

Effect of relative humidity on pomegranate quality under simulated ambient storage conditions

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Abstract

The effects of relative humidity (RH) on the quality of pomegranate fruit ('Wonderful') stored in ambient temperature (20°C) under low RH (65±6.79%) and high RH (95±1.23%) conditions were studied. Significantly high weight loss, up to 29.13±1.49% at day 30, was observed in fruit stored at low RH compared to 5.78±0.44% at a high RH. Fruit stored under low RH was also severely shrivelled and reduced in size. The high RH environment better maintained the fruit colour, texture and chemical quality attributes. A regression model was developed to estimate the time history of weight loss of pomegranate stored under 65 and 95% RH ambient storage conditions. The equations had a high goodness-of-fit with R-squared values of 0.99 and 0.94 for low and high RH, respectively. For a 30-day storage period, the weight loss was estimated to a worth \$0.58 kg⁻¹ and \$0.11 kg⁻¹ under low and high RH conditions, respectively. These findings show that pomegranate fruit should preferably be stored at RH conditions ≥95% to maintain appearance, sensory quality and reduce weight loss.

Keywords: *Punica granatum*, weight loss, shrivel, appearance, chemical attributes

INTRODUCTION

Relative humidity (RH) affects the behaviour, marketability, and consumer choices of fruit on retailer shelves (Tu et al., 2000; Nunes, 2008). Compromises of fruit handling conditions of temperature and RH are common in the distribution chain due to the inadequacy of facilities for ideal handling of each commodity leading to quality loss, physiological stress and reduced shelf life (Paull, 1999; Nunes, 2008). The effects of different storage temperatures and RH on physico-chemical and antioxidant properties of the entire fruit and the aril part of the fruit have been previously studied for different cultivars (Kader, 2006; Fawole and Opara, 2013; Arendse et al., 2014), however, much emphasis has been put on the effect of temperature with less insight on the RH and conditions outside cold storage and on local open market shelves. Landrigan et al. (1996) in their study on the influences of RH on postharvest browning of Rambutan at 20°C reported increased browning in fruit stored at low RH (65%) in comparison to fruit stored at high RH (95%) inferring this to non-enzymatic changes associated with desiccation at low RH. Similarly, Tu et al. (2000) reported the effects of RH on apple quality under simulated shelf temperature storage at 20°C with 30, 65, and 95% RH. They reported faster weight loss, firmness loss, juice content loss, increase in dry matter and increase in soluble solids content at low RH (30 and 65%), while at 95% RH, the apples developed a mealy texture after 2-3 weeks, though the firmness and weight were maintained better. They also observed a faster weight loss on decreasing RH from 95 to 65% than from 65 to 30%, attributing this to a larger vapour pressure deficit (VPD). Increasing the relative humidity and lowering the storage temperature lowers the VPD of a storage environment (Paull, 1999). A higher VPD of 92.97 and 100.71 Pa caused a weight loss of 2.01-3.12% in "open top and clamshell" packaged table grapes respectively compared to 1.08% weight loss in "4.5 kg multi-packaging" with a lower VPD of 40.95 Pa

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(Ngcobo et al., 2013).

Quality loss in pomegranate fruit has been reported to be high at high temperatures (above 10°C) and low RH (below 90%) leading to loss of weight, shrivelling, changes in the chemical composition (total soluble solids – TSS, pH, and titratable acidity – TA) and antioxidant properties of pomegranates postharvest (Fawole and Opara, 2013; Arendse et al., 2014). These changes are affected by the storage duration and storage conditions of temperature and RH, and affect the fruits' appearance, flavour and consumer acceptance. Weight loss is due to moisture loss through transpiration and to a relatively small extent, some weight loss in horticultural crops is due to carbon loss during respiration (Kader et al., 1984; Waelti, 2010).

