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RESEARCH ARTICLE

EFFECT OF STORAGE CONDITIONS ON THE POSTHARVEST PHYSICO-MECHANICAL PARAMETERS OF POMEGRANATE (*Punica granatum L.*)

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ABSTRACT

The physico-mechanical parameters of pomegranate were determined with respect to storage period under ambient (18ºC and 75% RH) and refrigerated (7.5ºC and 60% RH) conditions. Also, effects of individual fruit wrapping with EPE-foam, Polyethylene-film and non-wrapping were investigated. The physical parameters such as aril weight, rind weight, rind thickness, rind moisture, weight loss, and mechanical parameters including firmness, failure stress, failure strain and modulus of elasticity were determined after storage at two different conditions. At the end of 20 days storage, the physical parameters were better preserved for wrapped fruits and refrigerated condition. The weight losses for EPE-foam and polyethylene-film wrapped fruits were 0.8 and 0.98% at refrigerated and, also 1.51 and 1.84% at ambient conditions, respectively. During the same period non-wrapped fruits lost 4.97 and 9.5% of weight at ambient and refrigerated conditions, respectively. The firmness was maintained significantly better when fruits were wrapped with polyethylene-film as compared to those wrapped with EPE-foam both at ambient and refrigerated conditions. Also, changes of stress, modulus of elasticity and strain for wrapped fruits was lower than non- wrapped fruits.

Key words: Pomegranate, storage conditions, weight loss, firmness, wrapping.

INTRODUCTION

Pomegranate (*Punica granatum L.*) is an important fruit of many tropical and subtropical regions of the world (Nanda *et al*., 2001). The annual production of pomegranate in the world is about 1.5 million tones and Iran with more than 700000 tonnes is the largest producer of the pomegranates in the world (Anonymous, 2012). Pomegranate is consumed directly as fresh seeds as well as fresh juice which can also be used in flavouring and colouring agents (Gil *et al*., 2000). The post harvest physical and mechanical parameter determination are important in adoption and design of various handling, packaging, storage and transportation systems (Singh and Reddy, 2006). Force deformation characteristics of fruits beyond the elastic limit may be important to simulate the destruction that occurs in bruising. Elastic modulus is often used by engineers as an index of product firmness of fruits and vegetables to estimate harvest maturity or post harvest evaluation of firmness (Fidelibus *et al*., 2002). Fruit firmness is a critical quality attribute determining postharvest quality of fruits and vegetables (Gross *et al*., 2002).

Various industries use puncture tests as part of their quality control procedure. Cool store operators monitor firmness throughput the storage period as part of their inventory management. In addition, firmness is sometimes used to predict consumer responses (Jha *et al*., 2010). Singh and Reddy (2006) reported the mechanical properties of orange peel and ripe orange during storage. Miller (1987) determined stress index, modulus of elasticity and rupture force of freeze-damaged and non-damaged of citrus fruits. Many factors affect the postharvest physico-mechanical properties during storage. The major storage problem of pomegranate is desiccation of the fruit resulting in a brownish colored tough peel and browning of arils. To reduce the occurrence of these problems several technologies have been tested, including chemical, controlled and modified atmosphere storage, shrink films wrapping and coatings (Artes *et al*., 2000; Nanda *et al*., 2001; Mirdehghan and Rahimi, 2005; Barman *et al*., 2011). The storage temperature recommended for pomegranates have varied from 0 to 10ºC with a shelf life ranging from 2 weeks to 7 months depending on the cultivar (Gil *et al*., 1996).

Pomegranates are sensitive to low temperatures. When fruit are exposed to temperature below 5-6 ºC chilling injury appears as pitting of the skin, browning of the white segments separating the arils and discoloration of the arils, and husk scald, which generally is more sever at temperatures of 6-10 ºC (D'Aquino *et al*., 2010). Individual film wrapping of fresh fruits and vegetables will greatly reduce weight loss by reducing the transpiration rate, and maintain the fruit firmness (Risse, 1989). Nanda *et al*. (2001) reported that polyolefin films and skin coating with a sucrose polyester extended the shelf life and quality of soft-seeded 'Ganesh' pomegranate stored at 5, 15 and 25ºC. Barman *et al*. (2011) used putrescine and carnauba wax pretreatments to improve the pomegranate storability at 3ºC up to 60 days. D'Aquino *et al*. (2010) assessed the effectiveness of individual film packaging, applied as a standalone treatment or in combination with fludioxonil, on reducing the occurrence of weight loss and decay. Results indicated that film wrapping almost inhibited

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weight loss and preserved the fruit freshness for whole storage time. There is a dearth of information on post harvest physico-mechanical properties changes of pomegranate under ambient and refrigerated storage conditions which are helpful to decide handling, packaging, storage and transportation systems to be adopted and their designs. Therefore, the aims of this study are (1) to determine the physical and mechanical properties of pomegranate fruit under ambient and refrigerated storage conditions, and (2) to investigate the effects of individual wrapping with and without polyethylene film on weight loss, firmness, failure stress, failure strain and Young's modulus of elasticity for two commercial cultivars of pomegranate.

