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Effect of Fruit Properties on Pomegranate Bruising

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Pomegranate fruit quality is adversely affected by bruise damage. Bruises are formed by a variety of static loads and dynamic impacts on the fruit when it strikes any other object during handling, sorting, packaging, or transportation. In order to be able to reduce this damage, it is necessary to ascertain the influence of fruit properties on bruise susceptibility. An experimental study was performed with varying storage time, temperature, and impact region. In these experiments, pomegranates were dropped from three heights onto a flat aluminum surface. Significant effects on bruising in relation to storage time, temperature, impact region, and their interactions were found ($p < 0.05$). It was concluded that higher fruit temperature, firmness, and peel thickness reduced bruise damage to the pomegranate fruit. Moreover, storage time and increased radius of curvature increased the bruise volume and bruise area, respectively.

Keywords: Fruit quality, Storage time, Fruit temperature, Drop impact, Bruise susceptibility.

INTRODUCTION

Pomegranate cultivation (*Punica granatum* L.) is mainly confined to semi-arid, mild temperate to subtropical climates. Pomegranates are naturally adapted to regions with hot summers and cool winters, such as Mediterranean countries, Iran, Afghanistan, India, China, Japan, and the United States (California).[1,2] Pomegranate arils (the edible portion of the fruit) are high in antioxidant activity, vitamins, sugars, acids, polysaccharides, polyphenols, and some important minerals.[3−5] Nearly all parts of this fruit can be utilized. The flesh arils can be used as a garnish, in fruit cups, compotes, salads and desserts, and as a snack. The pomegranate peel is highly valued for its astringent properties.

Whole pomegranate fruit can be maintained at room temperature for a week or in refrigerated conditions in an airtight container for up to three months. The fruit will continue to ripen to full flavor at these temperatures. Fruit at 4–5°C can be stored for weeks or even months, especially at high relative humidity (RH; 90%). Storing at warmer temperatures or lower humidity increases

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dehydration, causing the fruit peel to harden and shrink. Mechanical properties analysis of fruits and vegetables during postharvest influences the choice and design of handling, packaging, and storage methods as well as transportation systems. It is also instructive in the design and construction of the machines used as well as new processing and marketing systems.[6,7] Fruit damage is one of the main reasons for the decreasing market value and quality of agricultural products between the point of harvesting and consumption. Pomegranates have to be treated carefully to maintain quality and prevent losses due to damage. The major contributing factor to such losses is bruising. This is defined as the fruit damage consisting of a discoloration in the fruit flesh which does not usually break through the skin.[8] Over the years, several studies have been carried out to assess the mechanical properties and susceptibility to bruising of fruits and vegetables.[9−16] In the course of loading and offloading, the fruit loads or packages are thrown from certain heights onto other surfaces and this also results in impact damage. This impact could result from either vibration or a sudden drop. This article focuses on dynamic loading due to drop impact as this appears to be the most prevalent during the postharvest activities. Extensive studies of bruise damage in apples caused by dynamic impacts have been carried out, using a variety of techniques, such as drop and pendulum tests and with spring-loaded devices to propel an apple against a counterface.[17,20] These impact techniques seek to locate and control the impact energy on the tested fruits. Also, these studies were carried out to demonstrate the relation between fruit impact region and bruising. Van Zeebroeck et al.[21] stated that at low impact force, higher radius of curvature decreased bruise damage, whereas at high impact force, higher radius of curvature increased bruise damage in apples. In addition, Lewis et al.[22] showed that the radius of curvature at the point of impact strongly influences the bruise volume (BV), with larger radii giving rise to larger bruises. This means that if the point of impact is on the cheek of an apple, the bruise will be larger than if the point of impact is on the stem or calyx shoulders, which generally have smaller radii. Zarifneshat et al.[23] showed that peaches with a low radius of curvature suffered more bruise damage than peaches with higher radius of curvature, but no interaction was found between radius of curvature and impact level. Martínez-Romero et al.[24] showed that increasing storage time for apricot fruit resulted in a reduction in tissue firmness and the elastic modules and, hence BV was increased. Yurtlu and Erdoúan[25] conducted dropping impact test with three drop height and five storage times for pears and apples. They found that increasing storage time led to a decreased bioyield point force, elastic moduli, and fruit firmness, and the resulting bruising increased. The objective of this study was to investigate the effects of fruit temperature, storage time and impact regions on pomegranates at different levels of impact energy in terms of bruise area (BA) and BV. This will consequently allow the identification of factors that have the greatest effect on bruising.