Limitations in the handling chain and retail market call for a better understanding of the effects of RH and temperature on the fruit quality and shelf life from all participants in the fruit distribution chain (Paull, 1999; Nunes, 2008). In this study, physico-chemical changes of pomegranate fruit ('Wonderful') at 20°C under two RH conditions were monitored. The objective of the study was to investigate the effects of RH on pomegranates at room temperature. The weight loss, firmness, size and chemical properties of pomegranate fruit was studied.

MATERIALS AND METHODS

Pomegranate fruit and storage conditions

Fresh pomegranate fruit ('Wonderful') was obtained at commercial maturity from Sonlia Pack-house (33°34'851"S, 19°00'360"E), Western Cape, South Africa (fruit diameter 8.0±0.15 cm) and transported in an air-conditioned vehicle to Stellenbosch University Postharvest Technology Research Laboratory. The fruits were transported in ventilated cartons of dimensions 0.32 m length, 0.29 m width and 0.105 m height. After equilibration to room temperature (20±2°C and 65±5.55% RH), the fruits were randomly divided into two groups containing 200 fruits each. One group was placed in a simulated shelf storage condition of 65±6.79% RH at 20±0.36°C (low RH environment) while the other was placed under 95±1.23% RH at 20±0.31°C (high RH environment). High RH was achieved using an air-assisted 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 hygrottransmitter sensor (0-100% RH). It was set to RH 95%. Tiny Tag TV-4500 data loggers (Gemini Data Logger, Sussex, UK) were used to monitor and record the temperature and RH in the two study environments. Physico-chemical quality attributes of 10 pomegranates in each of the two environments were monitored for 30 d at 3 d intervals.

Measurement of physical and chemical properties

1. Weight loss.

In each environment, 10 fruits were randomly selected and marked. The marked fruits were weighed at 3 day intervals for 30 d using an electronic weighing scale (Mettler Toledo, Model ML 3002E, Switzerland with 0.0001 g accuracy). The cumulative fruit weight loss was calculated using Equation 1:

$$W = \left(\frac{W_0 - W_1}{W_0} \right) \times 100 \quad (1)$$

where W = cumulative fruit weight loss percentage; W_0 = initial fruit weight at start of experiment and W_1 = fruit weight on each sampling day during storage. Values were presented as mean weight loss for the 10 fruit in each environment ± standard error (SE).

Developments of fruit shrivel and any decay incidences were also monitored throughout the 30-day storage period in the two environments.

2. Fruit colour.

The 10 fruits in each environment marked for cumulative weight measurement were also marked for colour measurements. Using a calibrated Minolta Chroma Meter (Model CR-400/410, Minolta Corp, Osaka, Japan), the colour change of the pomegranate skin was measured on each sampling day on two marked spots on each fruit surface. The International Commission on Illumination (CIE) L*, a*, b* coordinates were measured, and Chroma (C*) was calculated according to Equation 2 (Pathare et al., 2013):

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

3. Fruit puncture resistance and size.

Fruit puncture resistance was measured using the Fruit Texture Analyser (GUSS-FTA, Model GS, South Africa). With the calyx of fruit parallel to the platform, a 5 mm cylindrical probe was used to puncture 8.9 mm into the fruit at penetration speed of 10 mm s⁻¹. This was done on two opposite sides of the 10 fruits from each environment. The fruit size was measured using the Electronic Fruit Size Measure (EFM) connected to the Fruit Texture Analyser. Measurements were done on 10 fruits from each test environment.

4. Titratable acidity, total soluble solids and pH.

On each sampling day 10 fruits from each storage environment were hand peeled and juiced separately using a Liquafresh juice extractor (Mellerware, South Africa) without crushing the seeds. The titratable acidity, total soluble solids and pH measures were taken for each fruit juice at room temperature. For the titratable acidity, 2 mL of fresh juice was diluted with 70 mL of distilled water and titrated with 0.1 M NaOH solution to an endpoint of pH 8.2 using Metrohm AG 862 compact titrosampler (CH-9101 Herisau, Switzerland). The results were expressed as % citric acid. The total soluble solids measure was taken using a digital refractometer (Atago, Tokyo, Japan). The pH was measured using a calibrated pH meter (Crison, Model 924, Barcelona, Spain). The ratio of TSS to TA was also calculated for further exploration of the TSS/TA relationship.

