}	-	-
	NP	CC	1.9^{k}	3.1^{hij}	3.6^{hi}	4.4^{fg}	5.8^{d}
		AT, ARH	1.7^{k}	5.8^{d}	6.5^{cd}	-	-
	LDPE	CC	1.9^{k}	2.2^{jk}	3.0^{hij}	4.4^{fg}	6.2^{d}
		AT, ARH	1.7^{k}	4.5^{fg}	5.3^{de}	-	-
NPP	Bio	CC	1.9^{k}	2.6^{ij}	2.6^{ij}	8.7^{b}	8.1^{bcd}
		AT, ARH	1.7^{k}	4.5^{fg}	4.3^{fg}	-	-
	NP	CC	1.9^{k}	2.5^{j}	2.7^{ij}	8.4^{bc}	11.5^{a}
		AT, ARH	1.7^{k}	5.0^{def}	7.5^{bcd}	-	-

Means within a column followed by the same letter/s are not significantly different from each other, according to Duncan's Multiple Range Test ($P \leq 0.05$). HWT, hot water treatment; NPP, no pre-packaging; Bio, biodegradable corn starch packaging; LDPE, low-density polyethylene packaging; NP, no packaging; CC, cold chain; AT, ambient temperature; ARH, ambient relative humidity.

locations to the avocado puree. Besides, the increase in acidity could be due to the increase in the concentration of free fatty acids as a result of trigliceride lipolysis (Jacobo-Velazquez and Hernandez-Brenes, 2011). An increase in the acidity can be one of the changes associated with avocado deterioration. Avocado samples devoid of pre-packaging and packaging treatments displayed the lowest pH values. However, it should be highlighted that hot water pre-treated samples, packaged in biodegradable films and stored under ambient conditions, exhibited a decrease in pH values over a 14-day storage period by 10.8%, compared to a decrease by 9.9% in control avocado samples. The lower pH values of hot water treated avocado samples can be attributed to tissue damage. The pH values of hot water treated samples without packaging and stored under cold chain conditions fluctuated during the 28-day storage. While cold storage proved to be highly beneficial for avocados, the use of hot water treatments appeared to have reduced the pH more than in the control samples, which is not desirable.

3.4. Total soluble solids

The storage conditions and the storage period significantly ($P \leq 0.05$) affected the total soluble solids (TSS) of avocados stored for the 28 days (Table 5). A general increase in the TSS was observed in avocados subjected to the different treatments throughout the storage period. The increase in the TSS occurred at a faster rate at ambient conditions

Table 7. Changes in the subjective quality attributes subjected to different postharvest treatments.

Treatment			Final state of avocado	Rating
	LDPE	CC	Dull exterior, remained firm and green	Good
		AT, ARH	Dull exterior, soft, darkening of the skin, mould development, shrivelling	Poor
HWT	Bio	CC	Dull exterior, remained firm and green	Good
		AT, ARH	Dull exterior, soft, darkening of the skin, mould development, shrivelling	Poor
	NP	CC	Dull exterior, remained firm and green	Fair
		AT, ARH	Dull exterior, soft, darkening of the skin, high degree of shrivelling	Poor
	LDPE	CC	Shiny exterior, slight softening and darkening of the skin	Excellent
		AT, ARH	Shiny exterior, softening and darkening of the skin, slight mould development	Fair
Avoshine®	Bio	CC	Shiny exterior, remained firm and green	Excellent
		AT, ARH	Shiny exterior, softening and darkening of the skin, slight mould development	Fair
	NP	CC	Shiny exterior, slight softening and darkening of the skin	Very good
		AT, ARH	Shiny exterior, softening and darkening of the skin, slight mould development	Poor
	LDPE	CC	Dull exterior, slight softening and skin darkening	Fair
		AT, ARH	Dull exterior, excessive softening, darkening of the skin, mould development, shrivelling, condensation within packaging	Poor
NPP	Bio	CC	Dull exterior, slight softening and skin darkening	Fair
		AT, ARH	Dull exterior, excessive softening, darkening of the skin, mould development, shrivelling, condensation within packaging	Poor
	NP	CC	Dull exterior, softening and skin darkening	Poor
		AT, ARH	Dull exterior, most excessive softening, darkening of the skin, mould development, shrivelling	Very bad

