Effect of modified atmosphere packaging on the extension of storage life and quality maintenance of pomegranate (cv. ‘Bhagwa’) at ambient and low temperatures

D. V. Sudhakar Rao¹ · K. S. Shivashankara²

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Abstract Pomegranates (cv. ‘Bhagwa’) packed in four semi-permeable films (Cryovac[®] BDF-2001, D-955, RD-106 and normal LDPE) were stored at ambient temperature (25–30 °C, 60–70% RH) and low temperature (8 °C, 80–85% RH) to study the effect of modified atmosphere (MA) packaging on storage life extension and quality maintenance. O₂ and CO₂ levels generated inside MA packs differed significantly with the film type wherein extremely high CO₂ (> 70%) and low O₂ (1% or less) were observed in BDF film during 3 weeks at ambient temperature and 3 months at 8 °C. Moderate O₂ (3–8%) and CO₂ (7–11%) were maintained in D-955 film, whereas very high O₂ (18–20%) and low CO₂ (2–4%) were maintained in RD-906 film. Significantly low weight loss of 0.73 and 0.52% was observed in MA packed (D-955) fruits after 3 weeks at ambient and 3 months at 8 °C respectively compared to 19.0 and 17.8% in non-packed fruits. Fruits packed in D-955 film also retained original peel colour (L*, h° and C*), whereas colour was adversely affected in fruits packed in low permeable BDF film. MA packaging maintained peel thickness and peel moisture, significantly higher than non-packed fruits at both temperatures. TSS, acidity,

sugars, antioxidants and sensory qualities were better in D-955 and LDPE packed fruits at both ambient and 8 °C storage, whereas quality was adversely affected in BDF film packed fruits. MA packed (D-955 and LDPE) fruits had less spoilage up to 3 weeks at ambient (5.5 and 8.3%) and 3 months at 8 °C (2.8 and 9.7%). Quality got deteriorated by 4 weeks at ambient temperature and 4 months at 8 °C with enhanced spoilage. Pomegranate fruits cv. ‘Bhagwa’ can thus be stored safely for 3 weeks at ambient and 3 months at 8 °C storage by MA packaging in D-955 or LDPE film with least weight loss and maintenance of nutritional quality.

Keywords Pomegranate · MA packaging · Storage temperature · Weight loss · Quality assessment · Antioxidants

Introduction

Worldwide consumer demand for pomegranate (*Punica granatum* L.) fruits is increasing steadily due to its nutritional and health promoting benefits. This necessitates the need to supply markets with high quality pomegranates for extended periods. However, in spite of low respiration rate, pomegranate is a highly perishable fruit (Sudhakar Rao 2018). Storage of pomegranates at ambient temperature reduces the shelf life mainly due to increased desiccation resulting in a brownish coloured tough peel. Fruits exhibit shriveling symptoms when weight loss exceeds 5% or more (Palou et al. 2007). Further, pomegranate is susceptibility to chilling injury (CI) when stored below 5 °C (Elyatem and Kader 1984) resulting in necrotic pitting, discoloration of the rind, paleness of arils and susceptibility to decay. To improve fruit storability and shelf life, several physical and

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✉ D. V. Sudhakar Rao
dvsrao@iihr.res.in; sudhadvrao@gmail.com

¹ Division of Post Harvest Technology and Agricultural Engineering, ICAR-Indian Institute of Horticultural Research, Hessaraghatta Lake (PO), Bangalore 560 089, India

² Division of Plant Physiology and Biochemistry, ICAR-Indian Institute of Horticultural Research, Hessaraghatta Lake, Bangalore 560 089, India

chemical postharvest treatments have been evaluated (Opara et al. 2015), including intermittent warming, film wrapping, waxing, polyamines, controlled atmosphere and modified atmosphere packaging, among others (Artés et al. 1998; Nanda et al. 2001; Hess-Pierce and Kader 2003; Mirdehghan et al. 2007; Caleb et al. 2012; Selcuk and Erkan 2014, 2015, 2016; Meighani et al. 2015; Sudhakar Rao 2018).

