Some Mechanical Properties of Pomegranate Peel and Fruit

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Abstract: Mechanical property data of pomegranate fruits are limited. The objective of this study was to determine the compression and cutting properties of whole fruit as well as the puncture strength of peel samples of fruit at different storage times. The results showed that storage time had a significant effect on all the properties except for peel shear strain (p<0.05). The whole fruit cutting energy, maximum cutting force, peel shear strength and strain and shear modulus showed an increase with storage time. However, firmness, bioyield force, and modulus of elasticity increased at first and then decreased with storage time.

Key words: Storage, firmness, cutting, force, energy, modulus of elasticity

INTRODUCTION

The pomegranate (Punica granatum L.) is grown in many subtropical countries especially in the Mediterranean region; it is also grown extensively in India, Pakistan, Afghanistan, Iran, Saudi Arabia and in the subtropical areas of South America (Elyatem and Kader, 1984). Nearly all parts of this fruit can be utilized but the crop is important mainly for its arils (the edible portion of the fruit). Pomegranate fruits contain a considerable amount of arils ranging between 518 to 740 g kg⁻¹ of fruit weight depending on cultivar (Safa and Khazaei, 2003). In the last few years there has been a growing market demand for industrial processing of pomegranate arils to obtain pomegranate juice, jam, etc. (Fadavi et al., 2005).

In spite of the many advantages of the pomegranate fruits, they are currently a relatively minor crop with a limited market (Sarig et al., 2001). The major obstacles to realising the fruit's full potential are the difficulties involved in extracting the arils (Sarig et al., 2001). There is, therefore, the need to develop equipments that would be capable of handling and extracting the arils of pomegranate fruits with minimum damage and losses. The post-harvest mechanical properties data of fruits and vegetables are important in adoption and design of various handling, packaging, storage and transportation systems (Singh and Reddy 2006). Determining of physical and mechanical properties of pomegranate fruit and its arils are useful for design and construction of such machines as well as for design new processing and marketing systems. Whole pomegranates keep well at room temperature for a week or refrigerated in an air-tight container for up to three months. Fruit stored at 0- 5 °C will keep weeks/months, especially at high relative humidity (90%). Storing at a warmer temperature or lower humidity increases dehydration, causing the fruit peel to harden and shrink. Storage conditions (temperature, humidity, and storage time) have a considerable effect on changes in fruits quality and mechanical properties. Mechanical properties of fruits are significant characteristics in terms of quality and therefore must be assessed objectively.

No published paper on mechanical properties of pomegranate fruit and peel was found. The specific objectives of this study were 1) to determine basic mechanical properties of pomegranate peel and fruit and 2) to determine the effect of storage time (at three levels of 0, 2 and 6 months after harvesting) on the mechanical properties of pomegranate including;
shear properties of peel, the compression properties of whole fruit and whole fruit cutting force, energy.

**MATERIAL AND METHODS**

**Sample preparation**

Pomegranate fruits were obtained from a commercial orchard in the region of Saveh (Markazi province, Iran), and harvested at the commercial maturity stage. Fruits were collected manually and transported on the same day to the laboratory at the University of Tehran. The damaged fruits were removed and the healthy fruits of uniform size (average weight and main diameter of 256.42gr and 81.05mm, respectively) and appearance were randomly distributed into groups of 10 fruits for further tests. The fruits were stored in refrigerator at 5°C and 70% RH and were kept there for a maximum of 6 months while the experiments were completed. The tests were conducted on samples of three groups as freshly harvested and stored for two and six months from time of harvest.

In order to determine the moisture contents of the pomegranate peel, about 5 g of peel sample was taken into an aluminum container at the time of experimentation and the peel sample was dried in hot air oven at 80 °C for 24h (Singh and Reddy 2006). The moisture content of peel of freshly harvested fruits and those after two and six months of storage were determined equal to 65, 45 and 25% (wet basis), respectively.

**Compression test**

The compression test was used to evaluate the effects of storage time on force and energy required to rupture the pomegranate fruit under quasi-static loading. All the tests were conducted using a material testing machine (H50 K-S, Hounsfield, England). For each test, a single fruit was placed on a flat steel plate so that its stem-calyx axis was horizontal and then compressed with another flat plate (10×10cm) attached to the load cell of the material testing machine (Fig. 1). The compression force was applied at a deformation rate of 25 mm/min, up to a maximum deformation of 20 mm. The compression test was carried out in ten replications in each storage time.