HWT, hot water treatment; NPP, no pre-packaging; Bio, biodegradable corn starch packaging; LDPE, low-density polyethylene packaging; NP, no packaging; CC, cold chain; AT, ambient temperature; ARH, ambient relative humidity.

compared to the cold chain storage conditions. The increased temperature and reduced RH under ambient storage conditions may have contributed to the increased hydrolysis of carbohydrates stored within the avocado fruit into soluble sugars. This results in a higher TSS and a reduction in the avocado shelf life, which is undesirable. Packaging treatments displayed a higher significance ($P \leq 0.05$), compared to pre-packaging on the avocado TSS. Packaged avocado samples, generally demonstrated lower TSS values, compared to unpackaged control samples at both cold chain conditions and ambient conditions. This is in agreement with Tefera et al. (2007) and Workneh et al. (2011). However, Aguirre-Joya et al. (2017) found no distinct change in the TSS of avocado fruit in both refrigerated and room storage conditions but rather a general increase in the TSS values during storage. Avocados treated with wax, LDPE, and control storage conditions displayed the lowest rate of increase in the TSS of only 19.0% from Day 0 to Day 28 indicative of slower senescence and ripening and a longer shelf life.

3.5. Total titratable acid

Table 6 presents the changes in the total titratable acid (TTA) of the avocado pulp. The storage conditions and the storage period were highly significant ($P \leq 0.05$) in terms of the avocado TTA. A general increase in the TTA was observed for all treatment conditions. The increase in the TTA was observed to occur at a faster rate under ambient conditions for a 14-day storage period, compared to cold chain conditions for a 28-day storage period. This shows that the avocado samples at cold chain conditions had an addition 14 day shelf life compared to those at ambient conditions. Maftoonazad and Ramaswamy (2008) observed a similar trend of a more rapid rise in the TTA at higher temperatures of avocado samples. Pre-packaging and packaging were found to have a significant ($P \leq 0.05$) influence on the changes of the avocado TTA. Pre-package avocados displayed lower TTA values, compared to non-pre-packaged samples. Similarly, packaged samples demonstrated lower TTA values than unpackaged samples. The four-way interaction between pre-packaging, packaging, storage conditions, and the storage period was found to significantly ($P \leq 0.05$) effect the avocado TSS. The increase in the TTA corresponds to a decrease in the pH. The lowest rate of increase in the TTA from 1.9 to 3.7 occurred in samples coated with Avoshine®, packaged in LDPE film and stored at cold chain conditions for 28 days. In contrast, the highest rates of increase in the TTA from 1.9 to 11.5 and from 1.7 to 7.5 were observed for control samples stored at the cold chain and ambient storage conditions, respectively. This, therefore, illustrates the benefit of pre-packaging and packaging treatments in maintaining the quality of avocado fruit.

3.6. Subjective quality attributes

Avocado samples stored at ambient conditions succumbed to more mould development, especially in the packaged treatment. The microenvironment within the packaging was conducive for the proliferation of mould, due to the higher temperature and RH. Droplets of moisture began to collect in packaged samples at ambient conditions, indicating a loss in moisture from the avocado, which resulted in excessively higher PWL. The visual comparison between avocado samples stored under ambient conditions and cold chain conditions revealed a higher percentage of marketable fruit at the lower temperature (Table 7). The colour change of the skin from a green to purple/black was most pronounced at ambient conditions due to the excessively higher temperatures. Control avocado samples devoid of pre-packaging and packaging treatments exhibited the darkest skin colour and showed extreme softening. These fruits were discarded after 14 days of storage due to excessive softening and decay. In general, avocado samples coated with wax and packaged in LDPE films displayed aesthetically appealing fruit, with a glossy exterior, particularly at cold chain conditions, and were able to remain in storage for the entire 28-day period.

4. Conclusion

The storage conditions and the storage period were found to have the greatest influence on all of the avocado quality parameters. The simulation of a realistic cold chain, incorporating stepping down the temperature from 5.5 °C to 4.5 °C over a 28 days, has proven to preserve the postharvest quality of avocados, compared to storage at ambient conditions. Based on the results, samples stored at cold chain conditions had a shelf life of 14 days more, compared to those at ambient conditions. The lower temperature was instrumental in reducing the rate of increase in DM and the subsequent moisture loss, lowering the viscosity, reducing the rates of pH reduction and in mediating the increase in TSS and TTA. The combination of the pre-packaging wax coating and LDPE film at cold chain storage conditions resulted in the least change in MC and DM quality parameters by 9.5% and 11.2%, respectively. The lowest reduction in the pH of 1.3% was observed under this treatment, which can be associated with the lowest increase in the TTA. Likewise, the lowest increase of 19.0% in the TSS was also observed. It can, therefore, be deduced that the combined use of Avoshine® coating, LDPE films, and cold chain storage conditions is beneficial in preserving the postharvest quality of avocados, by delaying the ripening process and consequently extending the shelf life of avocados by up to two weeks more, compared to storage at ambient conditions.