Modified atmosphere packaging (MAP) is a simple, economical and effective method in prolonging the postharvest life of many horticultural crops (Kader et al. 1989). The decreased O₂ and increased CO₂ inside the package retards the respiration rate, ethylene production, enzymatic activity, CI and decay, resulting in increased postharvest life and quality (Kader and Watkins 2000; Caleb et al. 2012). MAP also prevents weight loss and fruit shriveling by creating a higher RH in surrounding environment of the produce. MAP has been successfully applied for reducing water loss, shrinkage, scald development, decay and maintaining the fruit quality for 3 months or more in ‘Mollar de Elche’ (Artés et al. 2000), ‘Primosele’ (D’Aquino et al. 2010), ‘Bhagwa’ (Kumar et al. 2013), ‘Hicannar’ (Selcuk and Erkan 2014), ‘Wonderful’ (Porat et al. 2016) and ‘Beynar’ (Selcuk and Erkan 2016) cultivars of pomegranates at different storage temperatures. However, pomegranate cultivars responded differently to MAP, i.e., ‘Hicannar’ cultivar could be stored up to 100 days without decay or weight loss using MAP (Selcuk and Erkan 2014) whereas same authors (Selcuk and Erkan 2015) could successfully store ‘Hicannar’ cultivar of pomegranates up to 180 days by MAP with less weight loss or decay. Matityahu et al. (2016) while studying the effects of controlled atmosphere on the quality of three pomegranate cultivars at 7 °C, also suggested that each cultivar may require a specific storage protocol, with regard to the atmospheric composition in order to prolong storage beyond 2 months and to preserve the fruit quality. Kumar et al. (2013) used polypropylene (12.5, 25 and 37.5 µm) and StePac, Xtend[®] film bags to improve the shelf life and maintain quality of pomegranate (cv. ‘Bhagwa’) at 4 ± 1 °C and found that fruits can be stored up to 90 days at 4 ± 1 °C with maintenance of quality (TSS, firmness and sensory) of the fruit when packed in the latter. However, in their study neither the permeability characters of the films were mentioned nor the actual gas composition established inside the packs was measured and so did not correlate the obtained results with the gas composition which is an important criterion for modified atmosphere packaging studies. In the present investigation, we have used four semi-permeable films to create four different modified atmospheres to study their effect on weight loss, storage life and quality of ‘Bhagwa’ (a leading pomegranate cultivar of India) at both ambient and low

temperature (8 °C) conditions. The effect of these different modified atmospheres were correlated with all the quality attributes viz., fruit surface colour (Hunter L*, C*, H* values), peel thickness and moisture, physico-chemical, nutritional quality (TSS, acidity, sugars, vitamin C, anthocyanins, phenols, flavonoids and antioxidant capacity- FRAP and DPPH) and sensory parameters.

Materials and methods

Pomegranate (cv. ‘Bhagwa’) fruits were procured from a commercial orchard and transported carefully to the laboratory by packing them in CFB boxes with proper cushioning. Sound fruits of uniform size (300–350 g) and appearance were randomly distributed into different lots. The fruits were not washed or subjected to any postharvest chemical/fungicide treatment.

MA packaging

Pomegranates were packed in four semi permeable films having different gas permeabilities: (1) D-955 (a multi layered electronically cross-linked polyolefin film), (2) BDF-2001 (a multi-layered co-extruded polyolefin film), (3) RD-106 (a multilayered, cross-linked, antifog polyolefin film), all procured from Cryovac, Sealed Air Corporation, Duncan, S.C 29,334 (4) locally available LDPE film. The oxygen transmission rates (cc/m² day atm) of these films respectively were 6447, 4.8, 11,500, 7800; carbon dioxide transmission rates (cc/m² day atm) were 27,876, 19.2, 30,000, 42,000 and water vapour transmission rates (WVTR, g/m² day) were 10, 8.3, 35 and 23. Twelve fruits weighing approximately 4 kg were packed in 30 × 40 cm size bags of above films and heat sealed. The MA packed and non-packed pomegranates were master packed in 5 ply CFB boxes of 40 × 30 × 10 cm size and stored at ambient temperature (AT) (25–30 °C and 60–70% RH) and low temperature (LT) of 8 °C (80–85% RH). This low temperature was selected based on our previous published results on storage studies of three commercial cultivars of pomegranate (‘Ganesh’, ‘Bhagwa’ and ‘Mridula’) using shrink wrapping technology (Nanda et al. 2001; Sudhakar Rao 2018). Each treatment was replicated 6 times at ambient temperature and 12 times at LT.

Measurement of in-pack gas composition

Gas composition (% O₂ and CO₂) inside the MA packs was monitored at regular intervals throughout the storage period using a gas analyzer (CheckMate 3 Headspace Analyser, Dansensor, Denmark). The probe of the instrument

was pierced through a silicone septum glued to the film and in-pack gas composition was recorded.

Physiological loss in weight (PLW%)

Five individual fruits per replication from each pack were numbered and weights recorded at specified intervals over 1 month at ambient temperature and 4 months at 8 °C, and the cumulative losses in weight were calculated as percentages of initial weights.

Quality attributes

Three packs from each treatment were opened after 3 and 4 weeks storage at ambient temperature and after 2, 3 and 4 months storage at 8 °C. Two fruits per pack were selected at random from each treatment and evaluated for the following quality parameters. However, the data of some quality attributes were presented for relevant storage intervals only.

Fruit surface colour

Surface colour was measured using a color Reader, CR-10 (Minolta Co., Ltd, Osaka, Japan) having a measuring area of 8 mm diameter. Three measurements were taken at three equidistant points on the equatorial region of each individual fruit and the values were expressed in terms of L* (lightness), C* (chroma) and H* (hue) values.

Peel thickness and peel moisture content

After hand peeling, arils and rind were separated. The peel thickness was measured using a vernier caliper and peel moisture by standard oven dry method.

