Individual shrink wrapping extends the storage life and maintains the quality of pomegranates (cvs. ‘Mridula’ and ‘Bhagwa’) at ambient and low temperature

D. V. Sudhakar Rao¹

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Abstract The present investigation was carried out to study the response of two commercial pomegranate cultivars to individual shrink wrapping in extending the storage life and quality maintenance. Pomegranate fruits (‘Mridula’ and ‘Bhagwa’) were individually shrink wrapped using three semi-permeable films (Cryovac® BDF-2001, D-955 and normal LDPE) and stored at ambient (25–32 °C and 49–67% RH) and low temperature (8 °C and 75–80% RH). Shrink wrapping greatly reduced weight loss in both cultivars irrespective of the film used and storage temperature. Weight loss in shrink wrapped (D-955 film) ‘Mridula’ and ‘Bhagwa’ after 1 month storage at ambient temperature was respectively 1.40 and 1.05%, when compared to 22.92 and 22.53% in non-wrapped fruits. After 3 months at 8 °C, shrink wrapped ‘Mridula’ and ‘Bhagwa’ fruits lost only 0.43 and 0.68% weight respectively, compared to 17.23 and 21.67% in non-wrapped ones. Shrink wrapping significantly reduced the respiration rate at ambient temperature and the response varied with variety and film used. Shrink wrapped fruits of both cultivars retained the original peel colour (Hunter *h*_a and C* values) to a maximum extent during 3 months storage at 8 °C and shelf-life period at ambient temperature. Irrespective of variety and film, shrink wrapping maintained the peel

thickness and peel moisture content, significantly much higher than non-wrapped fruits at both temperatures. Compared to ‘Mridula’ cultivar, ‘Bhagwa’ responded well to shrink wrapping during prolonged storage at both temperatures with better maintenance of quality in terms of appearance, colour, juice content, TSS, acidity, sugars and sensory attributes. At ambient temperature, shrink wrapping with D-955 or LDPE film extended the storage life of ‘Mridula’ and ‘Bhagwa’ for 3 weeks and 1 month respectively, whereas at 8 °C both could be stored for 3 months with 3 days of shelf life.

Keywords Pomegranate varieties · Shrink wrapping · Storage temperature · Respiration · Weight loss · Rind and juice characters

Introduction

There has been a tremendous increase in trading of pomegranate (*Punica granatum* L.) in recent times, mainly due to the increased demand for health promoting effects of this fruit. Pomegranate, in spite of the low respiration rate (Ben-Arie et al. 1984) is a highly perishable fruit. The major post harvest problem is desiccation of the fruit resulting in a brownish coloured tough peel, and other quality losses occur during postharvest storage include decrease in firmness, aril colour, acidity and vitamin C (Artés et al. 1996). Although the peel appears to be thick, it has numerous minute openings that permit free movement of water vapour, making the fruit highly susceptible to water loss (Elyatem and Kader 1984). Shriveling symptoms are noticeable on fruit when weight loss exceeds 5% or more of the initial weight (Palou et al. 2007). Further, pomegranate is susceptible to chilling injury (CI) when

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✉ D. V. Sudhakar Rao
dvsrao@iitr.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

stored below 5 °C (Elyatem and Kader 1984) resulting in necrotic pitting and discoloration of the rind and paleness of arils. During the last decade, research activities on pomegranate fruit have been focused on the application of new postharvest storage technologies to extend the storage life and keeping the original quality of the freshly harvested fruit (Erkan and Kader 2011). Application of postharvest treatments such as optimum storage temperature, modified atmosphere packaging (MAP), controlled atmosphere (CA), shrink wrapping, heat treatment, coating and drying have been reported to affect the keeping and nutritional quality, as well as bioactive compounds of pomegranate (Artés et al. 2000a, b; Caleb et al. 2012; Meighani et al. 2015).

India produced about 2.44 million MT of pomegranate fruits during 2016–2017 (NHB) but could export only 0.05 million MT accounting for about 2% of total production (APEDA). Development of appropriate packaging and storage techniques for retaining the appearance and nutritional quality during long distance transport and prolonged storage will be helpful in its marketing and trade, both domestic and export. MAP has proven to be a successful means of reducing water loss, shrinkage, scald development and decay and can facilitate maintenance of fruit quality for 3 months or more after harvest of ‘Mollar de Elche’ (Artés et al. 2000a), ‘Shlefya’ (Ghafir et al. 2010), ‘Primsole’ (D’Aquino et al. 2010), ‘Mollar de Elche’ (Laribi et al. 2012) and ‘Hicannar’ (Selcuk and Erkan 2014) cultivars of pomegranates. Similarly, individual shrink wrapping was reported to extend the storability of ‘Ganesh’ cultivar of pomegranate to 12 weeks at 8 °C and 10 weeks at 15 °C and 3 weeks at ambient temperature with minimum weight loss (Nanda et al. 2001). However, the response of pomegranate to MAP differed with cultivars, i.e., ‘Hicannar’ cultivar could be stored up to 100 days by using MAP without decay or weight loss (Selcuk and Erkan 2014) whereas the same authors (Selcuk and Erkan 2015) could successfully store ‘Hicannar’ cultivar of pomegranates in marketable conditions up to 180 days by MAP without serious loss in weight or decay. Hence, the present investigation was carried out to study the response of two commercial red skin coloured and soft seeded cultivars of pomegranate (‘Mridula’ and ‘Bhagwa’) to individual shrink wrapping in extending the storage life and quality maintenance at both ambient and low temperature (8 °C).

Materials and methods

Two soft seeded varieties of pomegranate with dark red (cv. ‘Mridula’) and glossy red (cv. ‘Bhagwa’) rind colour were selected for the present investigation. Fruits were harvested

manually using sharp secateurs from a commercial orchard grown under standard horticultural practices and transported carefully to the institute by packing them in CFB boxes with proper cushioning. Diseased, bruised and injured fruit if any were rejected, and sound fruit of uniform size and appearance were randomly distributed into different lots. The fruits were neither washed nor given any postharvest chemical/fungicide treatment.

Individual shrink wrapping

Pomegranates were shrink wrapped individually using three 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), both procured from Cryovac, W. R. Grace and Co., Duncan, S.C and (3) locally available LDPE film. All were 25 µm thick and the oxygen transmission rates (cc/m² day atm) of these films respectively were 6447, 4.8, 7800; carbon dioxide transmission rates (cc/m² day atm) were 27,876, 19.2, 42,000 and water vapour transmission rates (WVTR, g/m² day) were 10, 8.3, and 23. The fruits were individually sealed in the above films using an L-bar sealer (Weldotron model 6300-L) and then heat-shrunk by passing them through a heat-shrink tunnel (Weldotron model 7121A, Weldotron Corporation, New Jersey) for 10–15 s at 150–170 °C. The shrink wrapped and non-wrapped pomegranates were master packed in CFB boxes (10 fruits per box and 6 replications per treatment) and stored at ambient temperature (25–32 °C and 49–67% RH) and at 8 °C (75–80% RH) in a walk-in-cold room.