MATERIALS AND METHODS

Sample preparation

Pomegranate fruits, cultivar 'Gol anar' were harvested at fully mature stage from different trees of a commercial orchard located in Behshahr, Mazandaran province of Iran. Random samples were drawn from a freshly harvested lot of pomegranates at the time of harvest. Fruit were divided into two groups and individually wrapped with polyethylene-film, EPE-foam (Table 1) and non-wrapped. One group of fruits was taken into ventilated corrugated fibreboard box and kept in an ambient condition of 18ºC and 75% RH. Another lot of fruits were kept in refrigerator at a temperature of 7.5 ºC and 60% RH. Post harvest physico-mechanical properties of pomegranate were determined with respect to the storage period in both ambient and refrigerated conditions.

Table 1. Physical properties of materials used for wrapping

Trade name	MFR (g/10 min)	Density (g/cm^3)
Polypropylene	1-3	0.9
EPE foam	1.9	0.924

Weight loss

In order to determine the weight loss of pomegranate during storage, 10 fruits in each experimental lot were numbered and kept in ambient and refrigerated conditions. Weight of the fruit was measured with respect to storage period with electronic balance having least count of 0.01 g. The loss in weight was expressed as percentage of original fresh weight of the fruit. The cumulative losses in weight were calculated as percent of initial weight lost.

Mechanical properties

The mechanical properties of pomegranate were evaluated using polyethylene film and EPE-foam wrapped and non-wrapped at two storage conditions. The evaluation of textural properties of fruits was carried out using a texture analyser (Model TA-XT2i). To measure the force compression and stress-strain curves, the samples were punctured with a 6 mm flat cylinder probe for compression from the initial height of the sample with 1 mm s^{-1} rate of force application. The average of maximum forces of the three punctures was taken. The cone test was used to estimate and control the firmness of pomegranate peel with 1 mm s^{-1} rate of force application (Katsiferis *et al.*, 2008). From the force-deformation data with the 6 mm cylinder probe, the stress (σ) and the strain (ε) ere calculated through following equations (Mayor *et al.*, 2007):

$$\sigma = {}^{F}/_{A_t} \quad (1)$$

$$A_t = A_o \times ({}^{H_o}/_{H_t}) \quad (2)$$

$$\varepsilon = \ln ({}^{H_o}/_{H_t}) \quad (3)$$

Where F is the compression force, A_o the original area of the cylinder probe ($A_o = \pi d^2/4$), A_t the contact area of compression at time t, H_o is the initial height of the fruit sample and H_t the height the sample at time t. The Young's modulus of elasticity (E_m) was calculated from the slope, equivalent to about 10 deformations. Failure stress (Mpa) and failure strain was determined from the maximum peak of the stress-strain curve.

Data analysis

Data were analysed statistically with the iterative non-linear regression routine of Statistical Analysis System (SAS Software, version 8.02, SAS Institute Inc., Cary, NC, USA). The non-linear equations were applied directly without data transformation.

RESULTS AND DISCUSSION

Weight loss and firmness

Pomegranate fruit weight loss greatly affected by the storage conditions. Also, the non-wrapped fruits had significant difference with wrapped fruits (Fig. 1). As it is seen, the non-wrapped fruits after 20 days of storage at ambient (18ºC and 75%RH) lost about 9.5% of the initial weight, while the weight loss at refrigerator (7.5ºC and 60%RH) was about 4.9%. At the constant relative humidity, air temperature is the main factor affected the water loss. The higher the temperature in ambient resulted in the higher weight loss.

