



Analysing the dynamics of quality loss during precooling and ambient storage of pomegranate fruit

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ABSTRACT

In this paper the spatiotemporal profile of quality loss of pomegranate fruit (cv. Wonderful) was investigated during precooling and simulated shelf conditions. The effects of relative humidity (RH) inside the cold room, polyliner inside the packaging and stack orientation on fruit quality loss were studied. Weight loss during the precooling operation ranged from 0.01 to 0.06% h⁻¹ of the initial fruit weight and was highest in stack without liner and inside non-humidified room (0.06% h⁻¹). It was observed that fruit weight loss during precooling was minimised best in liner-based packaging. Results of the shelf life study demonstrated the importance of room humidification to preserve fruit quality. Storing fruit in a room at 95% RH minimised weight loss and best maintained fruit colour, firmness, size and chemical quality attributes of pomegranates. On the other hand, fruit stored at ambient condition (65% RH) up to 30 days had excessive weight loss (up to 29.13 ± 1.49%), which led to shrivelling, deformed appearance and considerably reduced overall visual quality.

1. Introduction

Shrivelling of the surface of the fruit due to rapid loss of moisture is among the main quality problems affecting postharvest life of pomegranate fruit (Fawole and Opara, 2013; Arendse et al., 2014). On top of losing marketable fruit weight, shrivelled fruit have lower visual appeal and thus reduced commercial value (Pathare et al., 2013). Weight loss in fruit is mainly due to transpiration and to a relatively small extent due to respiratory activity (Waelti, 2010). Large vapour pressure deficit (VPD) between fruit surface and the surrounding air leads to increased rate of moisture loss (Xu and Burfoot, 1999; Hamdami et al., 2004). Hence, water loss can be reduced by proper packaging, temperature control and storage room humidification (Paull, 1999; Delele et al., 2009a; Waelti, 2010; Montero-Calderon and Cerdas-Araya, 2012).

For pomegranate fruit, the influence of storage conditions (temperature, humidity) on the physico-chemical and antioxidant properties of different cultivars has been studied (Kader, 2006; Caleb et al., 2012; Fawole and Opara, 2013; Arendse et al., 2014). Quality loss has been reported to be high at elevated temperatures (above 10 °C) and low RH (below 90%), leading to weight loss, shrivelling, and changes in the chemical and antioxidant properties of affected fruit (Fawole and

Opara, 2013; Arendse et al., 2014).

Cooling pomegranate fruit preserves quality, but weight loss remains a challenge during cold storage (Arendse et al., 2014). Humidification of the storage room is normally practiced to reduce moisture loss (Paull, 1999; Delele et al., 2009a, 2009b; Waelti, 2010). After fruit attain the storage temperature, the RH of the storage room is kept at the required level using intermittent humidification technique (Delele et al., 2009a; Vigneault et al., 2009). However, humidification can also cause several storage problems affecting fruit. For instance, during cold storage of table grapes, humidification increased stem dehydration, browning of berries, increased the incidence of SO₂ injury and package wetting (Ngcobo et al., 2013a). Wetting of the packaging material impairs the structural integrity of stacks (Hung et al., 2010). Also, condensate may cumulate on fruit surface and create favourable conditions for microbial proliferation (Brown et al., 2004). Generating nano-mists that easily and quickly evaporate in the storage room is a recent method proposed to reduce condensation on surface of fruit and packaging materials (Hung et al., 2010, 2011). The use of polyethylene, polypropylene and polyvinyl chloride films in fresh produce packaging has been reported to lower transpiration rates by lowering VPD between the fruit and surrounding air, creating near saturation conditions in the

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fruit microenvironment that helps check water loss (Mahajan et al., 2008; Ngcobo et al., 2013b; Opara and Mditshwa, 2013). However, condensation of water inside packages with internal liners may predispose fresh produce to decay and sliminess (Mahajan et al., 2008).

Normally, temperature and humidity control are based on measurements taken from specific locations in the storage room even though it is well known that these parameters are spatially non-uniform. For instance, cooling rate was shown to vary between fruit inside individual carton and from location to location in a pallet depending on carton venthole design and carton arrangement on stacking (Ambaw et al., 2017; Mukama et al., 2017). This suggests that the dynamics of fruit quality parameters could also be spatially different during pre-cooling and cold storage operations. Knowledge of the spatiotemporal profile of quality indicators, like weight loss, is crucial for determining useful relationships or patterns for effective quality control strategies. An example of this is identifying locations in the stack having higher rate of weight loss and using such locations as potential spots for monitoring and control of quality during the operation. However, this is not yet clearly understood.

Weight loss of pomegranate fruit has been reported to be high at humidity lower than 90% (Fawole and Opara, 2013; Arendse et al., 2014). Additionally, the effect of conditions of temperature and humidity under which pomegranate fruit are marketed in open retail markets with regards to quality are not known.