Respiration rate

Six replicate single fruits were enclosed in airtight respiratory jars for ≤ 1 h after which a sample of headspace gas was drawn and injected into the gas chromatograph (Agilent 6890 Series) fitted with a Porapak Q column. CO₂ was detected using a thermal conductivity detector (TCD) with N₂ as the carrier gas (30 ml/min). Injector, oven and detector temperatures were set at 100, 100 and 110 °C respectively during above measurements (Sudhakar Rao and Gopalakrishna Rao 2008). As pomegranate is non-climacteric fruit with low respiration rates, the respiration rate of pomegranates was measured only at ambient conditions (25–32 °C and 49–67% RH) to see if shrink wrapping had any positive effect and expressed as mg CO₂/kg/h.

Weight loss

Weights of five individual fruit per replication from each packaging treatment (total 30 fruits per treatment) were recorded periodically over 1 month at ambient temperature and 3 months at 8 °C, and the cumulative losses in weight were calculated as percentages of initial weights.

Quality attributes

Two fruit per replication were selected at random from each treatment and evaluated for physical and chemical attributes after 3 weeks and 1 month in case of ambient temperature stored fruits and after 2 and 3 months in case of low temperature (LT) stored fruits. LT stored fruits for 3 months were also analyzed 3 days after shifting to ambient temperature (20–30 °C and 45–62% RH).

Fruit surface colour

The surface colour was measured using a color Reader, CR-10 (Minolta Co., Ltd, Osaka, Japan; measuring area of 8 mm with 8/d viewing geometry using CIE Standard illuminant D65). Three different measurements were taken at three equidistant points on the equatorial region of each individual fruit and the values are expressed in terms of L* (lightness), C* (chroma) and H* (hue) values. L* represents lightness of the color and ranges from 0 (black) to 100 (white). Hue is the actual colour of an object such as red, green, yellow, blue, etc. and a hue angle of 0° = red; 90° = yellow; 180° = bluish green; and 270° = blue. Chroma represents the purity/saturation of a colour, how pure or intense the hue is.

Peel thickness, peel moisture and juice content

The fruits were hand-peeled, the arils and rind separated and the peel thickness was measured using a vernier calipers and peel moisture by standard oven dry method. Arils were removed from the fruit and juice was extracted manually by squeezing the arils in a flexible polyethylene film bag so as to collect the entire juice. The juice recovery was expressed as percentage of fruit weight.

Chemical quality attributes

The juice extracted from arils as mentioned above was utilized for analyzing total soluble solids, total titratable acidity 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). TSS was measured using a hand refractometer (Erma Inc., Tokyo, Japan) and values were corrected to 20 °C.

Sensory quality

Fruit appearance/freshness, aril colour, aril texture/juiciness and taste was evaluated by a panel of ten judges after 3 weeks and 1 month storage at ambient temperature. At 8 °C, sensory evaluation was done once after 3 months storage and again after 3 days of shifting to ambient temperature. The 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 with brown tough peel, brown colour arils with low juiciness and becoming dry). Scores of 3 (like moderately with retention of fruit freshness, colour and juiciness of arils) and above were considered acceptable for commercial purpose.

Statistical analysis

The observations recorded under each parameter were statistically analyzed using two factorial design with varieties and film types as sources of variation, except for sensory evaluation where simple CRD was used (Sunder et al. 1972). 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

Respiration rate

The respiration rate of pomegranate fruits was relatively low even at ambient temperature and was lower for ‘Bhagwa’ and ‘Mridula’ cultivar during initial storage. Irrespective of the cultivar and film type the respiration rate declined with duration of storage (Fig. 1). It is known fact that pomegranate follows the non-climacteric respiration pattern with low respiration rate that decreases throughout the postharvest period. Nanda et al. (2001) also noted constant decline in respiration rate of ‘Ganesh’ cultivar of pomegranates during storage. Irrespective of the film, shrink wrapping significantly reduced the respiration rate in ‘Bhagwa’ cultivar (Fig. 1). Lower respiration rate of shrink wrapped fruits may be attributed to the lower gas exchange through the film and consequently lower availability of oxygen to the fruit tissue for respiration. The reduction in respiration observed in shrink wrapped ‘Ganesh’ cultivar of pomegranate was also attributed to low permeability of the films used for wrapping (Nanda et al. 2001). However, in the present study, in case of ‘Mridula’ cultivar, the fruits wrapped with BDF film (with very low gas permeability) had significantly higher

Fig. 1 Respiration rates of shrink wrapped and non-wrapped pomegranate fruits (cvs. 'Mridula' and 'Bhagwa') during 4 weeks storage at ambient temperature (25–32 °C and 49–67% RH). Error bars represent $\pm$ SE

respiration rate as compared to those wrapped with other films and even non-wrapped fruits. This indicates, the response of shrink film vary with cultivar even in low respiring non-climacteric fruits like pomegranate which could be due to difference in their respiration rate and other peel characters.

Weight loss

Shrink wrapping of pomegranates greatly reduced weight loss in both cultivars during storage at ambient and low temperatures irrespective of the film used. At ambient temperature, even after 1 month of storage the shrink wrapped fruits lost less than 2% weight compared to more than 20% in case of non-wrapped pomegranates. Among the films used, fruits wrapped in BDF film had least weight loss followed by D-955 film and the fruits wrapped in LDPE film had slightly (0.5–1.0%) higher weight loss (Fig. 2a) in both cultivars. At 8 °C also, shrink wrapping significantly reduced weight loss during 3 months of storage, irrespective of cultivar or film used for wrapping (Fig. 2b). After 3 months of storage at 8 °C, the shrink wrapped fruits lost about 1.0% weight when compared to 17–22% in non-wrapped ones. Here also the least weight loss was observed in fruits wrapped with BDF and D-955 films followed by those wrapped with LDPE film. Even 3 days after shifting to ambient temperature, the weight

loss was still less than 1% in BDF and D-955 film wrapped fruits and less than 2% in case of LDPE film wrapped fruits. Between two cultivars, non-wrapped 'Mridula' showed higher weight loss (21.7%) than non-wrapped 'Bhagwa' (17.2%) cultivar.