5. Statistical analysis.

Analysis of variance (ANOVA) was carried out using STATISTICA 12 (StatSoft, Inc. Oklahoma, USA) according to Duncan's multiple range tests. All the data was analysed in a 2-way ANOVA (factor A: humidity; factor B: storage time). The results were presented as mean (\pm SE) values.

RESULTS AND DISCUSSION

Physical properties

1. Weight loss and fruit shrivel.

Throughout the storage period, pomegranate fruit continuously lost weight (moisture). There were no significant fruit weight loss differences from the two RH environments from day 0 to day 6 (Figure 1). However, the weight loss from the low RH environment was significantly higher compared to the high RH environment from day 9 until day 30 ($p < 0.05$) with losses up to $29.13 \pm 1.49\%$ in the low RH environment compared to $5.78 \pm 0.44\%$ in the high RH environment by day 30 (Figure 1). Elyatem and Kader (1984) reported that the pomegranate fruit peel is highly porous thus enabling free movement of water vapour. High RH has been reported to reduce the vapour pressure deficit (VPD) between the fruit and the environment resulting into reduced moisture loss from the fruit (Ladaniya, 2008; Waelti, 2010; Ngcobo et al., 2013). Similar weight loss observations were made by Arendse et al. (2014) and Fawole and Opara (2013) for fruit stored at conditions of 22°C $65 \pm 5.5\%$ RH. In a similar study on apples, Tu et al. (2000) reported more rapid weight loss in apples stored at 30% RH (up to 6% by day 18) and 65% RH (about 4.5% by day 30) compared to only about 1.0% weight loss by day 30 at 95% RH conditions at 20°C.

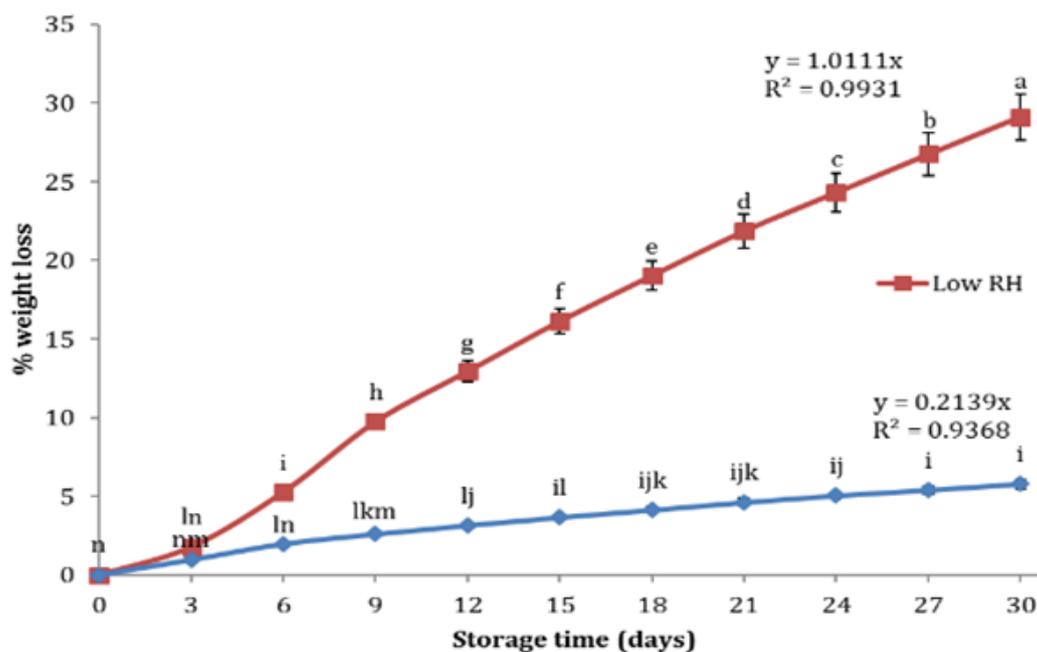


Figure 1. Weight loss of pomegranate fruit at 20°C and different RH (low = 65±6.79%; high = 95±1.23%). Vertical bars denote the standard error of the mean and different letter(s) indicate significant difference ($p < 0.05$).