Declarations

Author contribution statement

A. Kassim: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

T. S. Workneh: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

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References

Aguilar-Mendez, M.A., Martin-martinez, E.S., Tomas, S.A., Cruz-Orea, A., Jaime-Fonseca, M.R., 2008. Gelatine-starch films: physicochemical properties and their application in extending the post-harvest shelf life of avocado (*Persea americana*). J. Sci. Food Agric. 88, 185–193.

Aguirre-Joya, J.A., Ventura-Sobrevilla, J., Martinez-Vazquez, G., Ruelas-Chacon, X., Rojas, R., Rodriguez-Herrera, R., Aguilar, C.N., 2017. Effects of a natural bioactive coating on the quality and shelf life prolongation at different storage conditions of avocado (*Persea americana* Mill.) cv. Hass. Food Packag. Shelf Life 14, 102–107.

Aiello, G., La Scalia, G., Micale, R., 2011. Simulation analysis of cold chain performance based on time–temperature data. Prod. Plann. Contr. 23, 468–476.

Blakey, R.J., 2012. Personal Communication, Everdon Estate, Limpopo, RSA.

Blakey, R.J., van Rooyen, Z., Kohne, J.S., Malapana, K.C., Mazhawu, E., Tesfay, S.Z., Savage, M.J., 2015. Growing avocados under shadenetting in South Africa. Acta Proc. Cult. Manag. Tech. 230–235.