The apparently tough skin of pomegranates has numerous minute openings as reported by Elyatem and Kader (1984) which permit free water vapour movement making the non-wrapped fruits more susceptible to water loss. Shrink wrapping effectively reduced the transpiration rate of pomegranates due to the low WVTR of the films, thereby significantly reducing the weight loss. Reduction in weight loss by shrink wrapping has also been reported by Nanda et al. (2001) and Mphahlele et al. (2016) in pomegranate; Ladaniya et al. (1997) in 'Nagpur' mandarins; Miller et al. (1983) and Sudhakar Rao and Shivasankar (2015) in mango; Hale et al. (1986) in Florida grapefruit; Singh and Sudhakar Rao (2005) in papaya; Sudhakar Rao et al. (2000) and Dhall et al. (2012) in cucumber. The difference in prevention of weight loss by different films is attributed to the differences in their WVTR as mentioned earlier. Ladaniya et al. (1997) also recorded differences in weight loss of 'Nagpur' mandarin oranges shrink wrapped with different polymeric films of variable permeabilities. The lower weight loss in shrink wrapped fruits was also reflected by a lower loss in rind thickness and rind moisture content (Table 2) of wrapped fruit as compared to non-

Fig. 2 Effect of shrink wrapping on weight loss (%) of pomegranates (cvs. 'Mridula' and 'Bhagwa') during storage at **a** ambient temperature (25–32 °C and 49–67% RH); **b** low temperature (8 °C and 75–80% RH). Error bars represent $\pm$ SE

wrapped fruits at both the temperatures in both the cultivars.

Fruit surface colour

Red colour of the peel is an important visual quality factor for marketing of pomegranate. At harvest, the Hunter L^* value (that indicates brightness) of the fruit were 38.63 and 49.33 for 'Mridula' and 'Bhagwa' cultivars, respectively. Similarly, the surface colour hue angle and chroma values respectively were 21.48 and 50.56 for 'Mridula' and 26.19 and 58.74 for 'Bhagwa' cultivar. These colour values indicate, 'Bhagwa' cultivar had more bright red peel colour than 'Mridula' and the same trend continued during one month of storage at ambient temperature irrespective of the packaging. Shrink wrapping had significant effect in the retention of brightness (L^* values) of fruits in both cultivars

compared to non-wrapped ones which became dull in appearance as indicated by lower L^* values (Table 1).

Among different shrink films, fruits wrapped in D-955 and LDPE films had significantly higher L^* values in both cultivars after 4 weeks of storage at ambient temperature. Beyond three weeks of storage fruits wrapped in BDF film, which is extremely (> 1000 times) low permeable to both oxygen and carbon dioxide gases, had significantly lower L^* values. There was a significant decrease in the h_0 value of non-wrapped pomegranates of both cultivars during storage indicating reddening of peel colour. This could be attributed to the concentration of peel colour due to more moisture loss (as shown in Table 2a) from the peel of non-wrapped fruits. By the end of 4 weeks storage, the peel moisture was reduced to 24.76 and 23.32 in 'Mridula' and 'Bhagwa' cultivars, respectively from the initial content of 77.17 and 78.0%. The lowest hue angle recorded in control fruits of 'Mridula' cultivar when compared to wax treated fruits after 60 days of storage resulted in non-desirable deep tan red colour with dull shining (Barman et al. 2011). However the C^* values which represent the intensity of colour decreased significantly in these fruits. In shrink wrapped fruits the original red colour of the peel retained to a greater extent in both varieties with slight increase in h_0 values and slight decrease in C^* values during the 4 weeks of storage at ambient temperature. Among different shrink films, the peel colour was maintained better (lower h_0 value and higher C^* values) when the fruits were wrapped with D-955 or LDPE film. Beyond three weeks of storage, fading of red peel colour was observed in the fruits wrapped with BDF film in both cultivars, with higher h_0 value and lower C^* values. This could be attributed to its low gas permeability to carbon-dioxide that might have caused some discolouration of surface peel colour.

At 8 °C also, shrink wrapping had significant effect on the retention of brightness (L^* values) of fruits during 3 months storage in both cultivars compared to non-wrapped ones which became dull in appearance as indicated by lower L^* values (Table 1b). The same trend continued even after shifting to ambient temperature for 3 days. Selcuk and Erkan (2014, 2015) also reported significantly higher L^* values in the MA packed pomegranate (cvs. 'Hicaznar' and 'Hicrannar') fruits than those of control during cold storage and shelf-life period at 20 °C. However, there was no significant difference in L^* values of both cultivars of pomegranates shrink wrapped with different films either during 3 months of storage at 8 °C or shelf-life period at ambient temperature. As observed at ambient temperature, at 8 °C also there was a significant decrease in the h_0 value of non-wrapped pomegranates of both cultivars during 3 months of storage indicating reddening of peel colour. Even at 8 °C, by the end of 3 months storage, the peel moisture was reduced to 43.38 and 49.69

in ‘Mridula’ and ‘Bhagwa’ cultivars, respectively (Table 2b) from the initial content of 77.17 and 78.0%. This moisture loss to the concentration of peel colour of non-wrapped fruits resulting in lower h° value than the initial values. However the C^* values which represent the intensity of colour were decreased significantly in these fruits.

In shrink wrapped fruits the original red colour of the peel retained to a maximum extent in both varieties with a slight increase in h° values and a slight decrease in C^* values during 3 months storage at 8 °C and shelf-life period at ambient temperature. In both cultivars, there were no significant differences in h° and C^* values of fruits shrink wrapped with different films during 3 months of storage at 8 °C. However, during 3 days of shelf life at ambient temperature, a slight fading of red peel colour was observed in the fruits wrapped with BDF film with higher h° value and lower C^* values. The capability of shrink film wrapping to retard the physico-chemical changes in fruit tissue depends upon the extent of atmospheric modification in or around the fruit. The negative effects are apparently related to the composition of the modified atmosphere generated inside the BDF shrunk package when the fruits were shifted to higher temperatures, which is inappropriate for these fruit.