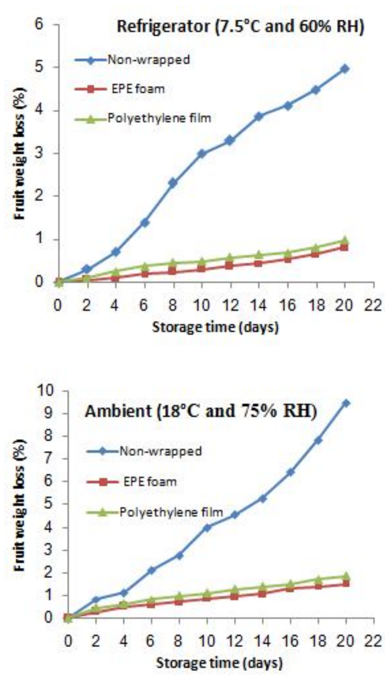


Figure 1. Weight loss of pomegranate under ambient and refrigerated conditions

At the ambient storage, the fruit lost 1.51 and 1.84% of weight when wrapped with polyethylene-film and EPE-foam, respectively, as compared to 0.8 and 0.98% of weight loss at refrigerator (Fig. 1). This was also reflected by a higher loss in rind weight, rind thickness and rind moisture content of storage at ambient as compared to refrigerator (Table 2). Nanda *et al*. (2001) reported that at 25ºC after 25 days of storage, shrink film wrapped pomegranates with BDF-film and D-955 film reduced the weight loss about 1.2 and 2.3%, respectively as compared to 14% of non-wrapped fruits. D'Aquino *et al*. (2010) found that pomegranate wrapping with polyolephinc heat-shrinkage film almost inhibited weight loss during 42 days storage time. The rate of weight loss in non-wrapped fruits was much higher than two other wrapped fruits. Water loss from the fruit is driven by the water gradient between the internal fruit space and the surrounding air. Therefore, the weight loss of wrapped fruits due to limited exchange of the moisture content with the surrounding air is less. No significant difference was observed between the weight loss of fruits wrapped in polyethylene-film and EPE-foam at both storage conditions but polyethylene film wrapped fruit showed a little less weight loss (Fig. 1).

firmness among all the treatments. According to Fig. 1 it could be due to less weight loss of fruit during the first 6 days. At the end of storage period, polyethylene film and EPE-foam wrapped fruits had approximately the same firmness. The firmness was maintained significantly better when fruits were wrapped with polyethylene-film as compared to those wrapped with EPE-foam both at ambient and refrigerated conditions (Fig. 2). Similar observations on maintenance of firmness using film-wrapped materials were reported for pomegranate (D'Aquino *et al*., 2010 and Nanda *et al*., 2001), apples (Chai *et al*., 1991), orange (Katsiferis *et al*., 2008), mango (Qin *et al*., 2006) and tomato (Hertog *et al*., 2006).

Physical parameters

Table 2 shows some physical parameters of pomegranate during storage at different conditions. Aril weight of non-wrapped fruits had significant difference with wrapped fruits at ambient but at the refrigerated conditions the difference for all treatments was significant. Aril weight had higher value at ambient and refrigerated conditions for non-wrapped fruits. It probably reflects the greater losses in peel weight of non-wrapped fruit. Also, There was no significant difference of

Table 2. Effects of film wrapping on the physical parameters of pomegranates cultivar 'Gol anar' at two different conditions

Treatment	Before storage	Ambient (18ºC and 75% RH)			Refrigerator (7.5ºC and 60% RH)		
		Non-wrapped	EPE-foam	Polyethylene	Non-wrapped	EPE-foam	Polyethylene
Aril weight (%)	52.7	59.7 [a]	54.6 [b]	55.3 [b]	62.7 [A]	59.4 [B]	57.9 [C]
Rind weight (%)	31.6	23.3 [a]	29.5 [b]	30.4 [b]	27.3 [A]	30.9 [B]	31.8 [B]
Rind thickness (mm)	0.36	0.22 [a]	0.24 [a]	0.26 [a]	0.25 [A]	0.25 [A]	0.24 [A]
Rind moisture (%)	70.6	60.5 [a]	65.9 [b]	66.1 [b]	63.7 [A]	69.2 [B]	68.5 [B]

Values within the same row and section with different letters are significantly different at p≤0.05.

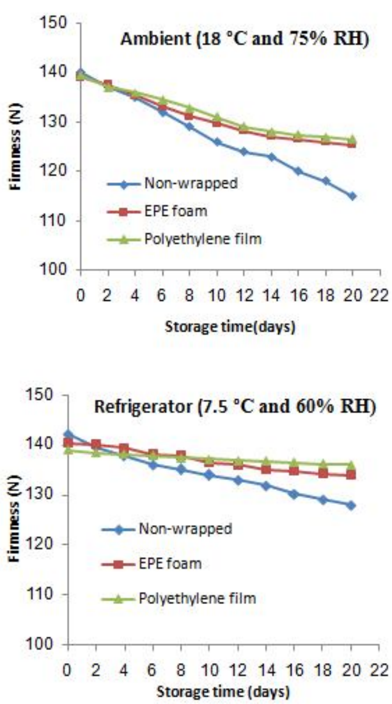


Figure 2. Effects of film wrapping on the firmness of pomegranate fruit during ambient and refrigerator storage