Therefore, the objectives of this study were to: 1) quantify the spatial and temporal weight loss profile during precooling of pomegranate fruit, 2) study the effects of internal packaging, humidification and package orientation on the moisture loss, and 3) investigate the physico-chemical quality attributes of pomegranate fruit stored at two different humidity conditions. The two humidities chosen for this study were to simulate open retail market conditions (low humidity (65%)) and cool store/refrigerated display chamber humidity conditions (high humidity (95%)).

2. Materials and methods

2.1. Pomegranate fruit

Pomegranate fruit (cv. Wonderful) were harvested at commercial maturity from Merwesfont farm in Bonnievale (33°58'12.02" S, 20°09'21.03" E), Western Cape, South Africa and transported in an air-conditioned vehicle to Postharvest Technology Research Lab at Stellenbosch University.

2.2. Package materials

In this study, corrugated fibreboard carton box (CFC) was used to contain the pomegranate fruit. The box has 6 semi-circular vent-holes on the long side located at the top and bottom rim of the side (Fig. 1 (a)). On the short side, the box has 2 semi-circular vent-holes at the top rim of the side. The box has 5 circular vent-holes on the bottom side (Fig. 1 (a) and (b)), and each box contained 12 fruit with average weight of 4.32 ± 0.39 kg per carton. Fruit were placed on a tray with depressions to position individual fruit (Fig. 1 (c)). Fruit weight loss during precooling of two different package designs were investigated: package with internal polyliner and another without polyliner. Plastic wrapping was done by placing pomegranates in a single non-perforated 10 μ m thick high density polyethylene (HDPE) plastic film (Fig. 1 (d)).

2.3. Air suction equipment (ASE)

The ASE is a box with suction fan attached to one end (Fig. 2 (a)). The suction was generated by using a centrifugal fan (KDD 10/10 750W 4P-1 3SY, AMS supplies, Sandton, South Africa). The stacked fruit, as covered with plastic sheet, was placed in front of the ASE so that air was drawn horizontally through it (Fig. 2 (b)).

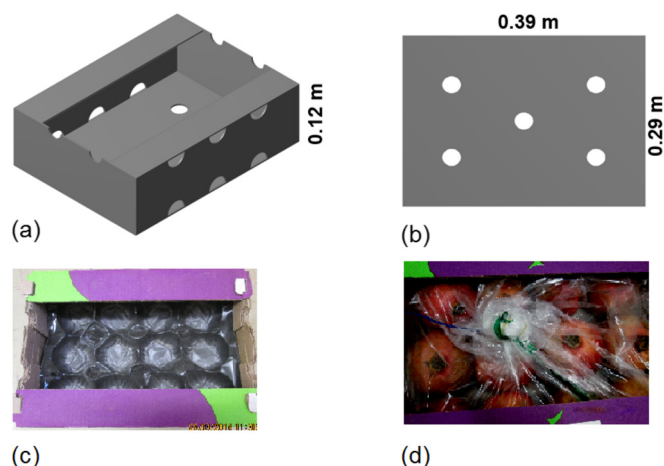


Fig. 1. The corrugated fibreboard carton box (CFC) used to contain the pomegranate fruit. Isometric projection of the box (a), bottom view of the box (b), tray with depressions to position individual fruit (c) and pomegranate fruit as wrapped in plastic liner (d).

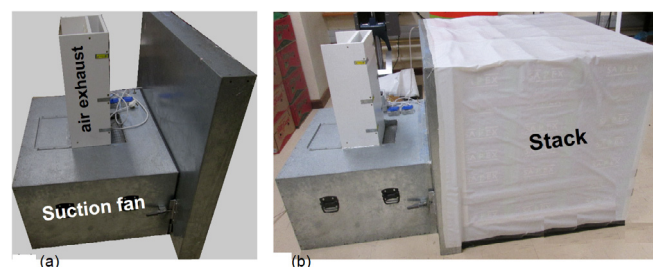


Fig. 2. The air suction equipment (ASE) (a) and ASE/stack assembly (b).