MATERIAL AND METHODS

Physical and Mechanical Fruit Characteristics

Pomegranates (*Punica granatum* cv. Malas Saveh) were hand harvested at commercial maturity from the Pomegranate Research Center located at Saveh, Iran. They were safely packed with polythene bags and transported to the laboratory immediately after harvesting to reduce water loss. The pomegranates with bruises and other visible damage were rejected. Pomegranates with a mass between 300 and 320 g were selected, numbered, and stored in optimal conditions (5°C, 85% RH) from 10 to 48 hours before testing.

The mass and dimensions of each fruit were measured along with peel thickness and radius of curvature in three regions of each fruit as depicted in Fig. 1. Fruit firmness was determined by measuring the maximum force during piercing of the sample to a depth of 10 mm at a velocity of 100 mm min^{-1} with an 8 mm diameter cylindrical penetrometer mounted onto a STM-5 Universal Testing Machine

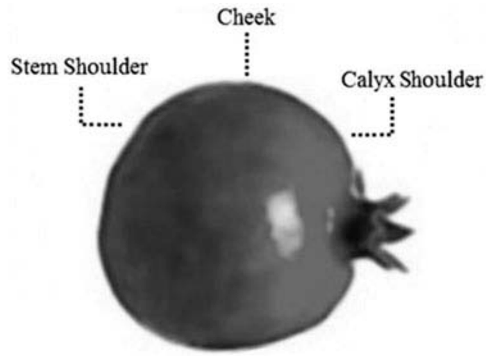

FIGURE 1 Pomegranate regions that peel thickness, radius of curvature, and firmness were measured.

(SANTAM, Design CO. LTD., England).Two maximum force readings were recorded from two opposite sites on the cheek for each fruit. The average value of the two readings from the cylindrical penetrometer was taken as the firmness value.

Experimental Drop Testing

A drop testing technique against an aluminum plate was used to control the fruit impact energy (Fig. 2). The designed impact device was equipped with a vertical graduated rod of 1 m in order to control the drop height (h_{drop}). Impact levels above the mechanical critical impact level of pomegranate were chosen. The lower drop height represented typical impacts during handling and transporting, while the higher drop height was typical of a mechanical pomegranate harvester and packing processes. A digital video camera (Samsung, ES55, Korea) with 30 frames per second and calibrated background was used to determine the rebound height ($h_{rebound}$) in order to calculate