Commencement of fruit shrivel was observed in the low humidity environment on day 6, after the fruit had lost up to 5.28±0.32% weight (Figure 2B) and by day 9, the indents had grown bigger. In the high humidity environment, slight signs of shrivelling were only seen on day 24 after the fruit had lost 5.04±0.33% weight (Figure 2I). This observation was similar to one of Kader et al. (1984) where pomegranate fruit ('Wonderful') that lost weight up to 5% and above, begun shrivelling but contrary to Fawole and Opara (2013) who reported no sign of shrivelling in 'Bhagwa' and 'Ruby' until 12% weight loss. The observed differences may be attributed to the different cultivar types studied. By day 30, fruit in the low RH environment was severely shrivelled and deformed with less visual appeal (Figure 2J). Shrivel is due to loss of turgor pressure in the fruit cell walls as they continuously lose moisture (Paull, 1999). On hand peeling, it was also observed that the fruit's leathery skin at low RH continuously became thinner (Figure 2L) with storage duration compared to high RH, where there was no visible change in the fruit's leathery skin thickness even at day 30 (Figure 2M). This observation could suggest that the fruit loses moisture from the skin first before the arils, which are probably protected by the aril sac.

Figure 1 shows the regression equations that can be used to predict the weight loss of pomegranate fruit stored in two RH environments of 65 and 95%, Equations 3 and 4 respectively:

$$y = 1.0111x \quad (3)$$

$$y = 0.2139x \quad (4)$$

where y = predicted weight loss and x = storage time in days. The linear regression equations have high goodness-of-fit given high coefficients of determination; R-squared (R^2) values of 0.99 and 0.94 for low and high RH weight loss predictions respectively.

At a market price of \$1.87 kg⁻¹ of pomegranate (the price at which the experimental fruit used in this study was purchased), at the end of one month storage, the estimated cost of weight loss at 65 and 95% RH was 0.58 and \$0.11 kg⁻¹, respectively.

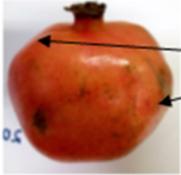
		
	A. Fruit at day 0	
Low RH ($65\pm 6.79\%$)		High RH ($95\pm 1.23\%$)
	Indents showing signs of shrivel commencement	
B. Day 6		C. Day 6
		
D. Day 9		E. Day 9
		
F. Day 18		G. Day 18
	Indents showing signs of shrivel commencement	
H. Day 24		I. Day 24
		
J. Day 30		K. Day 30
	Fruit leathery peel thin, with a dried out characteristic	
L. Day 30; cross-top cut		M. Day 30; cross-top cut

Figure 2. Pictorial presentation of the changes in appearance of pomegranate at 20°C at the studied RH conditions (low = $65\pm 6.79\%$; high = $95\pm 1.23\%$).

2. Fruit colour.

There was a continuous reduction in the CIE value a^* (redness) of the fruit in both RH storage environments throughout the storage period (data not shown). A significant 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 not significant throughout the storage period. This may be attributed to the breakdown of pigments in the fruit peel due to water stress and also the desiccation of the peel as observed in Figure 2. A similar reduction in fruit peel redness and colour intensity was observed by Fawole and Opara (2013) for 'Bhagwa' and 'Ruby' pomegranate fruit cultivars. On the contrary, Arendse et al. (2014) reported an initial increase in a^* and C^* values of the fruit peel ('Wonderful') at 5, 7.5 and 10°C, at 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. Fruit size and puncture resistance.