Nutritional quality

Juice was extracted manually by squeezing the arils and utilized for analyzing total soluble solids, total titratable acidity, vitamin C and sugars (only reducing sugars were estimated as non-reducing sugars were found to be negligible in pomegranate) using standard methods of analysis (AOAC 1995). A hand refractometer (Erma Inc., Tokyo, Japan) was used for measuring the TSS and values were corrected to 20 °C. Total phenols, flavonoids, anthocyanins, antioxidant capacity (FRAP) and DPPH radical scavenging abilities were estimated using the methods as described by Shivashankara et al. (2010). Total phenols were expressed as mg of gallic acid equivalents, flavonoids as mg of catechin equivalents, anthocyanin as mg cyanidin equivalents, FRAP and DPPH as mg of ascorbic acid equivalent antioxidant capacity (AEAC).

Sensory quality and spoilage

Fruit appearance/freshness, aril colour, aril texture/juiciness and taste were evaluated by a panel of 15 judges after 3 weeks at ambient temperature and 3 months at 8 °C. Evaluation was done on a scale of 1–5, where 5 = very good (like very much with harvest freshness, bright red juicy arils and without any off flavour) and 1 = very bad (dislike completely with desiccated fruits of brown tough peel, brown colour arils with low juiciness). Scores of 3 (like moderately with retention of fruit freshness, colour and juiciness of arils) and above were considered acceptable for commercial purpose. The number of fruits showing visual spoilage symptoms was recorded regularly and the incidence was determined as percentage of fruit affected.

Statistical analysis

The observations recorded under each parameter were statistically analyzed using completely randomized design. The data were analyzed by ANOVA and the significance among treatment mean values was determined by least significant difference (LSD) at the $P \geq 0.05$ level.

Results and discussion

In-pack gas composition

Irrespective of storage temperature and film used, a decrease in O₂ and an increase in CO₂ levels occurred inside MA packages. But the O₂ and CO₂ levels created inside the MA pack differed significantly with the type of film used (Fig. 1). Similar trends of decrease in O₂ and increase in CO₂ levels during storage of MA packed pomegranates were reported earlier (Artés et al. 2000; Selcuk and Erkan 2014, 2015, 2016). At both temperatures, CO₂ generated inside the BDF film was very high (> 70%) and O₂ decreased to very low levels (about 1% or less). On the other hand CO₂ concentration developed inside the RD-106 film was very low (< 4% at AT and < 2% at LT) and O₂ levels were very high (around 18–20%). Whereas in LDPE pack, the CO₂ concentration created inside was 6–8% at AT and around 4% at LT and O₂ levels maintained were moderately high (8–10%) at AT and very high (17–18%) at LT. Similarly CO₂ levels created inside the D-955 packs were 9–11% at ambient temperature and 7–9% at LT and O₂ levels at both AT (3–5%) and LT (5–8%) were moderately low. Significant variations observed in gas composition with different MA packs were due to variation in film permeability characteristics as reported under materials and methods. The BDF film was extremely low permeable to both O₂ and CO₂ gases

Fig. 1 In-pack gas composition in different MA packs of pomegranate (cv. 'Bhagwa') during storage at **a** ambient temperature (25–30 °C and 60–70% RH) and **b** LT (8 °C and 80–85% RH). Error bars represent $\pm$ SE

resulting in continuous dropping of O₂ concentration due to fruit respiration and severe accumulation of CO₂ inside the pack whether stored at AT or LT. Similarly, D-955 film which is less permeable to O₂ and CO₂ gases than RD-106 and LDPE film maintained significantly lower O₂ and higher CO₂ at both AT and LT storage. Singh and Sudhakar Rao (2005) also observed significant variations in in-pack O₂ and CO₂ levels during storage of papaya at 7 and 13 °C packed in more permeable Pebax C[®] followed by LDPE and less permeable PP film. The in-pack O₂ levels during 120 days storage of 'Beynari' pomegranates were also reported to be significantly different when packed in two different MA films of Xtend[®] film (17.60 kPa) and ZOEPAC film (12 kPa) mainly due to the differences in their gas permeabilities (Selcuk and Erkan 2016).

Physiological loss in weight

MA packaging significantly reduced the PLW (%) at both storage temperatures irrespective of the film used. At ambient temperature, MA packed fruits had < 2% PLW even after 1 month, compared to > 20% in case of non-packed pomegranates (Fig. 2). Similar trend was observed at LT, where PLW of MA packed pomegranates was < 1% even after 4 months compared to 23.5% in non-packed fruits. Among films used, PLW was slightly higher in RD-106 film packed fruits compared to those packed in other films at both temperatures. Minimum PLW (%) was also observed in 'Bhagwa' cultivar during storage at 4 ± 1 °C when the fruits were packed in PP bags (Kumar et al. 2013). Though pomegranate peel looks thick and tough, it has numerous minute openings (Elyatem and Kader 1984)