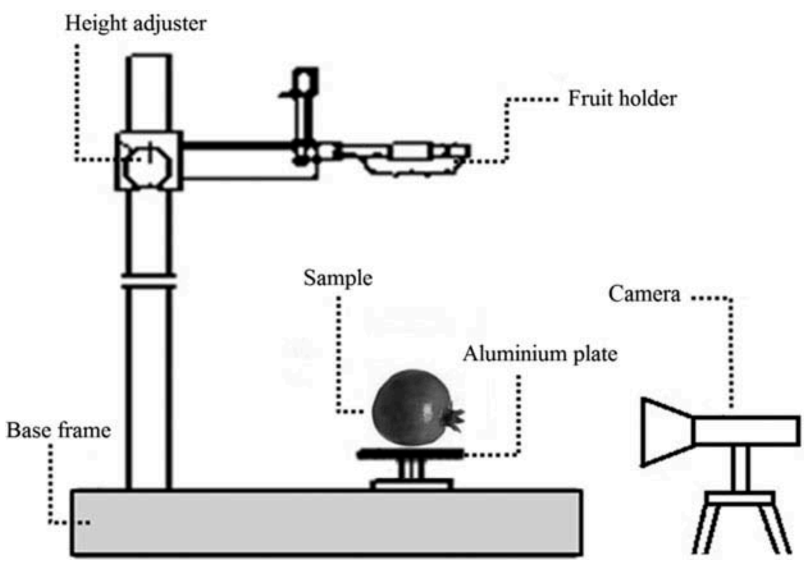

FIGURE 2 Drop test apparatus and camera set-up.

TABLE 1
Impact properties related to drop height for pomegranate fruits cv. Malas Saveh

	Levels of absorbed impact energy		
Parameters	*Low*	*Medium*	*High*
Drop height (m)	0.15	0.30	0.60
Potential energy (mJ)	408 ± 47	979 ± 94	1630 ± 158
Rebound energy (mJ)	88 ± 12	199 ± 23	241 ± 25
Absorbed impact energy (mJ)	320 ± 26	780 ± 81	1390 ± 127

Mean ± standard deviation for sample ($N = 60$) are presented.

energy absorbed during the impact (Eq. 1). After the dropping impact, the sample was caught by hand to prevent a second impact.

$$\text{Impact energy, } e_{impact} = m\ g\ (h_{drop} - h_{rebound}) \quad (1)$$

where m is the pomegranate mass and g is gravitational acceleration. Before impact tests, 81 pomegranate fruits were grouped according to storage time (0, 2, and 4 months), fruit temperature (5, 15, and 25°C), impact energy, and impact location. Pomegranates were dropped from three heights (0.15, 0.30, and 0.60 m) onto a flat aluminum surface (Table 1). The tests were conducted with three replications for each drop height, storage time and fruit temperature to ascertain the spread of results. Finally, each fruit received two impacts on different locations—stem shoulder, cheek, or calyx shoulder—ensuring that impact locations were about 90° apart from the firmness test positions. All the samples for each storage time were tested within 36 h.

After impact tests, fruits were stored at room temperature (21°C, 28% RH) for 48 h, during which time bruised tissues turned pale. In order to ascertain the correct impact position, some white powdered chalk was spread on the surfaces. The site of the pomegranate skin that came into contact with the impact surface was demarcated and after 48 h turned pale. Fruits were examined and cut along the bruising deformation surface. BA and BV of each fruit were calculated according to Eqs. (2) and (3)[22,26] by the same evaluator using a digital caliper with ±0.1 mm accuracy.

$$BA = \frac{\pi}{4} ab \quad (2)$$

$$BV = \frac{\pi d}{24}(3ab + 4d^2) \quad (3)$$

where, a and b are major axes (mm) of outer BA assumed to be an elliptical surface and d is bruise depth (mm) measured from peel thickness.

Statistical Analysis

All data were subjected to statistical analysis using the analysis of variance (ANOVA) test. Factorial experiments in a complete randomized block design were used to determine the effects of pomegranate fruit temperature, storage time, and impact regions on BA and BV at three impact levels.

RESULTS

Pomegranate showed significant differences among mean values of the studied parameters according to each region of fruit (Table 2). Fruits were irregular in shape, with a smaller radius of curvature in stem and calyx shoulder. Also, these regions have peel irregularities due to the calyx and stem, which could be important in term of fruit-to-fruit impact. The cheek region featured a high radius of curvature with a lack of peel irregularities and extended over a large area of the fruit. This cheek region proved highly susceptible to any bruise.