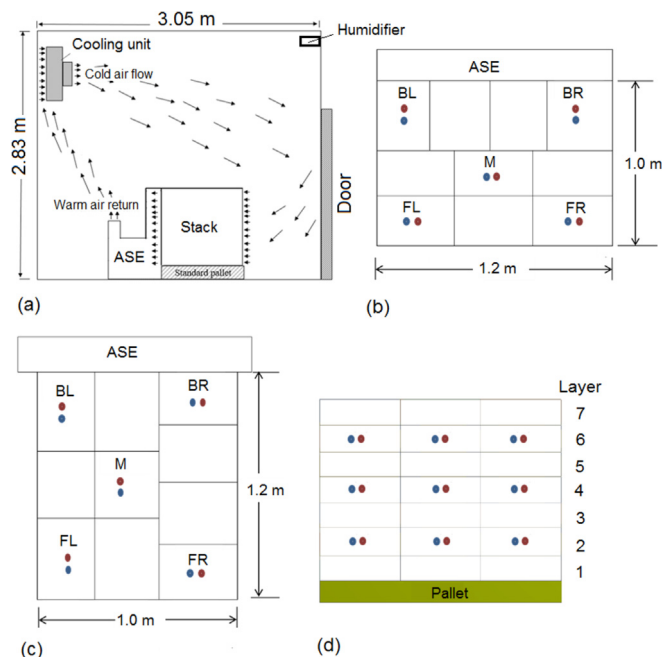


Fig. 3. Schematics showing the setup of the precooling experiment. The ASE/stack assembly as placed inside a cold storage room (a), sampling positions (temperature (red dots) and weight loss (blue dots)) in the stack oriented with its 1.2 m side perpendicular to the airflow (b) and in the stack oriented with its 1.0 m side perpendicular to the airflow (c), sampling fruits were in layer 2, 4 and 6 of the stack (d). Sample positions FL = front left, FR = front right, M = middle, BL = back left and BR = back right.

2.4. Cold storage room

The ASE/stack assembly (Fig. 2 (b)) was placed inside a 20 m³ cold storage room with dimensions 3.05 m (length), 2.4 m (width), and 2.83 m (height) (Fig. 3 (a)). The room is equipped with a cooling unit and a humidifier. The cooling unit has three evaporator fans each creating an air circulation rate of 1290 m³ h⁻¹. Cold room humidity is controlled using Aqua Room-2 humidifier (Miatec Inc. 9480SE, Lawnfield Road, Chackamas OR 97105 USA) with 1.4–2.1 bars pressure capacity, 2 L h⁻¹ liquid capacity, 10 µm droplet size and digital hygro-transmitter sensor (0–100% RH).

2.5. Experiments

2.5.1. Precooling experiments

70 cartons were stacked (7 layers of 10 cartons) on an ISO standard pallet (1.2 m × 1.0 m × 0.1 m). The stack was first equilibrated to ambient air conditions ($\approx 17^\circ\text{C}$ and 65% RH) before being placed inside the cold storage room. The sides and top of the stack were covered with plastic sheet so that chilled air is horizontally sucked through the stack by the ASE. Two different pallet orientations with respect to the ASE were considered: pallet with its 1.2 m side perpendicular to the air flow (Fig. 3 (b)) and pallet with the 1.0 m side perpendicular to the air flow (Fig. 3(c)). Due to difference in vent-hole proportion between the long and short side of the box, the vent area along the flow direction of the two different orientations are dissimilar. For the 1.2 m oriented stack, the vent-hole ratio along the flow direction were 9.45% and 2.15% at inlet and outlet, respectively. The 1.0 m orientation had vent-hole ratio of 4.24% at both the inlet and outlet end.

All precooling experiments were from the initial ambient condition ($\approx 17^\circ\text{C}$) down to $7 \pm 1.2^\circ\text{C}$. During the experiment fruit pulp temperature was monitored at intervals of 5 min using T-type thermocouples and a 34970a Data Acquisition/Data Logger Switch Unit (Agilent Technologies, Santa Clara CA 95051, USA). The measured temperature data was used to calculate the stack average 7/8th cooling time which determined the time to stop the precooling experiment. Additionally, fruit weight loss was measured by taking initial and final weight of sample fruit. The temperature and weight loss sampling positions were from stack levels 2, 4, and 6 (Fig. 3 (d)). The relative position of the samples in a layer are shown in Fig. 3 (b) and (c). A total of 24 measurements (2 pallet orientations × 2 RH conditions × 2 liner conditions × 3 repetitions) were taken. Table 1 summarizes the different configurations tested.

2.5.2. Measuring the effect of humidity on shelf life of pomegranate fruit

Here, the effect of storage humidity on the postharvest quality of pomegranate fruit was assessed. Two groups of 216 fruit each were equilibrated to ambient condition before the start of the experiment. Group 1 were kept under high humidity condition ($95 \pm 1.23\%$ RH) and group 2 under low humidity condition ($65 \pm 6.79\%$ RH). In both cases, the room temperature was kept at $20 \pm 0.36^\circ\text{C}$. Selected physico-chemical quality attributes of the stored fruit were measured over the storage period as summarized in Table 2.

2.6. Statistical analysis

Statistical analysis was done using Statistica software (Statistica version 12, StatSoft Inc., Tulsa, USA). Mixed model repeated measures analysis of variance (ANOVA) was done using the VEPAC module of Statistica 12 at 95% confidence interval. Variations in weight loss were compared between the package designs, stack levels, stack orientations and fruit position within a stack level. Statistical significance of the treatments was tested using Duncan's Multiple Range Test and means with $p < 0.05$ were considered significant.

Table 1
The different test configurations in the precooling study.