Fig. 2 Effect of MA packaging on the PLW (%) of pomegranates (cv. 'Bhagwa') during storage at **a** ambient temperature (25–30 °C and 60–70% RH) **b** low temperature (8 °C and 80–85% RH). Error bars represent $\pm$ SE

which permit free water vapour movement making non-packed fruits more susceptible to water loss. The effect of MAP in reducing PLW is due to the restriction of water vapor diffusion by the semi permeable films and in turn, generating a water vapour pressure and higher RH inside the package. This effectively reduced the transpiration rate of pomegranates, thereby significantly reducing the PLW. Reduction in PLW by MA packaging has also been reported in other pomegranate cultivars (Artés et al. 2000; Porat et al. 2009; D'Aquino et al. 2010; Selcuk and Erkan 2014, 2015). Lower weight loss in MA packed fruits was also reflected by a lower loss in rind thickness and rind moisture content (Table 1) of packed fruits as compared to non-packed fruits at both storage temperatures. The difference in prevention of weight loss by different MA packs is attributed to the differences in WVTR of the films used. Singh and Sudhakar Rao (2005) in papaya, Sudhakar Rao et al. (2000) in cucumber, Sudhakar Rao and Shivasankar (2015) in mango and Nanda et al. (2001) in 'Ganesh', Selcuk and Erkan (2014) in 'Hicrannar', Selcuk and Erkan (2015) in 'Hicaznar' cultivars of pomegranates also recorded differences in PLW when packed in different semi-permeable polymeric films.

Effect of MA packaging on quality attributes

Fruit surface colour

Peel colour is an important visual quality attribute for marketing of pomegranate fruits. At harvest, the Hunter L^* value (indicates brightness) of the fruit was 48.41 and the hue angle and chroma values were 27.39 and 49.43 respectively. Irrespective of film used, MA packaging had significant effect in maintaining the brightness (L^* values) of fruits at both temperatures compared to non-packed ones which became dull in appearance as indicated by lower L^* values (Table 1). This higher loss of peel brightness in non-packed fruits could be related to the higher dehydration of the fruit as also observed by Selcuk and Erkan (2015) in 'Hicrannar' pomegranate.

At ambient temperature after 3 weeks, fruits packed in D-955 film had significantly higher L^* values (quite similar to harvest values) whereas those packed in BDF film (which is > 1000 times low permeable to oxygen and carbon dioxide) had significantly lower L^* values. Beyond 3 weeks there was a decline in the L^* values of MA packed fruits irrespective of the film used. In non-packed pomegranates, there was a significant decrease in the h° value indicating reddening of peel colour during storage that could be attributed to the concentration of colour due to more (> 50%) peel moisture loss (Table 1). The lowest hue angle recorded in control fruits of 'Mridula' cultivar compared to wax treated fruits after 60 days of storage

resulted in deep tan red colour with dull shining (Barman et al., 2011). In MA packed fruits (except BDF film) original red peel colour was retained to a greater extent with slight increase in h° values and slight decrease in C^* values after 3 weeks storage. Peel colour was maintained better (h° and C^* values nearest to initial) in D-955 packed fruits followed by LDPE and RD-106 film packed ones. Similar retarding effects of high CO_2 and low O_2 levels (CA storage) on pomegranate skin colour loss have been reported by Kupper et al. (1995) and Holcroft et al. (1998). Beyond 3 weeks, hue angles slightly increased even in MA packed fruits indicating slight fading of red colour. Higher fading of peel colour was observed in BDF film packed fruits with higher h° value and lower C^* values. This could be attributed to very high levels of CO_2 and very low levels of O_2 maintained in these packs (Fig. 1) which caused some peel discolouration.

At 8 °C also, MA packaging had significant effect in maintaining the brightness (L^* values) during 4 months storage compared to non-packed fruits that became dull in appearance as indicated by lower L^* values (Table 1). Selcuk and Erkan (2014, 2015) also reported significantly higher L^* values for MA packed pomegranates (cvs. 'Hicrannar' and 'Hicaznar') compared to control stored at 6 °C. There was a significant decrease in the h° values of non-packed pomegranates at 8 °C also beyond 2 months indicating slight reddening of peel colour attributed to more (> 30%) peel moisture loss resulting in concentration of peel colour. In contrast, a decrease in peel redness during conventional air storage has been previously reported in other pomegranate cultivars (Elyatem and Kader 1984; Gil et al. 1995; Kupper et al. 1995; Palou et al. 2007) at other storage temperatures. At 8 °C, the original red peel colour was retained to a maximum extent in MA packed fruits with a slight increase in h° values till 3 months. Significantly lower changes in peel color (L^* , C^* and h°) values of pomegranates stored under MAP conditions than control fruits were also reported in other cultivars by Selcuk and Erkan (2014, 2015). This was mainly attributed to the high RH within the MA packages and higher weight loss in non-packed fruits. There were no significant differences in h° and C^* values of fruits packed in different films except BDF film which exhibited a slight fading of peel colour with higher h° and lower C^* values. The capability of MA packaging in retarding the physico-chemical changes in fruit tissue depends upon the extent of atmospheric modification in or around the fruit. The negative effects are in fact related to very high CO_2 and very low O_2 levels inside the BDF package, which were not optimum for these fruits.