There was a general reduction in fruit size throughout the storage period. The loss in size was however bigger 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 d storage period (Table 1). This could be attributed to a higher moisture loss from fruit in the low RH environment. 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 to 103.74±4.45 N and 101.36±3.77 N at low and high RH, respectively, at the end of the 30 d storage period (Table 1). This could have been a result of the drying out of the pomegranate peel as observed in Figure 2. This observation is in agreement with one made by Arendse et al. (2014) who found an increase in puncture resistance for fruit stored at 5, 7.5, and 10°C with a 92% RH at the end of one month of storage before a decrease until the end of the 5th month of storage.

Table 1. Changes in physical and chemical attributes of pomegranate fruit ('Wonderful') stored at low (65±6.79%) and high (95±1.23%) RH at 20°C for 30 d.

Storage duration (days)	RH	Size (mm)	Firmness (N)	TSS (°Brix)	TA (% citric acid)	pH	TSS/TA
0		86.70±0.67 ^a	99.59±4.54 ^{c-e}	15.24±0.50 ^g	1.76±0.13 ^{bc}	3.65±0.06 ^a	9.36±1.12 ^{a-e}
9	Low	84.52±0.59 ^{b-d}	99.89±5.22 ^{c-e}	16.50±0.28 ^{ab}	1.91±0.13 ^{a-c}	3.32±0.03 ^{bc}	8.94±0.56 ^{b-e}
	High	85.55±0.41 ^{ab}	99.75±7.22 ^{c-e}	15.40±0.17 ^{e-g}	1.78±0.15 ^{bc}	3.32±0.04 ^{bc}	9.65±1.12 ^a
21	Low	82.10±0.46 ^{e-g}	101.43±9.72 ^{b-e}	16.54±0.25 ^{ab}	2.30±0.16 ^a	3.16±0.04 ^{b-d}	7.36±0.45 ^{a-d}
	High	84.60±0.61 ^{b-d}	100.58±7.78 ^{b-e}	15.67±0.38 ^{b-g}	1.78±0.13 ^{bc}	3.36±0.04 ^{bc}	9.33±0.71 ^{a-e}
30	Low	75.40±0.61 ⁱ	103.74±4.45 ^{a-e}	16.72±0.24 ^{a-c}	2.33±0.22 ^a	3.08±0.04 ^{ef}	7.80±0.78 ^{c-e}
	High	84.55±0.31 ^{b-d}	101.36±3.77 ^{b-e}	15.71±0.24 ^{d-g}	1.78±0.14 ^{bc}	3.25±0.05 ^{b-d}	9.40±0.86 ^{a-e}

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

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 of the high RH environment stored fruit, however, some significant changes were observed in the fruit stored in the low RH environment (Table 1). The TSS increased slightly from 15.24 °Brix at day 0 to 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. This increase may be attributed to the concentration of the sugars as the fruit lost moisture. Similar observations of increase in the TSS with storage, were made by Ghafir et al. (2010) and Ilhami Köksal (1989). The 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 1). This could also be attributed to the concentration of the acids as the fruit loses moisture. The pH reduced slightly at the end of storage in the two environments. This could be due to the observed concentration of acids as the fruit loses moisture. At the

end of the 30 day storage period, the TSS/TA values were 7.79 in the low RH environment and 9.40 in the high RH environment. 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 the soluble solids content of the apples from 13.1±0.2 to 13.5±0.2, 13.2±0.2 and 13.7±0.2%, respectively, at the end of the 30 day storage period.

CONCLUSION

The results from this study showed that the postharvest life of pomegranate fruit is affected by the RH during ambient storage. Storing fruit under 95% RH treatment maintained the fruit colour best, minimised weight loss, and hence, associated cost, maintained firmness, fruit size and the chemical quality attributes of pomegranates compared to the low RH ambient conditions. These findings can be applied in efforts to establish the best storage conditions of pomegranates to maintain the quality and reduce incidence of postharvest losses along the value chain from harvest to consumers.