		Precooling Test		Orientation	Liner	Humidification	Description
		Humidified	No humidification				
With Liner	LH 1.2			1.2	Yes	Yes	Airflow perpendicular to the 1.2 m side of the pallet. Package with liner and the room is humidified to $95 \pm 1.23\%$ RH
	LH 1.0			1.0	Yes	Yes	Airflow perpendicular to the 1.0 m side of the pallet. Package with liner and the room is humidified, $95 \pm 1.23\%$ RH
	L 1.2			1.2	Yes	No	Airflow perpendicular to the 1.2 m side of the pallet. Package with liner and the room is at ambient humidity condition, $65 \pm 6.79\%$ RH
	L 1.0			1.0	Yes	No	Airflow perpendicular to the 1.0 m side of the pallet. Package with liner and the room is at ambient humidity condition, $65 \pm 6.79\%$ RH
With no liner	H 1.2			1.2	No	Yes	Airflow perpendicular to the 1.2 m side of the pallet. Package with no liner and the room is humidified, $95 \pm 1.23\%$ RH
	H 1.0			1.0	No	Yes	Airflow perpendicular to the 1.0 m side of the pallet. Package with no liner and the room is humidified, $95 \pm 1.23\%$ RH
	No 1.2			1.2	No	No	Airflow perpendicular to the 1.2 m side of the pallet. Package with no liner and the room is at ambient humidity condition, $65 \pm 6.79\%$ RH
	No 1.0			1.0	No	No	Airflow perpendicular to the 1.0 m side of the pallet. Package with no liner and the room is at ambient humidity condition, $65 \pm 6.79\%$ RH

Table 2
Measurements taken to assess the effect of storage humidity on the shelf life study.

	Sampling	Measurement	Instrument	Reference
Weight loss	Randomly selected 10 fruit	Weight of the marked fruit were taken initially and at 3-day intervals for 30 days	(Mettler Toledo, Model ML 3002E, Switzerland with 0.0001 g accuracy).	
Color	The fruit selected for weight loss measurement	The colour of the pomegranate skin taken initially and at 3-day intervals for 30 days on two marked spots on each fruit surface.	Minolta Chroma Meter (Model CR-400/410, Minolta Corp, Osaka, Japan).	(Pathare et al., 2013):
Firmness	Randomly selected 10 fruit	5 mm cylindrical probe was used to puncture 8.9 mm into the fruit at penetration speed of 10 mm/s. This was done on two opposite sides of 10 fruit from each environment.	Fruit Texture Analyser (GUSS-FTA, Model GS, South Africa).	Arendse et al., 2014
Size	The fruit selected for firmness	Circumference	Electronic Fruit Size Measure (EFM) connected to Fruit Texture Analyser	
Shriveling	All fruit in each storage environment	Visual assessment for shrivel incidence		
Titratable acidity (TA)	Randomly selected, peeled and juiced 10 fruit	2 ml of fresh juice was diluted with 70 ml of distilled water and titrated with 0.1 M NaOH solution to an endpoint pH 8.2	Liquafresh juice extractor (Mellerware, South Africa).	Fawole and Opara, 2013
Total soluble solids (TSS)	Juice from titratable acidity sampling	Drops of juice were placed on refractometer	Metrohm AG 862 compact titrosampler (CH-9101 Herisau, Switzerland).	Fawole and Opara, 2013
pH	Juice from titratable acidity sampling	pH probe placed in the juice	Digital refractometer (Atago, Tokyo, Japan)	Fawole and Opara, 2013
			Calibrated pH meter (Crisson, Model 924, Barcelona, Spain).	

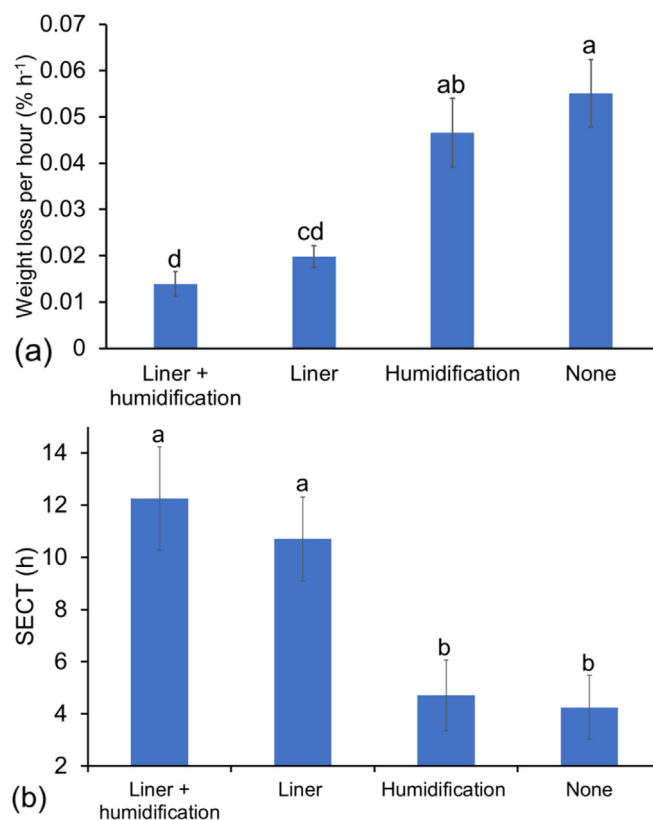


Fig. 4. Weight loss per hour of pomegranate fruit (mean $\pm$ STDV) during precooling (a) and the corresponding 7/8th cooling time (SECT (b)). All humidification was at $95 \pm 1.23\%$ RH. When no humidification, the cool storage room was kept at ambient humidity condition of $81 \pm 3.79\%$ RH. The weight loss and SECT values are stack means. Means with different letters are significantly different ($p < 0.05$).