Table 1 Effect of MA packaging on the surface colour, peel thickness and peel moisture content of pomegranate during storage at ambient and low temperature

Storage temp./film type	Ambient temperature (25–30 °C and 60–70% RH)								At 8 °C (80–85% RH)																
	L value		Hue angel		Chroma value		Peel thickness (mm)		Peel moisture (%)		L value		Hue angel		Chroma value		Peel thickness (mm)		Peel moisture (%)						
	3 W	4 W	3 W	4 W	3 W	4 W	3 W	4 W	3 W	4 W	2 M	3 M	4 M	2 M	3 M	4 M	2 M	3 M	4 M	2 M	3 M	4 M			
D-955	46.8	44.3	27.9	31.1	49.8	49.5	3.5	3.50	77.0	75.1	45.5	45.3	42.3	27.8	28.1	32.4	54.2	54.6	52.0	3.6	3.5	3.3	78.5	78.0	77.8
BDFF	41.9	40.9	34.2	34.4	46.1	46.8	3.5	3.47	77.7	77.2	43.7	45.1	40.0	32.3	34.9	36.5	48.2	42.4	53.8	3.6	3.5	3.4	79.2	77.9	77.5
LDPE	44.1	42.6	29.6	31.1	49.2	49.5	3.4	3.47	76.5	74.9	44.5	45.3	41.9	27.9	28.1	35.5	55.1	55.1	50.8	3.5	3.4	3.3	77.9	77.3	76.2
RRD-106	45.7	44.6	29.7	33.3	49.6	49.6	3.3	3.08	75.6	74.1	45.1	44.9	44.4	28.6	29.0	32.6	55.8	53.3	51.8	3.4	3.2	3.1	77.6	75.0	74.4
Control	36.7	35.7	21.5	19.7	40.4	39.3	2.2	2.04	36.8	25.8	42.9	37.6	34.5	28.3	23.1	21.9	52.3	47.5	41.6	2.1	1.8	1.4	57.9	53.1	45.0
Initial	48.4		27.4		49.4		3.5		78.4		48.4			27.4			49.4			3.6			78.4		
CDD 5%	2.2	2.1	1.6	1.34	1.5	1.08	0.3	0.37	1.21	1.40	1.8	1.3	1.8	1.4	1.2	0.8	1.4	1.5	1.3	0.19	0.1	0.1	1.03	1.29	1.35

W weeks, M months

Peel thickness

A significant decrease in peel thickness of non-packed fruits compared to MA packed fruits was observed at both storage temperatures (Table 1). Peel thickness in non-packed fruits decreased from the initial value of 3.55 to 2.20 and 2.09 mm by the end of 3 weeks and 3 months at ambient and low temperature storage respectively. MA packaging maintained peel thickness effectively and peel thickness in packed fruits decreased very marginally (by < 0.1 mm) after 3 weeks at ambient or 3 months at 8 °C. At ambient temperature, there was no significant difference in peel thickness of fruits packed with different films whereas at 8 °C peel thickness maintained significantly better when packed in D-955, BDF and LDPE films compared to RD-106 film. Pomegranates lose moisture mainly from peel leading to loss in rind weight and decrease in its thickness. Due to maintenance of high humidity, MA packed fruits had significantly less moisture loss from the peel (Table 1) compared to non-packed fruits, thus maintaining the peel thickness and freshness. Shrink wrapped fruits of ‘Ganesh’ (Nanda et al. 2001), Mridula and Bhagwa (Sudhakar Rao 2018) cultivars of pomegranates were also reported to lose significantly less rind weight and rind moisture compared to non-packed fruits.

Peel moisture

Maintenance of peel turgidity in pomegranate is very important for retention of not only freshness but also protecting and giving cushioning effect to the arils inside. Moisture loss from peel not only results in difficulty of peeling but also causes crushing of arils just below it leading to softening and browning in due course. Irrespective of the film used, MA packaging maintained peel moisture content significantly much higher than non-packed fruits at both temperatures (Table 2). By the end of 3 weeks at ambient temperature, non-packed fruits lost more than 50% of their initial peel moisture whereas MA packed (D-955, BDF and LDPE) fruits lost $< 2\%$. Fruits packed in RD-106 showed slightly higher peel moisture loss of 3.0% during similar period. Peel moisture loss increased as the duration of storage increased to 4 weeks in all treatments except in BDF film which had lowest WVTR. At 8 °C also, MA packed (D-955, BDF and LDPE) fruits lost $< 1\%$ peel moisture compared to 25% loss in non-packed fruits after 3 months. Peel moisture was retained better in these packs even when storage was prolonged to 4 months. At 8 °C also, fruits packed in RD-106 showed slightly higher peel moisture loss compared to other films which is attributed to its high WVTR compared to other films. Significant retention of rind moisture when semi permeable films were used for shrink wrapping of

pomegranates cv. ‘Ganesh’ was also reported by Nanda et al. (2001), during storage at 25, 8 °C and 15 °C.

Juice quality attributes

At ambient temperature after 3 weeks, a slight but non-significant decrease in TSS (%) was observed in MA packed fruits except in BDF film where significant decrease in TSS was observed. TSS decreased further when storage increased to 4 weeks in all MA packs (Table 2). The higher loss in fruits packed in BDF film is attributed to very high CO₂ and very low O₂ levels maintained in these packs (Fig. 1) that might have caused anaerobic fermentation. This was also reflected by decreased levels of sugars in the fruits packed in this film during storage (Table 2). Similar trend was also observed in the fruits stored at 8 °C beyond 3 months. Koksai (1989) in ‘Gok Bahce’ cultivar of pomegranate reported concentration of soluble solids in non-packed fruits attributed to the higher moisture loss during storage. However, in our study, there was no significant increase in TSS (%) of non-packed fruits stored at both temperatures (Tables 2 and 3) though higher weight loss was observed in these fruits. This is due to the fact that the moisture loss recorded during storage was mainly from the rind and not from the arils and hence no increase in TSS due to concentration. Nanda et al. (2001) also made similar observation and did not observe any increase in TSS during storage of ‘Ganesh’ cultivar at 8, 15 or 25 °C.