Chen, N.J., Wall, M.M., Paull, R.E., Follett, P.A., 2009. Variation in 'Sharwil' avocado maturity during the harvest season and resistance to fruit fly infestation. HortScience 44 (6), 1655–1661.
Dodd, M.C., Nelson, R.M., Nortje, G., Louw, E., 2007. Identifying and rectifying complacency in the South African avocado cold chain. In: Proceedings VI World Avocado Congress.
Getinet, H., Seyoum, T., Woldetsadik, K., 2008. The effect of cultivar, maturity stage and storage environment on quality of tomatoes. J. Food Eng. 87 (4), 467–478.
Getinet, H., Workneh, T.S., Woldetsadik, K., 2011. Effect of maturity stages, variety and storage environment on sugar content of tomato stored in multiple pads evaporative cooler. Afr. J. Biotechnol. 10, 18481–18492.
Hall, G.F., 2011. Avoshine EU Product Information Manual. Revision No. 1. Citrashine (Pty) Ltd, Pretoria, RSA.
Hassan, M.K., Dann, E., 2019. Effects of treatment with electrolyzed oxidizing water on postharvest diseases of avocado. Agriculture 9, 241–255.
Hofman, P.J., Jobin-Decor, M., 1999. Effect of fruit sampling and handling procedures on the percentage dry matter, fruit mass, ripening and skin colour of 'Hass' avocado. J. Hortic. Sci. Biotechnol. 74, 277–282.
Jacobo-Velazquez, D.A., Hernandez-Brenes, C., 2011. Sensory shelf-life limiting factor of high hydrostatic pressure processed avocado paste. J. Food Sci. 76, 388–395.
Kremer-Kohne, S., Duvenhage, J.A., 1997. Alternatives to polyethylene wax as post-harvest treatment for avocados. South Afr. Avocado Growers' Assoc. Yearbk. 20, 97–98.
Landahl, S., Meyer, M.D., Terry, L.A., 2009. Spatial and temporal analysis of textural and biochemical changes of imported avocado cv. Hass during fruit ripening. J. Agric. Food Chem. 57, 7039–7047.
Lutge, A., Bertling, I., Bower, J.P., 2012. Effects of low temperature storage and cold chain breaks on anti-oxidants and C7 sugars in 'Fuerte' avocados from South Africa. South Afr. Avocado Growers' Assoc.Yearbk. 35, 22–27.
Maftoonazad, N., Ramaswamy, H.S., 2008. Effect of pectin-based coating on the kinetics of quality change associated with stored avocados. J. Food Process. Preserv. 32 (4), 621–643.
Mangaraj, S., Goswami, T.K., Mahajan, P.V., 2009. Applications of plastic films for modified atmosphere packaging of fruits and vegetables: a review. Food Eng. Rev. 1, 133–158.
Mazhawu, E., Clulow, A., Savage, M.J., Taylor, N.J., 2018. Water use of avocado orchards–Year. Avocado Growers' Assoc. Yearbk. 41, 37–41.
Milne, D.L., 1998. Avocado quality assurance: who? where? when? how? South Afr. Avocado Growers' Assoc. Yearbk. 21, 39–47.
Mohammed, M., Wilson, L.A., Gomes, P.I., 1999. Postharvest sensory and physiochemical attributes of processing and nonprocessing tomato cultivars. J. Food Qual. 22, 167–182.
Moore-Gordon, C.S., Wolstenholme, B.N., 1996. The hass small-fruit problem: role of physiological stress and its amelioration by mulching. South Afr. Avocado Growers' Assoc. Yearbk. 19, 82–86.
Moore-Gordon, C.S., Wolstenholme, B.N., Levin, J., 1995. Effect of mulching on hass avocado fruit growth and yield in the KwaZulu-natal midlands. South Afr. Avocado Growers' Assoc. Yearbk 18, 62–65.
Obenland, D., Collin, S., Sivert, J., Negm, F., Arpaia, M.L., 2012. Influence of maturity and ripening on aroma volatiles and flavour in 'Hass' avocado. Postharvest Biol. Technol. 71, 41–50.
Ozdemir, F., Topuz, A., 2004. Changes in dry matter, oil content and fatty acids composition of avocado during harvesting time and post-harvesting ripening period. Food Chem. 86, 79–83.
Perez, K., Mercado, J., Soto-Valdez, H., 2004. Effect of storage temperature on the shelf life of hass avocado (*Persea americana*). Food Sci. Technol. Int. 10 (2), 73–77.
Sakurai, N., Nevins, D.J., 1997. Relationship between fruit softening and wall polysaccharides in avocado (*Persea americana* Mill) mesocarp tissues. Plant Cell Physiol. 38, 603–610.
Sanchez, C., Blanco, D., Oria, R., Sanchez-Gimeno, A.C., 2009. White guava fruit and purees: textural and rheological properties and effect of the temperature. J. Texture Stud. 40, 334–345.
Shezi, S., Magwaza, L.S., Tesfay, S.Z., Mditshwa, A., 2020. Biochemical changes in response to canopy position of avocado fruit (*cv.*'Carmen' and 'Hass') during growth and development and relationship with maturity. Sci. Hortic. 265, 109227–109237.
Tabilo-Minizaga, G., Moyano, R., Simpson, R., Barbosa-Canovas, G.V., Swanson, B.G., 2005. Flow and viscoelastic properties of pressurized avocado puree. J. Food Process. Preserv. 29, 196–207.
Tefera, A., Seyoum, T., Woldetsadik, K., 2007. Effect of disinfection, packaging, and storage environment on the shelf life of mango. Biosyst. Eng. 96, 201–212.
Vorster, L.L., Toerien, J.C., Bezuidenhout, J.J., 1990. Temperature management of avocados - an integrated approach. South Afr. Avocado Growers' Assoc. Yearbk 13, 43–46.
Workneh, T.S., Osthoff, G., Steyn, M.S., 2011. Physiological and chemical quality of carrots subjected to pre- and postharvest treatments. Afr. J. Agric. Res. 6, 2715–2724.
Wu, C.T., Roan, S.F., Hsiung, T.C., Chen, I.Z., Shyr, J.J., Wakana, A., 2011. Effect of harvest maturity and heat pretreatment on the quality of low temperature storage avocados in Taiwan. J. Facul. Agr. Kyushu Univ. 56, 255–262.
Xiao, L., Kiyoto, M., 2001. Effects of modified atmosphere packages (MAP) using films with different permeability characteristics on retaining freshness of avocado, papaya and mango fruits at normal temperature. Environ. Control Biol. 39, 183–189.
Zauberman, G., Jobin-Decor, M.P., 1995. Avocado (*Persea americana* Mill.) quality changes in response to low-temperature storage. Postharvest Biol. Technol. 5 (3), 234–243.