3. Results and discussion

3.1. Weight loss during precooling of pomegranate fruit

On average, weight loss ranged from $0.01\% \text{ h}^{-1}$ to $0.06\% \text{ h}^{-1}$ of the initial fruit weight. Clearly, fruit weight loss was highest ($0.06\% \text{ h}^{-1}$) for the stack without liner and in a non-humidified cool store (“None” in Fig. 4 (a)). Stack with plastic liner and in a humidified room (“Liner + Humidification” in Fig. 4 (a)) experienced the lowest weight loss ($0.01\% \text{ h}^{-1}$). The weight loss per hour in the humidified room without liner (“humidification” Fig. 4 (a)) was almost equivalent to the weight loss per hour in the setup without humidification and liner (“None” Fig. 4 (a)). This could conclude that during precooling, the weight loss is primarily driven by the draught effect of the cooling air, taking with it moisture from the fruit environment (Thompson et al., 2008). Liners protect fruit from this draught effect. Thus, fruit during forced air cooling should not be exposed to unnecessary flow rates of air for longer times than recommended (De Castro et al., 2005). However, the presence of liner always increased fruit cooling time (Fig. 4(b)) such that stacks with liner had SECT higher than 10 h compared with less than 5 h for stacks without liner.

3.1.1. Effect of stack orientation

The average weight loss per hour of precooled pomegranates in the 1.0 m orientated pallet was $0.03\% \text{ h}^{-1}$ while those in the 1.2 m orientated pallet it was $0.04\% \text{ h}^{-1}$ (Fig. 5). The 1.0 m side of the pallet had relatively lower ventilation compared to the 1.2 m orientation as described in section 2.5.1. Low ventilation rate results in relatively lower convective mass transfer coefficient from the fruit surface to the

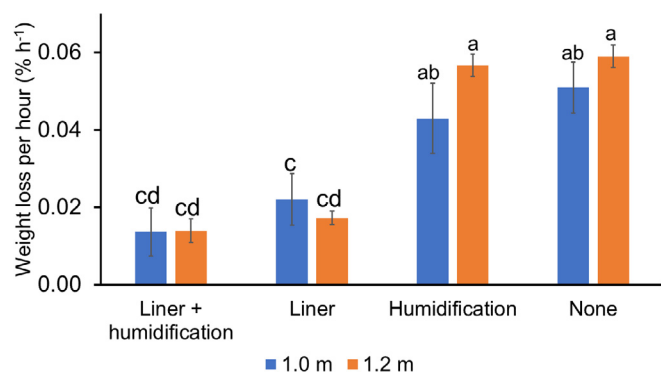


Fig. 5. Effect of stack orientation on the weight loss (mean $\pm$ STDV). Blue bars are average weight loss per hour of stacks oriented with the 1.0 m side perpendicular to the airflow direction and the other the same for stacks oriented with the 1.2 m perpendicular to the airflow direction. Means with different letters are significantly different ($p < 0.05$).

ambient air. This leads to the observed low weight loss profile. However, this also leads to a relatively longer cooling time.

3.1.2. Spatial variation in weight loss

Spatial variability of the weight loss is important to identify the high and low weight loss regions. The spatial dependence of fruit weight loss was shown by plotting the mean weight loss values at the sampling positions for the two stack orientations (Fig. 6). The standard deviation of the measurements ranged from 0.003 (for stacks with liner) to 0.007 (for stacks without liner). Weight loss was higher in the region at the back side of the stack than the front (Fig. 6). This may be attributed to the slower rate of cooling of pomegranates at the back region of the stack due to the reduced ventilation. Fruit in the upstream region received the chilled air first, thereby subjecting them to a faster cooling rate. Increase in air temperature as it moves across a stack causes local variations in heat loss in the stacked products (Baird et al., 1988) and holding pomegranate fruit at higher temperatures for longer periods causes higher moisture loss rates (Arendse et al., 2014). There was no significant difference in weight loss between layers of the stack in all cases.

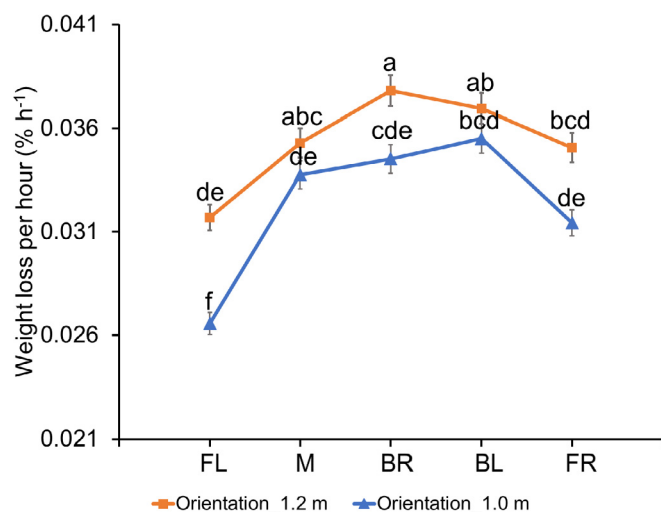


Fig. 6. Spatial variation of weight loss during precooling of pomegranate fruit. FL = front left, M = middle, BR = back right, BL = back left and FR = front right sample locations. Means with different letters are significantly different ($p < 0.05$).