The acidity of non-packed pomegranates decreased during storage at both temperatures. But, till 3 weeks at ambient and 3 months at 8 °C, acidity was maintained well in all MA packed fruits except BDF film packed fruits where a significant increase in acidity was observed (Tables 2, 3). However, beyond this period the acidity decreased at both temperatures even in MA packed fruits other than BDF film, where a further increase in acidity was recorded. Pomegranate is a non-climacteric fruit and loss in acid occurred with ongoing metabolism, in agreement with that observed in ‘Wonderful’ (Mphahlele et al. 2016), ‘Mollar’ (Artés et al. 1998, 2000) and ‘Hicrannar’ (Selcuk and Erkan 2014) pomegranate cultivars. Less acidity reduction in MA packed fruits could be due to reduction of respiration compared to non-packed fruits. Higher levels of acidity in fruits packed in BDF-film indicates occurrence of some anaerobic respiration as anaerobic atmospheres were generated in this film (Fig. 1). This was also reflected by poor taste score for the fruits packed in this film (Table 4). Pomegranate was found to be highly sensitive to low-oxygen atmospheres which had a detrimental effect on fruit quality owing to greater accumulation of fermentative volatiles (Defilippi et al. 2006).

Table 2 Effect of MA packaging on the quality of pomegranate during storage at ambient temperature (25–30 °C and 60–70% RH)

Storage temp./film type	TSS (%)		Acidity (%)		Sugars (%)		Vitamin C	FRAP	DPPH	Total phenols		Total flavonoids		Anthocyanins	
	3 weeks	4 weeks	3 weeks	4 weeks	3 weeks	4 weeks	3 weeks	3 weeks	3 weeks	3 weeks	3 weeks	3 weeks	3 weeks	3 weeks	3 weeks
D-955	16.20	15.50	0.62	0.58	13.91	12.73	11.07	221.10	569.62	156.34	11.51	74.97			
BDF	14.93	14.60	0.73	0.90	12.10	11.34	11.67	232.81	527.15	153.51	11.06	76.16			
LDPE	16.00	15.75	0.64	0.57	13.60	12.54	11.34	227.71	592.38	163.06	11.08	79.08			
RD-106	16.00	15.85	0.63	0.58	13.25	11.96	11.50	202.89	528.24	144.15	12.23	74.84			
Control	16.60	16.53	0.59	0.54	14.21	12.90	7.71	198.68	459.81	142.3	9.75	65.49			
Initial	16.47		0.65		14.59		12.00	243.53	835.20	142.71	13.64	73.23			
CD 5%	0.70	0.45	0.05	0.10	0.84	0.79	0.53	11.5	51.45	8.14	0.73	10.62			

Vitamin C, mg/100 g; FRAP, mg AEAC/100 g; DPPH, mg AEAC/100 g; total phenols, mg/100 g; total flavonoids, mg/100 g; anthocyanin, mg cyanidin equivalents/100 g

Table 3 Effect of MA packaging on the quality of pomegranate during storage at low temperature (8 °C and 80–85% RH)

Storage temp./film type	TSS (%)			Acidity (%)			Sugars (%)			Vitamin C			FRAP			DPPH			Total phenols			Total flavonoids			Anthocyanins		
	2 M	3 M	4 M	2 M	3 M	4 M	2 M	3 M	4 M	2 M	3 M	4 M	2 M	3 M	4 M	2 M	3 M	4 M	2 M	3 M	4 M	2 M	3 M	4 M	2 M	3 M	4 M
D-955	16.3	15.9	15.1	0.62	0.59	0.58	13.7	12.9	12.4	9.7	9.9	7.8	228	287	271	561	668	1006	203	192	181	15.8	12.9	12.7	111	113	86
BDF	15.9	15.5	14.5	0.66	0.70	0.79	12.3	11.7	11.1	9.5	8.8	3.8	216	271	273	491	676	1159	190	190	191	13.0	13.8	15.5	93	102	77
LDPE	16.3	15.9	14.4	0.60	0.61	0.54	13.7	12.7	12.2	8.6	9.9	5.1	238	298	275	501	699	1216	199	195	186	14.0	12.6	13.4	116	103	72
RD-106	15.9	15.6	14.3	0.66	0.57	0.51	13.0	12.5	12.1	8.9	8.3	6.4	231	279	271	419	669	1056	195	192	192	14.3	10.5	14.8	111	109	86
Control	16.0	16.3	15.3	0.59	0.60	0.51	12.9	13.5	12.6	11.6	9.5	6.1	255	283	274	549	713	1034	208	197	191	12.9	13.1	13.2	122	126	96
Initial	16.5			0.65			14.6			12.0			243			835			143			13.6			73		
CD 5%	0.4	0.7	0.3	0.06	0.04	0.05	0.7	0.7	0.4	1.4	2.4	0.9	12	5	13	65	46	113	9	10	8	1.1	0.8	1.9	8	5.5	14