Peel thickness

There was a significant decrease in the peel thickness of non-wrapped fruits as compared to shrink wrapped fruits in both cultivars and at both storage temperatures (Table 2). In ‘Mridula’ cultivar, the peel thickness in non-wrapped fruits decreased from the initial value of 3.16 mm to 1.45 and 1.53 mm by the end of 3 weeks and 3 months at ambient and low temperature storage respectively. Similarly in case of ‘Bhagwa’ cultivar the peel thickness in non-wrapped fruits decreased from the initial value of 3.86 mm to 1.73 and 1.63 mm by the end of 3 weeks and 3 months at ambient and low temperature storage respectively. Irrespective of the cultivars and storage temperatures, shrink wrapping maintained the peel thickness effectively. The peel thickness in shrink wrapped fruits decreased only slightly (by < 0.2 mm) after 3 weeks of storage at ambient temperature or 3 months storage at 8 °C. In both cultivars, there were no significant differences in peel thickness of fruits shrink wrapped with different films during storage at ambient temperature or 8 °C. Pomegranates lose moisture mainly from the peel leading to loss in the rind weight and decrease in its thickness. Compared to non-wrapped fruits, shrink wrapped fruits had significantly less moisture loss from the peel (Table 2) thus maintaining the peel thickness and freshness. Wax coated and shrink wrapped fruits of pomegranates cv. ‘Ganesh’

Table 1 Effect of shrink wrapping on surface colour of pomegranate cultivars during storage

Film type	L* value						Hue angle value						Chroma value					
	3 weeks			4 weeks			3 weeks			4 weeks			3 weeks			4 weeks		
	M	B	T mean	M	B	T mean	M	B	T mean	M	B	T mean	M	B	T mean	M	B	T mean
<i>(a) at ambient temperature (25–32 °C and 49–67% RH)</i>																		
D-955	38.73	47.63	43.18	37.47	46.20	41.84	22.64	26.34	24.49	23.53	26.84	25.19	45.48	53.87	49.67	50.38	52.71	51.55
BDF	38.53	47.40	42.97	34.52	41.27	37.89	24.11	26.46	25.29	28.03	30.27	29.15	49.92	51.22	50.57	45.49	38.21	41.85
LDPE	38.35	47.43	42.89	37.37	45.87	41.62	23.51	28.77	26.14	24.12	28.17	26.15	50.05	55.54	52.80	48.56	52.20	50.38
Control	32.93	36.17	34.55	32.10	35.90	34.00	19.21	20.44	19.83	16.71	18.80	17.76	40.55	49.02	44.79	31.52	36.47	34.00
V mean	37.14	44.66		35.36	42.31		22.37	25.50		23.10	26.02		46.50	52.41		43.99	44.90	
Initial	38.63	49.33					21.48	26.19					50.56	58.74				
	CD 5%			CD 5%			CD 5%			CD 5%			CD 5%			CD 5%		
Variety (V)	1.59			1.82			1.64			1.34			1.45			1.08		
Treatment (T)	2.24			2.13			2.32			1.90			2.05			1.53		
VXT	3.17			3.63			3.29			2.68			2.90			2.16		

Table 1 continued

Film type	L* value			Hue angle value																
	2 months			3 months			3 months + 3 days			2 months			3 months			3 months + 3 days				
	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean		
(b) at low temperature (8 °C)	D-955	36.90	48.85	42.88	36.60	47.47	42.04	35.20	46.33	40.77	20.36	26.34	23.35	20.57	28.47	24.52	22.66	28.59	25.63	
	BBDF	38.30	46.83	42.57	37.58	46.93	42.26	36.67	45.37	41.02	21.39	25.59	23.49	21.00	28.97	24.99	25.69	36.81	31.25	
	LDPE	38.37	47.33	42.85	36.93	46.90	41.92	36.65	46.20	41.43	20.75	25.98	23.37	21.66	27.25	24.46	22.10	29.22	25.66	
	Control	33.70	39.18	36.44	32.33	36.30	34.32	28.73	34.87	31.80	16.96	24.03	20.50	15.42	22.12	18.77	13.33	22.28	17.81	
	V. Mean	36.82	45.55		35.86	44.40		34.31	43.19		19.87	25.49		19.66	26.70		20.95	29.23		
	Initial	38.63	49.33								21.48	26.19								
	Variety (V)			CD 5%			CD 5%			CD 5%			CD 5%			CD 5%			CD 5%	
	Treatment (T)			1.77			1.30			0.88			1.38			0.82			0.79	
	VXT			2.50			1.84			1.25			1.96			1.15			1.12	
				3.54			2.60			1.76			2.77			1.63			1.58	
Film type	Chroma value																			
	2 months																			
	M			B			T. Mean			M			B			T. Mean			3 months + 3 days	
(b) at low temperature (8 °C)	D-955	50.62	56.03	53.33	50.62	54.35	52.49	50.62	54.35	52.49	47.27	50.71	48.99							
	BBDF	47.33	55.40	51.37	46.73	53.29	50.01	46.73	53.29	50.01	45.03	48.36	46.70							
	LDPE	50.53	56.95	53.74	47.50	53.95	50.73	47.50	53.95	50.73	46.49	51.62	49.06							
	Control	39.88	50.88	45.38	35.37	43.89	39.63	35.37	43.89	39.63	24.14	37.66	30.90							
	V. Mean	47.09	54.82		45.06	51.37					40.73	47.09								
	Initial	50.56	58.74																	
	Variety (V)			CD 5%			CD 5%			CD 5%			CD 5%							
	Treatment (T)			0.77			0.73			0.73			1.28							
	VXT			1.39			1.53			1.53			1.61							
				1.54			1.45			1.45			2.56							
V. Mean variety mean, T. Mean treatment mean, M Mridula, B Bhagwa																				

lost significantly less rind weight and rind moisture compared to non-wrapped fruits (Nanda et al. 2001).

Peel moisture

Peel moisture is very important attribute for retention of not only freshness but also protecting and giving cushioning effect to the arils inside. Loss of moisture from peel not only results in difficulties in easy peeling but also causes crushing of aril just below it leading to softening and browning. Irrespective of the variety and film, shrink wrapping maintained the peel moisture content significantly much higher than non-wrapped fruits at both the storage temperatures (Table 2). By the end of 3 weeks at ambient temperature, non-wrapped fruits lost more than 50% of their initial peel moisture in both cultivars, whereas shrink wrapped fruits lost only about 1.5% peel moisture even after 4 weeks of storage. At 8 °C, shrink wrapped fruits (BDF and D-955) of both cultivars lost < 1% of their initial peel moisture as compared to about 30% loss in non-wrapped fruits after 3 months of storage. Among different films used, fruits wrapped with BDF maintained better peel moisture followed by D-955 film and those wrapped in LDPE film irrespective of the cultivar. Even 3 days after shifting to ambient temperature, shrink wrapped fruits especially those wrapped with BDF and D-955 films lost the peel moisture very less. Between two cultivars, non-wrapped ‘Mridula’ showed higher loss of peel moisture than non-wrapped ‘Bhagwa’ cultivar.

Pomegranates lose moisture after harvest mainly from the peel leading to desiccation. Prevention of the peel desiccation is highly desirable in pomegranate fruits as peeling of fruit will become highly cumbersome once peel becomes dry and tough. Shrink wrapping effectively avoided this problem attributed mainly to the low permeability of the shrink films to WVTR resulting in the least moisture loss from the rind. Shrink wrapped fruits of pomegranates cv. ‘Ganesh’ lost significantly less rind moisture compared to non-wrapped fruits (Nanda et al. 2001) at both 8 and 15 °C storage.