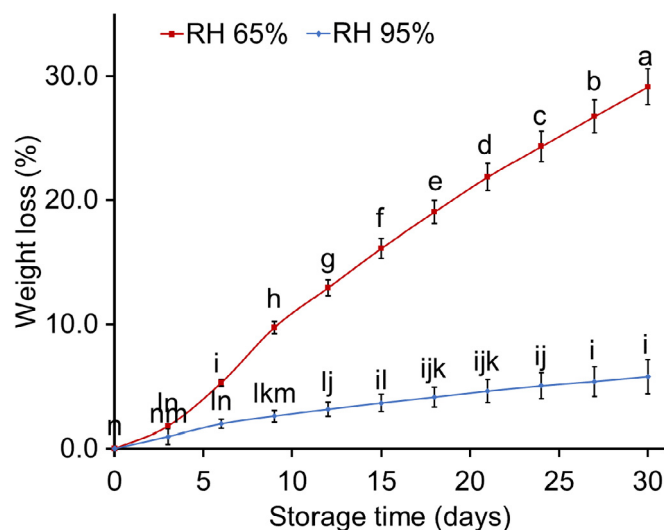


Fig. 7. Weight loss of pomegranate fruit at 20 °C: low humidity (RH $\approx$ 65%) and high humidity (RH $\approx$ 95%) storage condition. Vertical bars denote the standard error. Means with different letters are significantly different ($p < 0.05$).

3.2. Effect of humidity on shelf life quality of pomegranate fruit

3.2.1. Weight loss and fruit shrivel

Pomegranate fruit continuously lost weight throughout the shelf life period. Till day 3, there was no significant difference between the two RH environments (Fig. 7). However, fruit weight loss under the low RH environment became significantly higher starting from day 6, with losses reaching up to $29.13 \pm 1.49\%$ in the low RH environment compared to $5.78 \pm 0.44\%$ in the high RH environment (Fig. 7). Clearly, the high RH environment reduced the vapour pressure deficit (VPD) between the fruit and the environment, resulting in a significantly reduced moisture loss from the fruit (Ladaniya, 2008; Waelti, 2010; Ngcobo et al., 2013a). In their study of apples, Tu et al. (2000) reported a weight loss of up to 6% by day 18 under a 30% RH environment and about 4.5% by day 30 under 65% RH. On the other hand, fruit weight loss was only about 1.0% by day 30 at 95% RH conditions at 20 °C. Given that both apple and pomegranate have natural surface waxes (Fernandes et al., 1964), these findings showed that pomegranate is more susceptible to weight loss than apple fruit. Elyatem and Kader (1984) reported that pomegranate fruit peel is highly porous thus enabling free movement of water vapour.

Shrivel was observed on fruit from the low humidity environment on day 6. At this stage the average weight loss was $5.28 \pm 0.32\%$ of its initial weight, and by day 9, the dents on the fruit surfaces were larger. Shrivel is due to loss of turgor pressure in the fruit cell walls as they continuously lose moisture (Paull, 1999). Under high humidity environment, some fruit slightly shrivelled on day 24. This corresponded to a weight loss of $5.04 \pm 0.33\%$. By day 30, fruit in the low RH environment was severely shrivelled and deformed with less visual appeal (Fig. 8). Similar observation was reported by Kader et al. (1984) where pomegranate fruit (cv. Wonderful) was observed to show significant shrivel when weight loss gets higher than 5%. Therefore, during post-harvest handling of pomegranate fruit, weight loss should be kept below 5% to avoid commercial loss due to shrivelling. On the other hand, Fawole and Opara (2013) reported no sign of shrivel even at 12% weight loss for Bhagwa and Ruby cultivars. Hence, shrivelling is greatly cultivar dependent. A top cut (Fig. 8) showed a thinned out appearance of the fruit peel and core at low RH compared to high RH. This observation could suggest that the fruit loses moisture from the peel and core first before the arils, probably protected by the aril sac.



Fig. 8. Visual condition of pomegranate fruit 30 days under ambient humidity condition (low RH), RH $\approx$ 65% (top row) and under humidified condition (high RH), RH $\approx$ 95% (bottom row).