Vitamin C, mg/100 g; FRAP, mg AEAC/100 g; DPPH, mg AEAC/100 g; total phenols, mg/100 g; total flavonoids, mg/100 g; anthocyanin, mg cyanidin equivalents/100 g

Table 4 Effect of MA packaging on spoilage incidence and sensory quality of pomegranate during storage at ambient and low temperatures

Storage temp./film type	Spoilage (%)			Sensory score (out of 5.0)									
				3 weeks at ambient temperature					3 months at 8 °C (80–85% RH)				
	Ambient temperature			At 8 °C					Appearance				
	3 weeks	4 weeks	3 months	2 months	3 months	2 months	3 months	3 months	Aril colour	Aril texture	Taste	overall	overall
D-955	5.56	16.67	0.00	0.00	2.78	4.3	4.15	4.03	4.15	4.03	4.13	4.39	4.16
BDF	16.67	50.0	0.00	0.00	0.00	3.06	2.72	2.9	2.72	2.49	2.79	3.33	3.14
LDPE	8.33	20.83	2.78	2.78	9.72	4.17	4.1	3.96	4.1	3.94	4.04	4.2	4.03
RD-106	11.11	22.99	4.17	4.17	15.28	4.04	4	3.9	4	3.87	3.95	3.91	3.84
Control	8.33	11.11	6.67	6.67	10.0	1.95	3.69	1.95	3.69	3.36	2.74	1.86	3.05
CD 5%	1.45	3.56	1.24	1.24	1.87	0.35	0.30	0.30	0.30	0.32	0.15	0.34	0.17

Pomegranates mainly contained reducing sugars with non-reducing sugars accounting for less than 0.5% (data not shown). It being a non-climacteric fruit with low respiration rate, recorded a slight decrease in sugar content during storage at both temperatures (Tables 2, 3). There were no significant differences in sugar content of non-packed and those packed with D-955 or LDPE film till 3 weeks at ambient and 3 months at 8 °C storage. However, sugar content of pomegranate packed with BDF-film was significantly low at both temperatures. This is ascribed to very low permeability of these films leading to anaerobic respiration consuming more sugars, that was also reflected by poor taste score during sensory evaluation (Table 4).

Anthocyanin, phenols, flavonoids and antioxidants

Even though pomegranates are non-climacteric fruits, anthocyanins are reported to increase after harvest (Gil et al. 1995; Holcroft et al. 1998) and also during storage (Selcuk and Erkan 2014, 2015). However, in the present study at ambient temperature storage, there was no significant increase in total anthocyanins for all treatments but total phenols increased significantly in MA packed fruits (D-955, LDPE and BDF) after 3 weeks (Table 2). Vitamin C, FRAP and total flavonoids decreased significantly in control fruits which were maintained better in MA packed fruits irrespective of film used. Higher antioxidants content was due to better gas composition in the MA packages. At 8 °C, a significant increase in antioxidant parameters like FRAP, total anthocyanins and total phenols was recorded during 4 months storage (Table 3). Slight increase in total phenolics, total anthocyanins and antioxidant activity was also reported until the first 120 days of storage in MA packed ‘Hicaznar’ cultivar of pomegranates, and then decreased during the rest of the storage up to 180 days (Selcuk and Erkan 2015). A significant increase in total anthocyanins and certain flavonoids was also observed in MAP and shrink wrapped fruits during storage at low temperature for 4 months (Mphahlele et al. 2016). Among the films, LDPE and D-955 packed fruits recorded higher FRAP whereas total anthocyanins were higher in non-packed and D-955 packed fruits after 3 months at 8 °C. Film wrapping of fruits also maintained polyphenols, anthocyanins and antioxidants during low temperature storage of pomegranates (D’Aquino et al. 2010). Total anthocyanin contents of pomegranate arils first increased until 100 days of storage, and then decreased in all treatments, during cold storage at 6 °C which was attributed to the continued biosynthesis of phenolic compounds after harvest (Selcuk and Erkan 2014).