Juice content

During storage, irrespective of cultivar and temperature, there was an increase in the juice percentage (on fruit weight basis) of non-wrapped fruits (Table 2). The juice percentage in non-wrapped fruits of ‘Mridula’ cultivar increased from the initial value of 56.73% to 66.68 and 63.28% by the end of 4 weeks and 3 months at ambient and low temperature storage respectively. Similarly in case of ‘Bhagwa’ cultivar the juice percentage in non-wrapped fruits increased from the initial value of 48.66% to 62.8 and 60.31% by the end of 4 weeks and 3 months at

Table 2 Effect of shrink wrapping on peel thickness, peel moisture content and juice content of pomegranate cultivars during storage

Film type	Peel thickness (mm)						Peel moisture (%)						Juice content (%)					
	3 weeks			4 weeks			3 weeks			4 weeks			3 weeks			4 weeks		
	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean
<i>(a) at ambient temperature (25–32 °C and 49–67% RH)</i>																		
D-955	2.88	3.78	3.33	2.73	3.67	3.20	76.08	77.16	76.62	75.82	76.85	76.34	56.39	48.50	52.45	56.86	48.94	52.90
BDF	3.13	3.80	3.47	3.05	3.73	3.39	76.70	77.58	77.14	76.28	77.23	76.76	56.88	48.39	52.64	56.93	48.48	52.71
LDPE	2.90	3.73	3.32	2.67	3.57	3.12	75.78	77.10	76.44	74.89	76.25	75.57	57.09	47.88	52.49	57.29	49.28	53.29
Control	1.45	1.73	1.59	1.30	1.40	1.35	37.80	36.23	37.02	24.76	23.32	23.71	62.23	59.49	60.86	66.68	62.80	64.74
V. Mean	2.59	3.26		2.44	3.09		66.59	67.02		62.94	63.25		58.15	51.07		59.44	52.38	
Initial	3.16	3.86					77.17	78.00					56.73	48.66				
	CD 5%			CD 5%			CD 5%			CD 5%			CD 5%			CD 5%		
Variety (V)	0.28			0.18			1.21			0.99			1.02			0.71		
Treatment (T)	0.32			0.26			1.64			1.40			1.43			1.05		
VXT	0.43			0.37			2.15			1.98			1.71			1.54		

Table 2 continued

Film type	Peel thickness (mm)						Peel moisture (%)					
	2 months			3 months			2 months			3 months		
	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean
<i>(b) at low temperature (8 °C)</i>												
D-955	3.10	3.65	3.38	3.05	3.55	3.30	2.85	3.32	3.09	76.57	77.50	77.04
BDF	3.05	3.78	3.42	2.98	3.65	3.32	2.88	3.33	3.11	76.96	77.82	77.39
LDPE	3.07	3.75	3.41	2.92	3.50	3.21	2.70	3.28	2.99	76.37	76.80	76.59
Control	1.85	1.73	1.79	1.53	1.63	1.58	1.30	1.45	1.38	55.27	53.71	54.49
V. Mean	2.77	3.23		2.62	3.08		2.43	2.85		71.29	71.46	
Initial	3.16	3.86								77.17	78.00	
Variety (V)			CD 5%			CD 5%			CD 5%			CD 5%
Treatment (T)			0.19			0.14			0.13			NS
VXT			0.26			0.19			0.18			0.82
			0.37			0.27			0.25			1.29
												1.91
<i>(b) at low temperature (8 °C)</i>												
Film type	Juice content (%)						3 months					
	2 months			3 months			3 months			3 months + 3 days		
	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean
D-955	55.26	48.21	51.74	56.35	49.05	52.70	56.35	49.05	52.70	57.28	49.84	53.56
BDF	56.43	48.47	52.45	56.57	48.97	52.77	56.57	48.97	52.77	56.81	49.40	53.11
LDPE	55.99	48.57	52.28	57.02	49.12	53.07	57.02	49.12	53.07	57.99	50.82	54.41
Control	60.75	57.2	58.98	63.28	60.31	61.80	63.28	60.31	61.80	59.95	58.64	59.30
V. Mean	57.11	50.61		58.31	51.86		58.31	51.86		58.01	52.18	
Initial	56.73	48.66										
Variety (V)			CD 5%			CD 5%			CD 5%			CD 5%
Treatment (T)			0.43			0.49			0.49			0.57
VXT			0.56			0.71			0.71			0.82
			0.75			0.93			0.93			1.2
<i>V. Mean variety mean, T. Mean treatment mean, M Mridula, B Bhagwa</i>												

ambient and low temperature storage respectively. This proportionate increase in juice content probably reflects the greater losses in peel weight of non-wrapped fruits. Similar increases in juice percentage during storage of grapefruit (Purvis 1983) and ‘Ganesh’ cultivar of pomegranate (Nanda et al. 2001) were attributed to greater loss in their rind moisture/shrinkage. The shrink wrapped fruits in both cultivars and at both storage temperatures showed about the same juice percentage as in the freshly harvested fruits (Table 2). Film wrapping greatly reduced rind moisture loss resulting in retention of harvest freshness of the fruit in terms of peel weight and juice percentages. Shrink wrapped fruits of pomegranates cv. ‘Ganesh’ lost significantly less rind moisture compared to non-wrapped and wax coated fruits (Nanda et al. 2001) at all the three storage temperatures (25, 8 and 15 °C). Even 3 days after shifting to ambient temperature following 3 months LT storage, shrink wrapped fruits especially those wrapped with BDF and D-955 films maintained the initial juice content.

Juice quality attributes

As compared with values at harvest, a slight but non-significant increase in TSS (%) was found during storage of non-wrapped pomegranates of both cultivars at both storage temperatures (Table 3). This could be attributed to the higher moisture loss reported in these fruits leading to concentration of the soluble solids as also reported by Koksall (1989) in ‘Gok Bahce’ cultivar. However, Nanda et al. (2001) did not observe any increase in TSS during storage of ‘Ganesh’ cultivar at 8, 15 or 25 °C storage, as it was observed in their study that moisture loss during storage was mainly from the rind and not from the arils and hence no increase in TSS due to concentration. Irrespective of the variety and film, shrink wrapping maintained the initial TSS content at both storage temperature and there were no significant differences among different films in maintaining the TSS content.