Peel thickness values showed similar variation to radius of curvature along fruit regions, with minimum values close to the calyx shoulder and maximum values in the cheek region. Pomegranate fruits had a mean peel thickness of 3 mm. However, fruit firmness values showed different variation from radius of curvature and peel thickness in pomegranate fruits. Fruit firmness values increased from calyx to stem shoulder. In all cases, the firmness test was able to pierce the fruit peel and reach the seeds. There was a significant inverse linear correlation between radius of curvature and firmness for both outermost regions of the pomegranate (Table 3). Therefore, there was a significant positive linear correlation between firmness and peel thickness for each studied region. Also, for the whole fruit, fruit firmness showed a positive linear correlation with peel thickness (Pearson's Correlation = 0.542, $p < 0.001$). Accordingly, lower firmness values are found in the smoothest region of fruits where the lowest peel thickness values were reached.

BV was achieved in each fruit region. A linear fit was obtained with mean values of BV according to different levels of the studied parameters. Figure 3 shows a clear tendency between BV and the studied parameters. Impact energy was revealed to be the main parameter determining BV in pomegranate fruits. Impact location on fruit also played a decisive role in BV development. In all

TABLE 2
Pomegranate regions characteristics that subjected to impact

	Fruit region			
Parameters	*Stem shoulder*	*Cheek*	*Calyx shoulder*	*Mean value*
Peel thickness (mm)	3.3 ± 0.2^a	3.4 ± 0.2^b	2.3 ± 0.2^c	3.0 ± 0.5
Radius of curvature (mm)	51.5 ± 4.3^a	59.5 ± 5.3^b	45.1 ± 5.5^c	52.3 ± 7.6
Fruit firmness (Mpa)	55.1 ± 7.3^a	49.9 ± 9.5^b	43.8 ± 6.3^c	49.6 ± 9.0
Fruit length (mm)	–	–	–	80.7 ± 8.0
Fruit diameter (mm)	–	–	–	82.6 ± 8.6
Fruit mass (g)	–	–	–	313.3 ± 5.3

[a,b,c]Different letters in the same row indicate significant differences among regions of fruit (Duncan's post-hoc, $p < 0.05$);

Mean ± standard deviation for sample ($N = 30$) are presented.

TABLE 3
Linear correlation between pomegranate fruit characteristics

	Radius and firmness		*Peel thickness and firmness*	
Fruit region	*Pearson's coef.*	*Sig.*	*Pearson's coef.*	*Sig.*
Stem shoulder	−0.892	< 0.001	0.770	< 0.01
Cheek	0.554	< 0.01	0.539	< 0.001
Calyx shoulder	−0.817	< 0.001	0.584	< 0.001