![Compression test](image)

**Fig. 1. Quasi-static compression test of pomegranate fruit.**

A force-deformation curve was obtained for each test and the compression properties of pomegranate fruits were determined using these curves. The firmness was expressed as the force required to compress the fruit to 10 mm deformation (Singh and Reddy 2006). The modulus of elasticity was calculated based on the following assumptions and using Eq. (1) according to O’Brien et al. (1965) and Hacseferoğlu et al. (2007):

(a) The fruits are long elliptic in shape, (b) very small expansion in the longitudinal plane occurred with compression in vertical plane, and (c) each side of the fruit in contact with the flat plates has and equal deflection as shown in Fig.1 (O’Brien et al., 1965; Hacseferoğlu et al., 2007).

$$E = \frac{F_c}{\pi D_c^2}$$  \hspace{1cm} (1)

Where $F_c$ is compression force (N), $D_c$ is compression deformation (mm). The most important point of the compression curve was the bioyield point. At this point, an increase in deformation results from either a decrease or no change in force (Mohsenin, 1986). The energy requirement to compress the pomegranates was determined by calculating the area under the force-displacement curve from the beginning of compression to the bioyield point.

**Shear test**
The shear properties of pomegranate peel were determined following the method of Fidelibus et al. (2002). A schematic drawing of a shear punch test apparatus is shown in Fig. 2. The punch shear test cell consisted of two plates with a thickness of 10 mm. Each plate had a 9 mm diameter hole in the center. Steel pins held the plates in place. The flat faced punch used in this test had a diameter of 8 mm in order to avoid punch/holes contacts during compression. The shear test was carried out with the same material testing machine mentioned above. Circular samples of pomegranate peels with diameter of 30 mm were cut carefully from the equator of randomly selected fruits and then, each peel sample was placed between the two plates and the punch sheared the sample by passing through the holes of the plates. The thickness of the peel samples was measured using a caliper with a precision of 0.01 mm. All the tests were performed at deformation rate of 25 mm/min. The shear test was carried out in ten replications in each storage time.

Fig. 2. Schematic perspective of the shear punch fixture.

The shear stress was calculated assuming that the shearing force applied to the peel specimen was uniform and only stress generated during a test was a shear stress in the rz plane of a cylindrical coordinate system with z-axis parallel to the punch axis. Thus, the shear stress \( \tau_s \) was calculated using the following equation (Fidelibus et al., 2002; Emadi et al., 2005):

\[
\tau_s = \frac{F_s}{2\pi rl}
\]

Where \( F_s \) is shear force (N), \( r \) is Punch radius (mm), \( t \) is Peel thickness (mm). Shear strain \( \gamma \) was calculated as (Fidelibus et al., 2002; Emadi et al., 2005):

\[
\gamma = \frac{D_s}{t}
\]

Where \( D_s \) is shear deformation (mm). The maximum shear strength was estimated using Eq. (2) when the shear rupture occurred. Shear rupture was the point that a sudden drop occurred in the force-deformation curve as shown in Fig. 3. Shear modulus \( G \) was calculated as the slope of linear portion of shear stress versus shear strain curve. The linear portion of the curve generally occurred between a deformation range of about 0.5 to 1.5 mm (Fig. 3).

![Fig. 2. Schematic perspective of the shear punch fixture.](image)

![Fig. 3. Typical force-deformation curves for peel shear test obtained from material testing machine, (a): at harvest, (b): 2 month in storage, (c): 6 month in storage.](image)

Cutting test

The cutting test was used to evaluate the force, energy required to cut the whole pomegranate fruit into halves. A special type of shear rig with a stainless steel cutter at bottom was installed in the load cell of material testing machine for measuring the shear force. The cutting force was measured during the cutting process.
force and energy necessary to cut a whole pomegranate fruit into halves (Fig. 4). For each test, a single fruit was placed on a flat steel plate so that its stem-calyx axis was parallel to the plate and then the cutting force was exerted by the cutter at a speed of 25 mm/min to half the fruit. To prevent the cutter from touching the plate, the downward movement was stopped when the cutter was 10 mm from the plate. For each test, the loading force against depth of cutting was recorded continuously. The force–deformation curves were used to evaluate cutting force, energy and power. The average values of 10 fruits (replications) in each storage time are reported.

![Fig. 4. Schematic perspective of the cutting test set-up.](image)

The cutting energy ($E_1$) was calculated by measuring the area under the force-deformation curve.

**Statistical analysis**

To find the effect of storage time on mechanical properties of pomegranate fruits, one-way ANOVA was carried out. The difference between mean values of parameters was investigated by using Duncan’s Multiple Range tests. The ”MSTATC” statistical package (version 7) was employed in the analysis.