There was a decrease in acidity of both cultivars of non-wrapped pomegranates at both storage temperatures but was maintained well in shrink wrapped fruits (Table 3). This could be due to higher rates of respiration recorded (Fig. 1) in non-wrapped fruit as compared to a reduced rate in wrapped fruits. As pomegranate is a non-climacteric fruit, loss in acid occurred with ongoing metabolism, in agreement with that observed in ‘Wonderful’ (Kader et al. 1984 and Mphahlele et al. 2016), ‘Mollar’ (Artés et al. 1998, 2000a) and ‘Hicrannar’ (Selcuk and Erkan 2014) cultivars of pomegranate. However among different films, fruits wrapped with BDF-film showed significantly higher levels of acidity indicating occurrence of some anaerobic respiration as this film is very low permeable to both

Table 3 Effect of shrink wrapping on TSS, acidity and sugar content of pomegranate cultivars during storage

Film type	TSS (%)			Acidity (%)			Sugars (%)		
	3 weeks			3 weeks			3 weeks		
	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean
<i>(a) at room temperature (25–32 °C and 49–67% RH)</i>									
D-955	15.00	15.30	15.15	14.87	15.10	14.99	13.32	13.83	13.58
BDF	15.00	15.23	15.12	15.00	15.07	15.04	12.39	12.36	12.38
LDPE	14.91	15.10	15.01	14.85	15.20	15.03	13.35	13.5	13.43
Control	15.22	15.63	15.43	15.60	15.93	15.77	13.6	14.2	13.90
V. Mean	15.03	15.32		15.08	15.33		13.17	13.47	
Initial	15.05	15.5					13.8	14.3	
Variety (V)	CD 5%			CD 5%			CD 5%		
Treatment (T)	NS			NS			NS		
VXT	NS			NS			NS		
	NS			NS			NS		
	NS			NS			NS		
	NS			NS			NS		
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Film type	TSS (%)			Acidity (%)															
	2 months			3 months			3 months + 3 days			2 months			3 months			3 months + 3 days			
	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean	
<i>(b) at low temperature (8 °C)</i>																			
Variety (V)	D-955	15.20	15.60	15.40	15.00	15.20	15.10	14.73	15.03	14.88	0.38	0.51	0.45	0.37	0.54	0.46	0.37	0.55	0.46
	BD5F	15.20	15.60	15.40	15.10	15.30	15.20	14.70	14.78	14.74	0.45	0.55	0.50	0.48	0.61	0.55	0.52	0.63	0.58
	LD5E	15.25	15.20	15.23	15.20	15.40	15.30	14.40	15.23	14.82	0.39	0.48	0.44	0.35	0.50	0.43	0.34	0.49	0.42
	Control	16.00	15.40	15.70	15.50	15.80	15.65	15.40	15.72	15.56	0.30	0.38	0.34	0.28	0.34	0.31	0.25	0.30	0.28
	V. Mean	15.41	15.45		15.20	15.43		14.81	15.19		0.38	0.48		0.37	0.50		0.37	0.49	
Initial	15.05	15.5	CD 5%			CD 5%				CD 5%	0.52	0.55				CD 5%			CD 5%
Treatment (T)	Variety (V)		NS				0.14			0.12						0.03			0.04
			NS				0.20			0.27						0.04			0.05
	VXT		0.41			NS				0.24						NS			NS
Film type	Sugars (%)																		
Variety (V)	2 months			3 months			3 months + 3 days			2 months			3 months			3 months + 3 days			
	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean	
	<i>(b) at low temperature (8 °C)</i>																		
	D-955	13.26		13.5		13.38	12.74		13.0		12.87			12.64		13.12			12.88
	BD5F	12.81		12.64		12.73	11.79		11.33		11.56			11.12		10.93			11.03
Treatment (T)	LD5E	13.0		13.65		13.33	12.6		13.02		12.81			12.72		12.96			12.84
	Control	12.86		12.53		12.70	12.25		12.14		12.20			12.45		12.32			12.36
	V. Mean	12.98		13.08			12.35		12.37				12.23		12.33				
	Initial	13.8		14.3															
Treatment (T)	Variety (V)					CD 5%				CD 5%									CD 5%
						NS				NS									NS
	VXT					0.28				0.25									0.27
						0.54				0.64									0.72
<i>V. Mean variety mean, T. Mean treatment mean, M Mridula, B Bhagwa</i>																			

oxygen and carbon dioxide gases as compared to other films. This was also reflected by poor score for taste sensory quality for the fruits wrapped 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).

Sugars present in pomegranates were comprised of mainly reducing with non-reducing sugars accounting for less than 0.5% (data not shown). Pomegranate, being a non-climacteric fruit with a low respiration rate, recorded a slight decrease in sugar content during storage at both storage temperatures (Table 3). In both cultivars, at ambient temperature, there were no significant differences in the sugar content of non-wrapped fruits and those wrapped with D-955 or LDPE film. At 8 °C, the sugar content of both cultivars was maintained slightly better in the fruits wrapped with D-955 and LDPE film compared to non-wrapped fruits. Similar trend was observed when the low temperature stored fruits were shifted to ambient temperature. However, the sugar content of both cultivars of pomegranate wrapped with BDF-film was significantly low at both storage temperatures. Though, there might be more loss in sugar content in non-wrapped fruits than wrapped fruits due to comparatively higher respiration rate in the former, the estimated total sugar content was still not very low as the sugars got concentrated in these fruits due to high moisture loss. The low sugar content in BDF-film wrapped fruits could be mainly due to very low permeability of these films leading to anaerobic respiration that was also reflected by poor taste score during sensory evaluation.

Sensory quality

Shrink wrapped fruits of both cultivars registered significantly higher scores for all the sensory parameters evaluated, viz., fruit appearance, aril colour, aril texture and taste attributes when compared to non-wrapped pomegranates (Table 4). The adversely affected sensory attribute during storage of non-wrapped pomegranates at both storage temperatures in both cultivars was fruit visual appearance. The non-wrapped fruits became dull, desiccated and tough mainly due to high moisture loss as also reflected under weight loss (Fig. 2). Visual appearance was also reported to be strongly affected by higher weight loss making the control fruits unmarketable after 80 days of storage at 6 °C when compared to MA packed pomegranates (Selcuk and Erkan 2014). Even in the absence of shriveling, water loss can cause undesirable textural and flavor changes, ultimately resulting in loss of visual appeal (Artés et al. 2000a). The shrink wrapped fruits especially those wrapped in D-955 and LDPE film were fresh with

Table 4 Effect of shrink wrapping on sensory quality of pomegranate cultivars during storage