3.2.2. Fruit colour

There was continuous reduction in CIE value a^* (redness) of the fruit in both RH storage environments during the storage period (Fig. 9). Greater reduction in redness of the fruit was only observed after day 12 in the low RH environment while the reduction in the high humidity environment was minimal throughout the storage period. The colour intensity of the fruit (C^*) followed a similar trend as the fruit

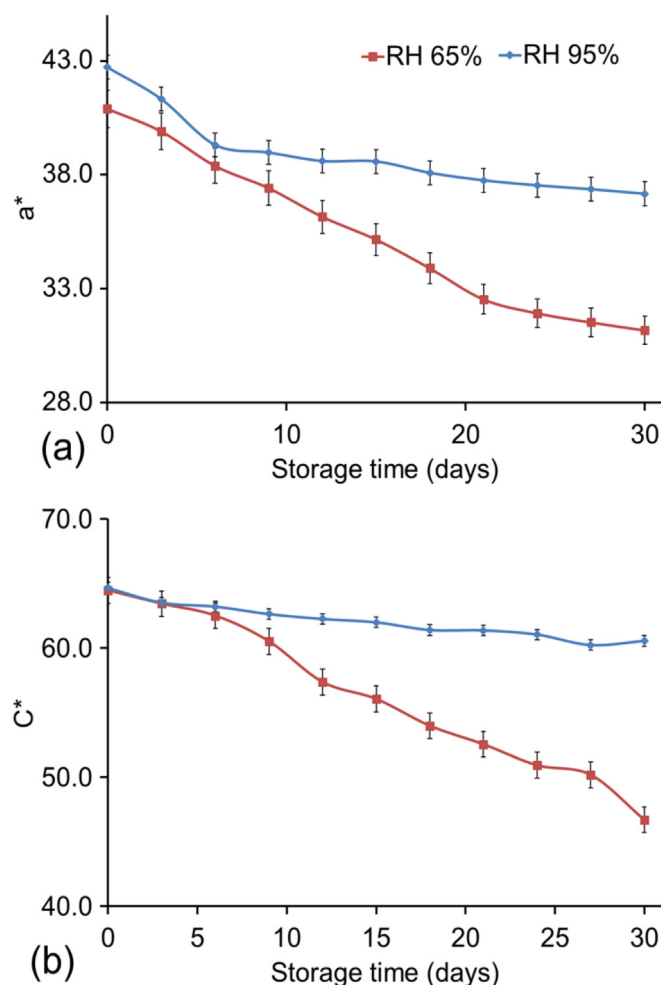


Fig. 9. Changes in a^* (redness (a)) and C^* (colour intensity (b)) of pomegranate fruit surface at low ($\approx$ 65%) and high ($\approx$ 95%) RH.

Table 3

Changes in size and puncture resistance (firmness) of pomegranate fruit (cv. Wonderful) stored at low ($65 \pm 6.79\%$) and high ($95 \pm 1.23\%$) RH at 20°C for 30 days.

Storage duration (days)	RH	Size (mm)	Firmness (N)
Initial		86.70 ± 0.67^a	99.59 ± 4.54^{cc}
9	Low	84.52 ± 0.59^{db}	99.89 ± 5.22^{cc}
	High	85.55 ± 0.41^{ab}	99.75 ± 7.22^{cc}
21	Low	82.10 ± 0.46^{bc}	101.43 ± 9.72^{cb}
	High	84.60 ± 0.61^{bc}	100.58 ± 7.78^{cb}
30	Low	75.40 ± 0.61^i	103.74 ± 4.45^{ca}
	High	84.55 ± 0.31^{db}	101.36 ± 3.77^{cb}

Values are presented as mean $\pm$ SE. Values in the same column followed by different letter(s) indicate significant difference ($p < 0.05$).

redness (Fig. 9). This may be attributed to breakdown of pigments in the fruit peel due to water stress and the desiccation of the peel as observed in Fig. 8. On the contrary, Arendse et al. (2014) reported an initial increase in a^* and C^* values of the fruit (cv. Wonderful) peel at 5°C , 7.5°C and 10°C , 92% RH for the first 3 months before reduction until the end of the 5th month of storage attributing the initial increase to anthocyanin biosynthesis in the fruit peel.

3.2.3. Fruit size and firmness

There was a general reduction in fruit size (circumference) throughout the storage period (Table 3). The loss in size was, however, higher in the low RH environment with up to 13.03% loss compared to about 2.47% loss in the high RH storage environment at the end of the 30-day storage period. This could be attributed to a higher moisture loss from fruit in the low RH environment. Fruit size may influence weight loss as it affects surface area over which moisture loss can occur keeping all other factors constant. The cultivar used in this study is one of the largest in size and the most widely cultivated in South Africa (Fawole and Opara, 2013; Arendse et al., 2014; POMASA, 2018).

There was no significant change in the fruit puncture resistance in the two environments with only a slight increase from 99.59 N at day 0– $103.74 \pm 4.45\text{ N}$ and $101.36 \pm 3.77\text{ N}$ at low and high RH, respectively, at the end of the 30-days storage period (Table 3). This could have been because of the drying out of the pomegranate peel as observed in Fig. 8. However, Arendse et al. (2014) observed an increase in puncture resistance for pomegranate fruit stored at 5°C , 7.5°C , and 10°C with 92% RH from $127.94 \pm 1.19\text{ N}$ to $130.29 \pm 1.36\text{ N}$, $133.52 \pm 1.45\text{ N}$ and $138.64 \pm 1.29\text{ N}$, respectively, at the end of the one month before a decrease until the end of the 5th month of storage. The authors attributed initial increase to moisture loss then the subsequent decrease to fruit and aril softening with storage period.