## RESEARCH RESULTS

### Fruit compression test

The results of analysis of variance (ANOVA) showed that storage time had a significant effect on force and energy at bioyield, fruit firmness and modulus of elasticity. Table 1 shows the results of the compression test of pomegranate fruits. The mean values of firmness for the fruits stored for 0, 2 and 6 months were significantly different ($P<0.05$). It was found that fruit stored for two months showed a 1.53-fold increase in their firmness (Table 1). However, with higher increase in storage time from 2 to 6 months, the fruit firmness showed a significant decreasing trend from 154.63 to 45.53 N (Table 1). The trend in firmness change of pomegranate fruits with storage time was similar to the results obtained by Mirdehghan et al. (2006). The initial increase in firmness was due to drying effect and toughening of the fruit peel while at this stage the contents of fruit were kept fresh. But the decrease in firmness at the end of the storage time was due to softening and chilling effects of the inner portion of the fruit. It should be noted that the results of the compression test can depend on the mechanical strength of the skin, the firmness of the flesh, the viscosity of the juice, the turgor pressure of the fruit, and the size of the fruit (Holt, 1970; Lustig and Bernstein, 1987).

### Table 1. The results of compression test for pomegranate fruits.

<table>
<thead>
<tr>
<th>Storage time (month)</th>
<th>Firmness (N)</th>
<th>Modulus of elasticity (MPa)</th>
<th>Bioyield force (N)</th>
<th>Bioyield energy (N.mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>101.33 $^a$</td>
<td>1.42 $^a$</td>
<td>47 $^a$</td>
<td>250 $^a$</td>
</tr>
<tr>
<td>(13.81) *</td>
<td>(0.24)</td>
<td>(13.39)</td>
<td>(129)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>154.63 $^b$</td>
<td>1.64 $^a$</td>
<td>200 $^b$</td>
<td>825 $^b$</td>
</tr>
<tr>
<td>(22.14)</td>
<td>(0.5)</td>
<td>(33.66)</td>
<td>(95.7)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>45.53 $^c$</td>
<td>0.81 $^b$</td>
<td>59 $^a$</td>
<td>697 $^b$</td>
</tr>
<tr>
<td>(5.74)</td>
<td>(0.2)</td>
<td>(24.77)</td>
<td>(68.4)</td>
<td></td>
</tr>
</tbody>
</table>

* The numerical values in the parenthesis are standard deviations and **In each column the means with the same letters have no significant difference at 0.05 significance level.

Modulus of elasticity of fruit showed a trend like firmness and slightly increased from 1.42 to 1.64 MPa with an increase in storage time from 0 to 2 months,
and after that decreased to 0.81 MPa up to the end of storage time. Also, Bioyield force of fruit increased from 47 to 200 N when storage time increased from 0 to 2 months and then decreased to 59 N up to the end of storage time. The bioyield force of pomegranate fruits at time of harvest is lower than those of orange fruits (134.8 N) and guna fruits (59.17 N), as reported by Aviara et al. (2007) and Singh et al. (2006), respectively.

Fig. 5 shows typical force–deformation curves obtained from compression of pomegranate fruits at different storage time.

Peel shear test

The peel of pomegranate consists of an inner white spongy portion called the albedo, and an outer colored portion called the flavedo. The flavedo consists of cuticle-covered epidermis and a few layers of tabular, thick-walled cells interspersed with oil glands (Albrigo and Carter, 1977). The albedo consists of several layers of branched, thin-walled cells, numerous intercellular air spaces, and a few oil glands. A typical force-displacement curve of peel sample under shear test is shown in Fig. 6. The curve illustrated three sections: A, B and C. In section A, the shearing of the pomegranate peel is achieved by compression which causes the albedo portion to compress before shearing the flavedo portion. As the punch moves, the shearing force increases until the punch penetrates into the flavedo portion and maximum shear force is achieved. Then, in section B, due to this failure in flavedo, the shearing force decreases. Then, in section C, the movement of the punch is continued with cutting of albedo.

The result of ANOVA showed that storage time had significant effect on peel shear strength and shear modulus, but its effect on shear strain at rupture was not significant. Table 2 shows the shear test results of pomegranate peel at different storage times. The shear strength, shear modulus and shear strain at rupture of peel increased with decreasing moisture content of peel during storage time. With an increase in storage time from 0 to 6 months, the shear strength, shear modulus and shear strain at rupture increased 36.84%, 28.94% and 31.8%, respectively. The shear strength generally increases with storage time, probably due to the drying effect of the peel tissue. In fact, several structural changes affect the
shear properties of food and fruit products during decreasing in moisture content (Mayor et al., 2007).