Film type	Appearance					Aril colour					Aril texture					Taste								
	3 weeks		4 weeks			3 weeks		4 weeks			3 weeks		4 weeks			3 weeks		4 weeks						
	M	B	T.	M	B	T.	M	B	T.	M	B	T.	M	B	T.	M	B	T.	M	B	T.			
			Mean			Mean				Mean				Mean				Mean			Mean			
(a) at ambient temperature (25–32 °C and 49–67% RH)																								
D-955	4.42	4.58	4.50	4.24	4.38	4.31	4.25	4.25	4.25	4.17	4.10	4.14	4.35	4.20	4.28	4.13	3.90	4.02	4.25	4.50	4.38	4.17	4.30	4.24
BDF	4.0	4.10	4.05	2.67	2.72	2.70	3.82	3.95	3.89	2.37	2.45	2.41	4.05	4.10	4.08	3.85	3.92	3.89	3.75	3.70	3.73	2.45	2.67	2.56
LDPE	4.33	4.30	4.32	4.13	4.20	4.17	4.25	4.40	4.33	4.03	4.20	4.12	4.25	4.15	4.20	4.03	4.0	4.02	4.30	4.45	4.38	4.03	4.35	4.19
Control	2.28	2.45	2.37	2.08	2.25	2.17	3.30	4.50	3.90	3.23	3.50	3.37	2.70	2.83	2.77	2.47	2.65	2.56	3.50	3.42	3.46	3.67	3.50	3.59
V. Mean	3.76	3.86		3.28	3.39		3.91	4.28		3.45	3.56		3.84	3.82		3.62	3.62		3.95	4.02		3.58	3.71	
			CD			CD			CD			CD			CD			CD			CD			CD
			5%			5%			5%			5%			5%			5%			5%			5%
Variety (V)			NS			NS			0.32			NS			NS			NS			NS			0.36
Treatment (T)			0.35			0.40			NS			0.46			0.37			0.37			0.42			0.44
VXT			NS			NS			NS			NS			NS			NS			NS			NS

Table 4 continued

Film type	Appearance					Arl colour					Arl texture																					
	3 months					3 months + 3 days					3 months					3 months + 3 days																
	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean	M	B	T. Mean														
<i>(b) at low temperature (8 °C)</i>																																
D-955	4.36	4.58	4.47	4.21	4.45	4.33	4.15	4.28	4.22	4.07	4.13	4.10	4.2	4.25	4.23	4.15	4.27	4.21														
BDF	4.10	4.33	4.22	3.67	3.83	3.75	4.05	4.17	4.11	3.82	4.03	3.93	4.05	4.00	4.03	3.95	3.87	3.91														
LDPE	4.23	4.53	4.38	4.13	4.33	4.23	3.98	4.25	4.12	4.11	4.29	4.20	4.00	4.17	4.09	4.08	3.93	4.01														
Control	2.22	2.35	2.29	2.12	2.08	2.10	3.20	3.50	3.35	3.13	3.43	3.28	2.90	3.00	2.95	2.35	2.68	2.52														
V. Mean	3.73	3.95		3.53	3.67		3.85	4.05		3.78	3.97		3.79	3.86		3.63	3.69															
			CD 5%			CD 5%			CD 5%			CD 5%			CD 5%			CD 5%														
Variety (V)			NS			NS			NS			NS			NS			NS														
Treatment (T)			0.38			0.31			0.46			0.40			0.37			0.40														
VXT			NS			NS			NS			NS			NS			NS														
Film type	Taste																															
	3 months																															
	M					B					T. Mean					3 months + 3 days			M					B					T. Mean			
<i>(b) at low temperature (8 °C)</i>																																
D-955	4.25					4.38					4.32					4.13					4.33					4.23						
BDF	3.75					3.83					3.79					3.45					3.67					3.56						
LDPE	4.00					4.25					4.13					4.03					4.07					4.05						
Control	3.30					3.25					3.28					2.67					2.83					2.75						
V. Mean	3.83					3.93					CD 5%					3.57					3.73					CD 5%						
											NS															NS						
Variety (V)											NS															NS						
Treatment (T)						0.30					0.30															0.43						
VXT						NS					NS															NS						
<i>V. Mean variety mean, T. Mean treatment mean, M Mridula, B Bhagwa</i>																																

bright red peel colour and secured high scores for appearance in both cultivars till 1 month of storage at RT and 3 months of storage at 8 °C. Visual appearance was also reported (Mphahlele et al. 2016) to be highly maintained in individual shrink wrapped pomegranate fruits of ‘Wonderful’ cultivar compared to control fruit during 4 months of storage at 7 ± 0.5 °C. The fruits of both cultivars wrapped in D-955 and LDPE-films also got better scores for aril colour, aril texture and taste at both ambient and low temperature. They were also quite acceptable even after shifting to ambient temperature following 3 months LT storage. The highest score of above treatments could be attributed to better quality retention in terms of weight loss, juice content, TSS, acidity and sugars by shrink wrapping as discussed earlier. In ‘Primosole’ pomegranate cultivar also, individual film wrapping with polyolephinic heat-shrinkable film either alone or in combination with fludioxonil treatment almost completely inhibited weight loss and husk scald and preserved fruit freshness for up to 12 weeks at 8 °C plus 1 week of simulated shelf life at 20 °C (D’Aquino et al. 2010). However, in case of BDF-film wrapped fruits, fading of peel colour and poor taste were observed in both cultivars, beyond three weeks of storage at ambient temperature or when the low temperature stored fruits were shifted to ambient temperature. These adverse peel colour and taste attributes in these fruits were also reflected by the measured higher h_0 and lower C^* values (Table 1); and high acidity and low sugar contents (Table 3). The negative effects are apparently related to the inappropriate gas composition generated inside the BDF shrunk packages especially at higher storage temperatures, which is attributed to its very low gas permeability to both oxygen and carbon dioxide gases as compared to other films. It is also evident from the published work that pomegranate is highly sensitive to low-oxygen which showed 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 O_2 than those stored in 5 kPa O_2 (Defilippi et al. 2006).

Conclusion

Individual shrink wrapping of pomegranate fruits (cvs. ‘Mridula’ and ‘Bhagwa’) with different semi-permeable films significantly reduced weight loss and maintained the quality both at ambient (25–32 °C) and low temperature (8 °C) storage conditions. Shrink wrapping with D-955 and LDPE films maintained the visual appearance of pomegranates up to 1 month at ambient temperature and up to 3 months at low temperature in both cultivars. However, considering the variation in maintenance of chemical and

sensory attributes, it can be concluded that shrink wrapped ‘Mridula’ could be stored for 3 weeks whereas ‘Bhagwa’ cultivar could be stored for even 1 month at ambient temperature with retention of quality. However, at 8 °C both cultivars could be stored for 3 months with $< 1\%$ weight loss and maintenance of quality in terms of appearance, colour, peel thickness, juice content, TSS, acidity, sugars and other sensory attributes. Shrink wrapping of pomegranates with very low permeable films viz., BDF-2001 though reduced the weight loss, maintained the peel thickness and moisture, but adversely affected the chemical and sensory attributes especially during prolonged storage.