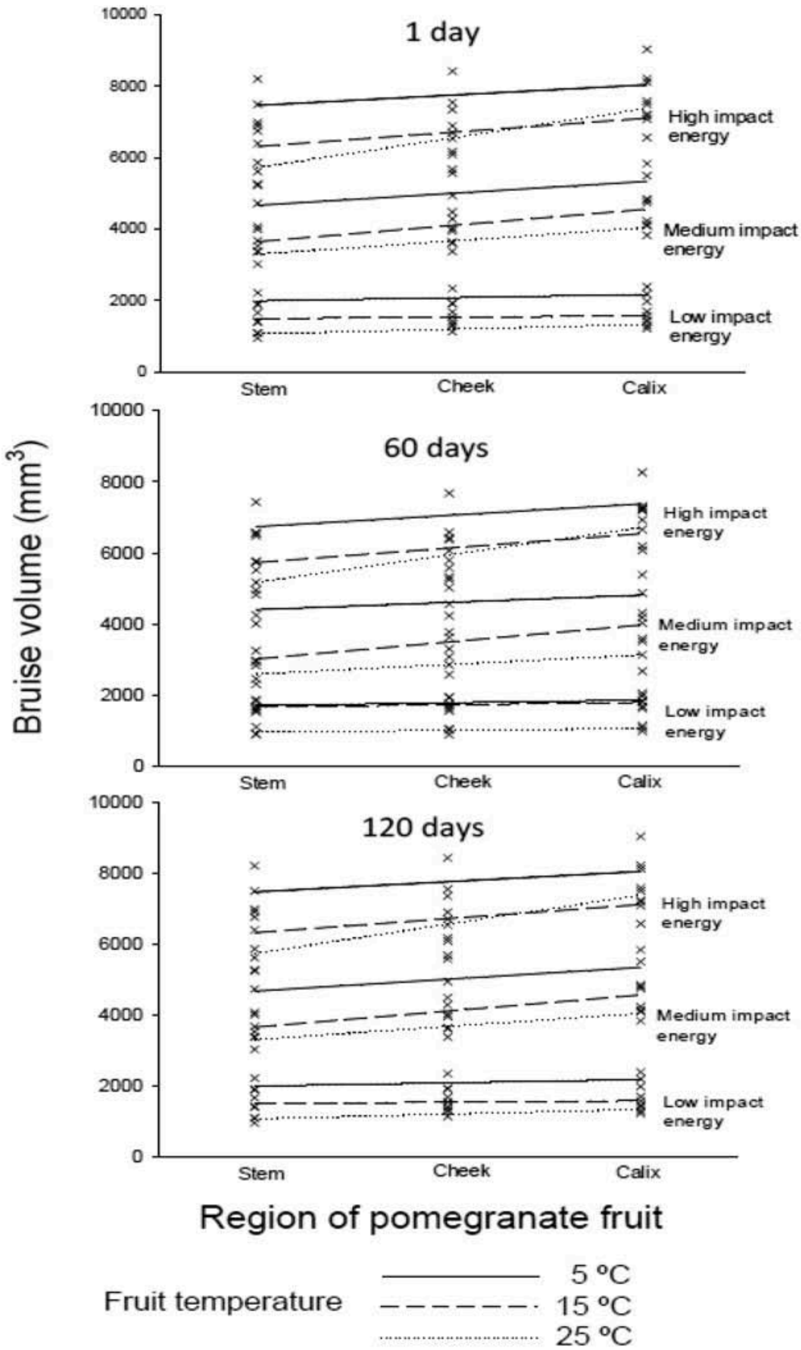

FIGURE 3 Pomegranate bruise volume according to fruit region for different impact energy levels, fruit temperature, and storage time.

TABLE 4
Results of regression analysis for bruise volume in pomegranate fruit (*Punica granatum* cv. Malas Saveh; $N = 243$)

	Regression coefficients		*Standardized coefficients*		
Included independent variables	*B*	*Std. error*	*Beta*	t	p
Constant	416.498	112.333		3.708	0.000
Storage time (days)	7.006	0.750	0.152	9.342	0.000
Storage temperature (Celsius)	−61.874	4.462	−0.225	−13.867	0.000
Impact energy (mJ)	4.780	0.083	0.929	57.244	0.000

Dependent variable: Bruise volume (mm^3).

cases, bruising increased from stem to calyx, displaying an inverse relation to fruit firmness measurements. However, storage temperature of fruit before impact had an inverse relation to BV. Therefore, high fruit storage temperature after impact reduced the pomegranate fruit susceptibility to bruising. However, in the cases with both high impact energy (1390 mJ) and high storage temperature (15–25°C) this relation was not clear-cut. Fruit storage time had a slight effect on BV in the time period considered in this study (1–120 days).

A multivariate linear regression analysis was performed using the BV data (Table 4). Studied parameters did not show collinearity and the coefficients of the regressions were all statistically highly significant. In addition, the value of the adjusted coefficient (R^2) was 0.937. Impact energy absorbed during impact process had the greatest effect on BV (beta standardized coefficient = 0.929) with a strong positive relation. Storage temperature was ranked as the second most important parameter (beta standardized coefficient = –0.225) with a negative relation to BV. Finally, storage time showed a significant effect but with a low positive relation to BV (beta standardized coefficient = 0.152).