Sensory quality

At both storage temperatures, except in BDF film, fruits packed in other films registered significantly higher scores for all sensory parameters evaluated when compared to non-packed pomegranates (Table 4). Visual appearance was the most adversely affected sensory attribute during storage of non-packed pomegranates at both temperatures. Non-packed fruits became dull, desiccated and tough mainly due to high moisture loss as also reflected under PLW and peel moisture (Fig. 2 and Table 1). Visual appearance was also reported to be strongly affected by higher weight loss in control fruits making them unmarketable after 80 days of storage at 6 °C when compared to MA packed pomegranates (Selcuk and Erkan 2014). Water loss can cause undesirable textural and flavor changes resulting in loss of visual appeal even in the absence of shriveling (Artés et al. 2000). MA packed fruits especially those packed in D-955 and LDPE film were fresh with bright red peel colour and secured high appearance scores after 3 weeks at ambient and 3 months at 8 °C storage. Visual appearance was also reported to be maintained well in MA packed pomegranate fruits of ‘Bhagwa’ cultivar up to 90 days at 4 ± 1 °C (Kumar et al. 2013), individual shrink wrapped fruits of ‘Wonderful’ cultivar after 4 months at 7 ± 0.5 °C (Mphahlele et al. 2016) and ‘Ganesh’ cultivar after 12 weeks at 8 °C (Nanda et al. 2001) compared to non wrapped fruits. MA packed fruits (D-955, LDPE or RD-106) stored at both temperatures also got better scores for aril colour, aril texture and taste. Better scores obtained for above treatments could be attributed to better quality retention in terms of surface colour, peel moisture, TSS, acidity and sugars as discussed earlier. However, the same ‘Bhagwa’ cultivar when stored at 4 ± 1 °C recorded better overall organoleptic scores for up to 60 days only with the best MA pack of StePac, Xtend® film (Kumar et al. 2013). In the present investigation, in case of BDF-film packed fruits, fading of peel colour and poor taste were observed at both storage temperatures. These adverse peel colour and taste attributes were also reflected by the measured surface colour values of lower L*, C* values and higher h° (Table 1); and high acidity and low sugar contents (Tables 2, 3). The negative effects are apparently related to very high levels of CO₂ and very low levels of O₂ maintained (Fig. 1) in these packs as compared to other films. From the literature, it is also evident that pomegranate is highly sensitive to low-oxygen which had detrimental effect on fruit quality (cv. ‘Wonderful’) owing to greater accumulation of fermentative volatiles (acetaldehyde, ethanol and ethyl acetate) in the fruits stored in 1 kPa O₂ than those stored in 5 kPa O₂ (Defilippi et al. 2006).

Spoilage (%)

Irrespective of the packaging treatment, spoilage observed at ambient temperature was higher than that at 8 °C. After 3 weeks at ambient temperature, spoilage was significantly low in D-955 packed fruits (5.56%) compared to all other packages (Table 4). This could be due to the optimum gas levels maintained in this film that were not conducive/congenial for the growth of spoilage organisms. However, as the storage duration increased to 4 weeks, significant increase in spoilage was observed in all MA packages that was even more than non-packed fruits. High temperature coupled with higher humidity levels, leading to more moisture condensation could be responsible for this high spoilage by fungi (*Aspergillus niger*, *Penicillium* spp. and *Alternaria* spp.) with increase in storage duration. Similar increased moisture condensation in PP bags compared to more permeable (higher WVTR) Xtend® film resulted in higher spoilage of ‘Bhagwa’ pomegranates stored at 4 ± 1 °C especially with increased storage duration (Kumar et al. 2013). Though RD-106 is an anti-fog film, the spoilage could not be controlled as free water droplet formation by vapour condensation also occurred in this film after certain storage duration. High humidity coupled with gas stress could be responsible for causing more rotting (16.67%) in BDF film packages.

At 8 °C, until 2 months of storage spoilage was negligible (< 4%) irrespective of the package used. After 3 months, spoilage was least in BDF (nil) and D-955 packed fruits (2.78%) compared to other packages. Spoilage in LDPE packed fruits was on par with non-packed fruits (about 10%) and it was slightly more in RD-106 film (15.3%). Selcuk and Erkan (2015) also observed similar decay % of 8.33 in both MAP and control pomegranate fruit (cv. ‘Hicaznar’) at the end of 210 days storage at 6 °C. D’Aquino et al. (2010) found no significant differences in decay percentage between packed and control pomegranates (cv Primosole) after 6 and 12 weeks of cold storage. Low temperature coupled with in-pack gas composition (5–8% O₂ and 7–9% CO₂) might be the reasons for less spoilage in D-955 packed fruits. Incidence of rotten pomegranates was also reported to be significantly reduced by exposure to 2–5 kPa CO₂ at 5, 7.5, or 10 °C (Hess-Pierce and Kader 2003). Moreover, Palou et al. (2007) found a clear inhibition of fungal growth on naturally infected ‘Wonderful’ pomegranates exposed to 5 kPa O₂ and 15 kPa CO₂ at 8.9 °C.

Conclusion

MA packaging of pomegranate fruits (cv. ‘Bhagwa’) with different semi-permeable films significantly reduced weight loss and maintained the quality both at ambient

(25–30 °C and 60–70% RH) and low temperature (8 °C and 80–85% RH) storage conditions. MA packaging with D-955 and LDPE films maintained the visual, nutritional and sensory quality of pomegranates for 3 weeks at ambient temperature and 3 months at 8 °C. Equal storage life of 90 days was also reported earlier by Kumar et al. (2013) in the same cultivar but at lower temperature of 4 ± 1 °C. But having information on cold storage behaviour of similar cultivar but at different low temperatures gives the choice for entrepreneurs/exporters to select the cold storage temperature based on the availability and feasibility. Further, if the same maximum storage life is achieved using different MA packaging films at higher temperature of 8 °C than at 2–4 °C studied by others, then that also helps in saving energy during cold storage. In our investigation, we also found that MA packaging of pomegranates with very low permeable film like BDF-2001 adversely affected the chemical and sensory attributes at both ambient and low temperature storage, though it was useful in reducing the weight loss and maintaining the peel thickness and moisture.

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