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References

- AOAC (1995) Official methods of analysis, 16th edn. Association of Official Analytical Chemists, Washington
- Artés F, Marin JG, Martinez JA (1996) Controlled atmosphere storage of pomegranate. *Z Lebensm Unters Forsch* 203:33–37
- Artés F, Tudela JA, Gil MI (1998) Improving the keeping quality of pomegranate fruit by intermittent warming. *Eur Food Res Technol* 207:316–321
- Artés F, Tudela JA, Villaseca R (2000a) Thermal postharvest treatments for improving pomegranate quality and shelf life. *Postharvest Biol Technol* 18:245–251
- Artés F, Villaseca R, Tudela JA (2000b) Modified atmosphere packaging of pomegranate. *J Food Sci* 65:1112–1116
- APEDA. http://agriexchange.apeda.gov.in/index/Product_description.aspx?hscode=08109010
- Barman K, Asrey R, Pal RK (2011) Putrescine and carnauba wax pretreatments alleviate chilling injury, enhance shelf life and preserve pomegranate fruit quality during cold storage. *Sci Hortic* 130:795–800
- Ben-Arie R, Segal N, Guelfat-Reich S (1984) The maturation and ripening of the ‘Wonderful’ pomegranate. *J Am Soc Hortic Sci* 109:898–902
- Caleb OJ, Opara UL, Witthuhn CR (2012) Modified atmosphere packaging of pomegranate fruit and arils: a review. *Food Bioprocess Technol* 5:15–30
- D’Aquino S, Palma A, Schirra M, Continella A, Tribulato E, La Malfa S (2010) Influence of film wrapping and fludioxonil application on quality of pomegranate fruit. *Postharvest Biol Technol* 55:121–128
- Defilippi BG, Whitaker BD, Hess-Pierce BM, Kader AA (2006) Development and control of scald on ‘Wonderful’ pomegranates during long-term storage. *Postharvest Biol Technol* 41:234–243
- Dhall RK, Sharma SR, Mahajan BVC (2012) Effect of shrink wrap packaging for maintaining quality of cucumber during storage. *J Food Sci Technol* 49:495–499
- Elyatem SM, Kader AA (1984) Postharvest physiology and storage behavior of pomegranate fruits. *Scientia Hortic* 24:287–298
- Erkan M, Kader AA (2011) Pomegranate (*Punica granatum* L.). In: Yahia EM (ed) Postharvest biology and technology of tropical and subtropical fruits. Woodhead Publishing, New York, pp 287–311
- Ghafir SAM, Ibrahim IZ, Abusrewel GS, Suaad ZA (2010) Response of local variety ‘Shlefy’ pomegranate fruits to packaging and cold storage. *Acta Hortic* 877:427–432

- Hale PW, Miller WR, Smool JJ (1986) Evaluation of a heat shrinkable copolymer film coated with imazalil for decay control of Florida grapefruits. *Trop Sci* 26:67–71
- Kader AA, Chordas A, Elyatem S (1984) Response of pomegranates to ethylene treatment and storage temperature. *Calif Agric* 38:14–15
- Koksal AI (1989) Research on the storage of pomegranate (cv. Gok Bahce) under different conditions. *Acta Hort* 258:295–302
- Ladaniya MS, Sonkar RK, Dass HC (1997) Evaluation of heat shrinkable film wrapping of ‘Nagpur’ Mandarin (*Citrus reticulata* Blanco) for storage. *J Food Sci Technol* 34:324–327
- Laribi AI, Palou L, Taberner V, Pérez-Gago MB (2012) Modified atmosphere packaging to extend cold storage of pomegranate cv. ‘Mollar de Elche’. <http://www.academia.edu/2500799/>
- Meighani H, Ghasemnezhad M, Bakhshi D (2015) Effect of different coatings on post-harvest quality and bioactive compounds of pomegranate (*Punica granatum* L.) fruit. *J Food Sci Technol* 52:4507–4514
- Miller WR, Hale PW, Spalding DH, Davis P (1983) Quality and decay of mango fruit wrapped with heat-shrinkable film. *HortScience* 18:957–958
- Mphahlele RR, Fawole OA, Opara UL (2016) Influence of packaging system and long term storage on physiological attributes, biochemical quality, volatile composition and antioxidant properties of pomegranate fruit. *Sci Hort* 211:140–151
- Nanda S, Sudhakar Rao DV, Krishnamurthy S (2001) Effects of shrink film wrapping and storage temperature on the shelf life and quality of pomegranate fruits cv. ‘Ganesh’. *Postharvest Biol Technol* 22:61–69
- NHB. <http://nhb.gov.in/PDFViwer.aspx?enc=3ZOO8K5CzcdC/Yq6HcdIxCOU1kZZenFuNVXacDLxz28=>
- Palou L, Crisosto CH, Garner D (2007) Combination of postharvest antifungal chemical treatments and controlled atmosphere storage to control gray mold and improve storability of ‘Wonderful’ pomegranates. *Postharvest Biol Technol* 43:133–142
- Purvis AC (1983) Moisture loss and juice quality from waxed and individually seal packaged citrus fruits. *Proc Fla State Hort Soc* 96:327–329
- Selcuk N, Erkan M (2014) Changes in antioxidant activity and postharvest quality of sweet pomegranates cv. Hicrannar under modified atmosphere packaging. *Postharvest Biol Technol* 92:29–36
- Selcuk N, Erkan M (2015) Changes in phenolic compounds and antioxidant activity of sour-sweet pomegranates cv. ‘Hicaznar’ during long-term storage under modified atmosphere packaging. *Postharvest Biol Technol* 109:30–39
- Singh SP, Sudhakar Rao DV (2005) Quality assurance of papaya by shrink film wrapping during storage and ripening. *J Food Sci Technol* 42:523–525
- Sudhakar Rao DV, Gopalakrishna Rao KP (2008) Controlled atmosphere storage of mango cultivars ‘Alphonso’ and ‘Banganapalli’ to extend storage life and maintain quality. *J Hort Sci Biotechnol* 83:351–359
- Sudhakar Rao DV, Shivasankar KS (2015) Individual shrink wrapping extends the storage life and maintains the antioxidants of mango (cvs. ‘Alphonso’ and ‘Banganapalli’) stored at 8 °C. *J Food Sci Technol* 52:4351–4359
- Sudhakar Rao DV, Gopalakrishna Rao KP, Krishnamurthy S (2000) Extension of shelf life of cucumber by modified atmosphere packaging (MAP) and shrink wrapping. *Indian Food Pack* 54:65–71
- Sunder RN, Nagraju S, Venkataram MN, Jaganath MK (1972) Design and analysis of field experiment. University of Agricultural Sciences, Bangalore, pp 141–167