DISCUSSION

Physical and Mechanical Characteristics of Pomegranate Fruit

Fruit firmness values increase from calyx to stem shoulder regions. Thus, the calyx shoulder is shown to be the more susceptible region to bruising due to minimum values of peel thickness and radius of curvature, and therefore, fruit firmness. Conversely, the stem shoulder region is shown to be the most resistant to bruising despite its intermediate values of peel thickness and radius of curvature. It should be noted that firmness depend on a wide range of parameters, such as the mechanical strength of the skin, the firmness of the flesh, the viscosity of the juice, and the turgor pressure of the fruit.[27,28]

Effect of Impact Energy and Impact Region on Bruising

Impact energy and impact region played a major part in bruising susceptibility of pomegranate fruit. In this study, the lowest and highest BVs were found in stem and calyx shoulder, respectively. This means that an increase in pomegranate firmness sees a reduction in BV. However, pomegranate fruit firmness is not only due to peel thickness or radius of curvature. Other parameters, such as flesh arils, turgor, and distribution, could contribute to bruise susceptibility. Another reason of the significant increase in fruit BV at the calyx shoulder was an increase in impact pressure at the same impact force (almost the same drop height) due to the lower contact area of this region with the counterface.

Increments of impact pressure produced greater bruise depth and BV values according to radius of curvature, as Zarifneshat et al.[23] also found. However, a reduction in the radius of curvature caused a reduction in impact surface area and hence, a reduction in the BA.

Effect of Storage Time on Bruising

The results show that BVs increases with increasing storage time, because the turgor pressure decreases from harvest date to four months after harvest. In fact, the postharvest storage of fruit is accompanied by loss of cell-wall integrity due to the breakdown of pectin substances, leading to an increase in soluble pectin and a decrease in fruit firmness.[29] Another reason for the significant decrease in firmness of fruits stored for 120 days was probably chilling injuries leading to increased loss of cell-wall integrity.[6]

Effect of Pomegranate Temperature on Bruising

In this study, higher refrigerated storage temperatures reduced the bruise damage. Zarifneshat et al.[23] worked with two apple storage temperatures (3 and 20°C) at three levels of impact energy and they also found that increasing temperature resulted in decreased bruising volume. An in-depth analysis of fruit bruising susceptibility is needed in order to establish the influence of temperature on the mechanical properties of pomegranates. For example, the elastic modulus is dependent on temperature.[21] Thus, the elastic modulus decreases with increasing fruit temperature[30] and the elastic modulus is positively related to bruise damage.[31] According to the Hertz theory, an equation used to calculate the stresses generated during the collision of two objects, the Stress created in the fruit tissue is proportional to the elastic modulus of two body-on collisions. On this basis, for a fixed drop height—assuming constant surface cushion hardness—an increment in the fruit elastic modulus due to temperature could increase the stress and, therefore, the bruising damage. In addition, other problems associated with low fruit temperature include chilling injuries, increases loss of cell-wall integrity, and greater sensitivity to other negative conditions.

A physical explanation of the effect of temperature on tissue firmness is given by Hertog et al.[32] The mechanical strength of the cell walls can be weakened by temperature-sensitive enzymatic activity. Temperature affects stiffness through the activity of cell-wall degrading enzymes. As viscosity of the cell walls increases with decreasing temperature, the cell walls might become more brittle resulting in an increased stiffness.[32] Toivonen et al.[33] also obtained similar results.

CONCLUSIONS

Impact energy is shown to be the main parameter in bruise susceptibility of pomegranate fruits. Others parameters such as storage time, fruit temperature, and fruit impact regions were less influential in terms of BV. BV increased from stem to calyx of fruits, with an inverse relation to fruit firmness measurements. The increase in storage time of the pomegranates, associated with lower firmness, resulted in a higher bruise susceptibility of pomegranate fruits. Pomegranates stored at 5°C suffered more bruise damage than pomegranates at 25°C, particularly at high impact energy levels.

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