3.2.4. Chemical properties

By the end of the 30-day storage period in the two RH environments, there was no significant change in the TSS, pH, TA, and TSS/TA ratio of the pomegranate fruit juices in the high RH environment stored fruit. However, there were significant changes in the quality attributes of fruit stored in the low RH environment (Table 4). The TSS increased slightly from 15.24 °Brix at day 0–15.71 °Brix at high RH while at low RH, a significant increase to 16.72 °Brix was observed at the end of the 30-day storage period. The increase in the °Brix could be attributed to concentration of sugars as the fruit lost moisture.

TA also increased significantly from 1.76% to 2.33% (%citric acid) in the low RH environment at the end of storage compared to the slight change to 1.78% in high RH at the end of storage (Table 4). This could be also attributed to the concentration of the acids as fruit lose moisture. On the contrary, Arendse et al. (2014) observed a decline in TA for pomegranate fruit (cv. Wonderful) stored at 21°C 65% RH for one month attributing it to rapid breakdown of organic acids. pH slightly reduced at the end of storage in the two environments. The

Table 4Changes chemical attributes of pomegranate fruit (cv. Wonderful) stored at low ($65 \pm 6.79\%$) and high ($95 \pm 1.23\%$) RH at 20°C for 30 days.

Storage duration (days)	RH	TSS (°Brix)	TA (% Citric Acid)	pH	TSS:TA
Initial		15.24 ± 0.50^a	1.76 ± 0.13^{cb}	3.65 ± 0.06^a	9.36 ± 1.12^{ae}
9	Low	16.50 ± 0.28^{ab}	1.91 ± 0.13^{ac}	3.32 ± 0.03^{bc}	8.94 ± 0.56^{eb}
	High	15.40 ± 0.17^{ac}	1.78 ± 0.15^{cb}	3.32 ± 0.04^{bc}	9.65 ± 1.12^a
21	Low	16.54 ± 0.25^{ab}	2.30 ± 0.16^a	3.16 ± 0.04^{bcd}	7.36 ± 0.45^{abd}
	High	15.67 ± 0.38^{ab}	1.78 ± 0.13^{cb}	3.36 ± 0.04^{bc}	9.33 ± 0.71^{ae}
30	Low	16.72 ± 0.24^{abc}	2.33 ± 0.22^a	3.08 ± 0.04^{fe}	7.80 ± 0.78^{ec}
	High	15.71 ± 0.24^{ad}	1.78 ± 0.14^{cb}	3.25 ± 0.05^{bcd}	9.40 ± 0.86^{ae}

Values are presented as mean $\pm$ SE. Values in the same column followed by different letter(s) indicate significant difference ($p < 0.05$).

TSS/TA values were 7.79 in the low RH environment and 9.40 in the high RH environment. These were lower than the value of 14.75 ± 0.32 reported by Arendse et al. (2014). In a similar study of apples by Tu et al. (2000), at 30%, 65% and 95% RH at 20°C , there was a slight increase in soluble solids content of the apples from $13.1 \pm 0.2\%$ to $13.5 \pm 0.2\%$, $13.2 \pm 0.2\%$ and $13.7 \pm 0.2\%$, respectively, at the end of the 30-day storage period. Thus, pomegranates exhibit greater changes in physico-chemical quality attributes at low RH compared to apples.

4. Conclusion

This study investigated the level of reduction of weight loss achievable by employing liner-based packaging or room humidification. The use of liner in the packaging showed best potential in reducing fruit weight loss during precooling. The use of liner is indeed a normal practice in the South African pomegranate industry. However, liners have delayed the fruit precooling.

This study also quantified the spatial variation in weight loss of pomegranate fruit during precooling operation. Fruit at the back of the stack had higher weight loss than those at the front. This goes in parallel with the temperature distribution in the stack as reported in previous studies (Ambaw et al., 2017; Mukama et al., 2017). The back side of the stack, which receives reduced and relatively warmer air is normally a high temperature region. The high temperature in this stack region leads to relatively higher fruit transpiration rate and weight loss, with about 0.04% higher weight loss than fruit in the front.

The shelf life study showed the importance of room humidification as a cold chain strategy to maintain pomegranate postharvest fruit quality. Storing fruit under 95% RH maintained fruit colour best, minimised weight loss, maintained fruit firmness, fruit size and the chemical quality attributes of pomegranates. Storing fruit under low RH ambient conditions led to excessive weight loss, which in turn resulted in excessive shrivelling, deformed appearance, and reduced visual quality of fruit. These findings can be applied in efforts to establish the best storage conditions of pomegranates to maintain quality and reduce incidence of postharvest losses along the value chain from harvest to consumers.

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