### Table 2. Peel shear test results

<table>
<thead>
<tr>
<th>Storage period (month)</th>
<th>Shear strength (MPa)</th>
<th>Shear modulus (MPa)</th>
<th>Shear strain at rupture (mm/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.73 ± 0.17 *</td>
<td>0.92 ± 0.4 *</td>
<td>0.93 ± 0.27</td>
</tr>
<tr>
<td>2</td>
<td>1.14 ± 0.12 b</td>
<td>1.33 ± 0.12 b</td>
<td>1.1 ± 0.17 (0.17)</td>
</tr>
<tr>
<td>6</td>
<td>1.27 ± 0.14 b</td>
<td>1.84 ± 0.1</td>
<td>1.18 ± 0.23</td>
</tr>
</tbody>
</table>

**Fruit cutting test**

Sample curves generated by the fruit cutting test at different storage times are shown in Fig. 7. Two distinct sections are obvious in the force-displacement curves of the fruit cutting test: 1) an initial linear section, and 2) nonlinear section with fluctuation which related to cutting of fruit contents. It was observed that the cutting of the pomegranate fruits was achieved by compression of whole fruit before cutting the flavedo (Fig.7). In other words, it showed the properties of solid cut after compression. At the moment of knife contact with the fruit, the force increased from zero until the maximum compression was attained before cutting the flavedo. The first peak of cutting curve was the force required to cut the flavedo (the outer and colored portion of the peel). Due to this failure in peel structure, a sudden drop occurred in the curve. Then, the compression continued with cutting of fruit. The maximum force of cutting occurred when the cutter displacement was approximately equal to radius of fruit where the contact area of cutter edge with fruit peel and arils and also frictional forces between cutter sides and fruit contents was the highest. As the cutter moved, the cutting process continued and the cutting force reduced since the contact area of cutter edge with fruit arils and also frictional forces between cutter sides and fruit contents was decreased.

As expected, the fruits with a lower storage times (fresh fruits) showed a higher resistance to deformation to the first peak of cutting force, flavedo cutting point, which increased in proportion to storage time. With an increase in storage time from 0 to 6 months, the fruit deformation to the flavedo cutting point increased from 6.5 to 27 mm. This kind of tendency is likely due to gradual changes in the inner portion of the fruit leading to fruit softening during storage time. As shown in Fig. 7, the force-deformation curve of cutting test for the fruits stored for 6 months had lower fluctuation when the cutter move in the inner portions of the fruit. This may also be attributed to the chilling injuries which caused the pomegranate arils to be softened. The most common symptoms of this problem are surface pitting, brown discoloration of the skin, husk scald, pale color of the arils, brown discoloration of the white segments, separating the arils, and a higher sensitivity to fungal development (Elyatem and Kader, 1984; Kader et al., 1984). The result of ANOVA showed that the storage time had a significant effect on flavedo peak cutting force, maximum force of cutting and cutting energy (p<0.01). Also the results showed that the mean values obtained for cutting force and energy with two
kinds of cutter (cutting angles of 10° and 20°) were not significantly different at 5% probability level.

Table 3 shows the values of flavedo peak cutting force, maximum force of cutting and cutting energy for pomegranate fruits cut by two kind of cutters with cutting angles of 10° and 20°, respectively. The flavedo peak cutting force, maximum force of cutting, and whole fruit cutting energy showed an increasing trend with increase in storage time. The flavedo peak cutting force of the fruits stored for 6 months was almost 1.85 times more than that for fresh ones. The average maximum cutting force ranged from 78.87 N for fresh samples to 160.5 N for 6-month storage samples. The maximum cutting force of orange fruits at time of harvest and after 10 days of storage in refrigerated condition were 85.7 N and 71.6 N, respectively, as reported by Singh et al. (2006). The cutting energy of whole pomegranate fruit at time of harvest was 3662.5 N.mm, while this value for orange fruit was reported 2983.4 N.mm by Singh et al. (2006). This pattern is due to decreasing in moisture content of the peel tissue which makes it more resistance to cutting forces.

Table 3. The result of cutting test for pomegranate fruits with two kinds of cutters.

<table>
<thead>
<tr>
<th>Cutting angle</th>
<th>Storage period (month)</th>
<th>Flavedo peak cutting force (N)</th>
<th>Maximum force of cutting (N)</th>
<th>Cutting energy (N.mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10°</td>
<td>0</td>
<td>60.725 a (15.81)*</td>
<td>75.73 a (4.36)</td>
<td>3662.5 a (125)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>81.03 b (5.35)</td>
<td>101.21 b (5.62)</td>
<td>5072.5 b (323.25)</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>108.75 c (8.53)</td>
<td>159.25 c (15.64)</td>
<td>6175 c (607)</td>
</tr>
<tr>
<td>20°</td>
<td>0</td>
<td>75.45 a (11.5)</td>
<td>82.02 a (9.04)</td>
<td>4192.5 a (865.5)</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>91.1 b (2.66)</td>
<td>90.04 b (7.42)</td>
<td>5300 b (175.87)</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>143.66 b (50.4)</td>
<td>161.75 b (16.58)</td>
<td>6325 b (434.62)</td>
</tr>
</tbody>
</table>

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