The firmness of pomegranate during storage period at different storage conditions are shown in Fig. 2. The firmness of pomegranate fruit reduced during 20 days of storage but up to 6 days of storage there was no significant difference in fruit

rind thickness at ambient and refrigerated conditions for all treatments but they were lower as compared to the value of rind thickness before storage. There was a significant loss in the rind weight of non-wrapped fruits as compared to wrapped fruits at both ambient and refrigerated conditions. Non-wrapped fruits lost 8.3% rind weight at ambient as compared to 4.3% at refrigerator. Also, polyethylene film and EPE-foam wrapped fruits lost 1.2 and 2.1% rind weight at ambient and 0.2 and 0.7% at refrigerated conditions. These were also reflected in lower loss of rind moisture in wrapped fruits as compared to non-wrapped fruits.

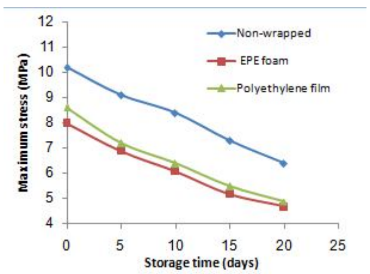
Mechanical parameters

The stress, modulus of elasticity and strain data results help us to understand the structure changes of the pomegranate fruits during storage at different conditions. The results of Table 3 show that the loss of pomegranate stress after 20 days of storage at ambient was about 34% (from 13.2 to 8.7 MPa), while it was about 10% (from 13.2 to 11.9 MPa) at refrigerated condition. At the same conditions wrapped fruits by EPE-foam and polyethylene film maintained the fruit stress much better especially at refrigerated condition. This could be related to the loss of elasticity as it is seen in Table 3. For non-wrapped pomegranates elasticity reduced about 17% at ambient and 10% at refrigerated conditions. The decrease of modulus of elasticity during storage may be due o the decrease of turgor pressure in fruit cells, caused by the membrane cell disruption. The results of Table 3 show also that the high modulus of elasticity and the high stress result in the fresher fruit (low strain) at wrapped fruits at refrigerator as compared to the ambient condition. The strain of fresh pomegranate is relatively low (0.43±0.04) and for non-wrapped fruits the strain increases to 0.77±0.03 and 0.5±0.01 at ambient and refrigerated conditions, respectively. This could be due to softening process during storage period. Change of maximum stress during storage period is shown in Fig. 3. As it can be seen, the maximum stress reduced with storage time and the rate of reduction is higher at ambient rather than refrigerated conditions. Also, maximum stress reduction for non-wrapped fruits is more than two other wrapped fruit at both conditions.

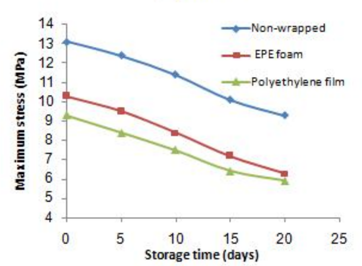
Table 3. Mechanical parameters of pomegranate before and after storage at two conditions

Treatment	σ (MPa)	E (MPa)	ε
Before storage	13.2± 2.3	18.9± 2.1	0.43± 0.04
Ambient			
Non-wrapped	8.7± 1.2	15.7± 1.3	0.77± 0.03
EPE-foam	6.4± 1.1	10.7± 1.6	0. 51± 0.02
Polyethylene film	6.7 ± 0.9	11.5± 1.4	0.62± 0.03
Refrigerator			
Non-wrapped	11.9± 1.3	17.2± 1.4	0.5± 0.01
EPE-foam	8.4± 0.71	14.7± 1.1	0. 42± 0.06
Polyethylene film	7.8± 0.98	13.5± 1.3	0.46± 0.02

Data are mean values of five replications



(A) Ambient



(B) Refrigerator

Figure 3. Maximum stress versus storage time at two different storage conditions

Conclusion

Storage of pomegranate at refrigerator preserved the physical and mechanical parameters much better than ambient condition. Individual wrapping of pomegranate fruits maintained physical parameters such as aril weight, rind weight, rind moisture and weight loss much better than non-wrapped fruits. The firmness was maintained significantly better when fruits were wrapped with polyethylene-film as compared to those wrapped with EPE-foam both at ambient and refrigerated conditions. Also, changes of stress, modulus of elasticity and strain for wrapped fruits was lower than non-wrapped fruits.

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