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Literature cited

- Arendse, E., Fawole, O.A., and Opara, U.L. (2014). Influence of storage temperature and duration on postharvest physico-chemical and mechanical properties of pomegranate fruit arils. *CYTA J. Food* 12 (4), 389–398 <https://doi.org/10.1080/19476337.2014.900114>.
- Elyatem, S.M., and Kader, A.A. (1984). Postharvest physiology and storage behaviour of pomegranate fruits. *Sci. Hortic. (Amsterdam)* 24 (3-4), 287–298 [https://doi.org/10.1016/0304-4238\(84\)90113-4](https://doi.org/10.1016/0304-4238(84)90113-4).
- Fawole, O.A., and Opara, U.L. (2013). Effects of storage temperature and duration on physiological responses of pomegranate fruit. *Ind. Crops Prod.* 47, 300–309 <https://doi.org/10.1016/j.indcrop.2013.03.028>.
- Ghafir, S.A.M., Ibrahim, I.Z., Zaied, S.A., and Abusrewel, G.S. (2010). Response of local variety 'Shlefy' pomegranate fruits to packaging and cold storage. *Acta Hortic.* 877, 427–431 <https://doi.org/10.17660/ActaHortic.2010.877.55>.
- Ilhami Köksal, A. (1989). Research on the storage of pomegranate (cv. Gok Bahce) under different conditions. *Acta Hortic.* 258, 295–302 <https://doi.org/10.17660/ActaHortic.1989.258.33>.
- Kader, A.A. (2006). Postharvest biology and technology of pomegranates. In *Pomegranates: Ancient Roots to Modern Medicine*, N.P. Seeram, R.N. Schulman, and D. Heber, eds. (Boca Raton, Florida: CRC Press), p.211–220.
- Kader, A.A., Chordas, A., and Elyatem, S.M. (1984). Response of pomegranate fruit to ethylene treatment and storage temperature. *Calif. Agric.* 38, 4–15.
- Ladaniya, M. (2008). *Citrus Fruit: Biology, Technology and Evaluation* (San Diego, USA: Academic Press), p.200–209, 288–313, 320–331, 334–336, 417–444.
- Landrigan, M., Morris, S.C., and Gibb, K.S. (1996). Relative humidity influences postharvest browning in Rambutan (*Nephelium lappaceum* L.). *HortScience* 31, 417–418.
- Ngcobo, M.E.K., Delele, M.A., Opara, U.L., and Meyer, C.J. (2013). Performance of multi-packaging for table grapes based on airflow, cooling rates and fruit quality. *J. Food Eng.* 116 (2), 613–621 <https://doi.org/10.1016/j.jfoodeng.2012.12.044>.
- Nunes, M.C.N. (2008). Impact of environmental conditions on fruit and vegetable quality. *Stewart Postharvest Rev.* 4 (4), 1–14 <https://doi.org/10.2212/spr.2008.4.4>.
- Pathare, B.P., Opara, U.L., and Al-Said, F.A. (2013). Colour measurement and analysis in fresh and processed foods: a review. *Food Bioprocess Technol.* 6 (1), 36–60 <https://doi.org/10.1007/s11947-012-0867-9>.
- Paull, R.E. (1999). Effect of temperature and relative humidity on fresh commodity quality. *Postharvest Biol. Technol.* 15 (3), 263–277 [https://doi.org/10.1016/S0925-5214\(98\)00090-8](https://doi.org/10.1016/S0925-5214(98)00090-8).

Tu, K., Nicolai, B., and De Baerdemaeker, J. (2000). Effects of relative humidity on apple quality under simulated shelf temperature storage. *Sci. Hortic. (Amsterdam)* 85 (3), 217-229 [https://doi.org/10.1016/S0304-4238\(99\)00148-X](https://doi.org/10.1016/S0304-4238(99)00148-X).

Waelti, H. (2010). Humidity management in CA storages (WSU Tree Fruit Research & Extension Centre, Postharvest Information Network), <http://postharvest.tfrec.wsu.edu/pages/J2I3B>.