Engineering properties and bruise susceptibility of peach fruits (*Prunus persica*)

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Abstract: In order to better design and modification of peach post harvesting systems such as sorting, conveying and packaging, selected engineering properties and bruise susceptibility of two Iranian peach varieties (Elberta and Spring time) were determined. Physical and mechanical properties such as dimensions, mass, volume, projected area, surface area, sphericity, static friction and rolling resistance coefficients on various surfaces, firmness and compressibility were measured. Also, effect of cultivar, drop height (50, 100 and 150 mm) and contact surface material (fruit, steel and rubber) on the bruise area and volume were investigated. Analysis of variance results indicated that cultivar had a significant effect (p<0.05) on certain engineering parameters such as dimensions, volume, mass, surface area, rolling resistance coefficient and firmness. The effect of cultivar on the bruise volume and area was not significant. The contact surface material and drop height had significant effect on the bruise area (p<0.01) and volume (p<0.05). Mean comparison of data revealed that the bruise area on all three contact materials was significantly different from each other, but on the rubber surface, it showed no significant differences in bruise volume. Also, bruise area was significantly different for 50 and 150 mm drop heights, while bruise volume had significant difference at all three drop heights. In general, results indicated that some engineering parameters are depended on cultivar and have more rules in designing of sorting and conveying systems. Also, in sorting or packaging lines safe drop height must be considered and it is closely related to the contact surface material.

Keywords: peach, physical and mechanical properties, bruise area, bruise volume

Citation: Tabatabaekoloor R. 2013. Engineering properties and bruise susceptibility of peach fruits (*Prunus persica*). Agric Eng Int: CIGR Journal, 15(4): 244−252.

1 Introduction

Iran produced about 612500 tons of peaches in 2012, which was approximately 8% of the world's peach production and ranked sixth in the world (Ministry of Agriculture, 2013). Among six cultivars of peaches that grown in Iran, Elberta and Spring time cultivars are the most common and popular cultivars. They are characterized by different ripening times from the beginning of June until the end of September. The fresh fruit postharvest sector is dynamic, due to increasing demand for quality produce (Aleixos et al., 2002). Although, internal quality assessment has an important role in the fruit postharvest stage, the external appearance of fresh produce will continue to be an important factor of marketability and consumer acceptance (Moreda et al., 2009). The various physical and mechanical characteristics of fruit such as size and firmness are much responsible towards the attraction of consumers (Jha et al., 2010).

The post-harvest physical and mechanical properties data of fruits are important in adoption and design of various equipment for sorting, conveying, packaging and improving processing lines in order to reduce the quality and quantity losses (Singh and Reddy, 2006; Sirisomboon et al., 2007). It is important to have an accurate estimate of some physical properties such as dimensions, mass, volume, surface area, sphericity, projected area and mechanical characteristics such as friction and rolling

Received date: 2013-06 18 **Accepted date:** 2013-09-20

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resistance coefficient, firmness and compressibility which may be considered as engineering parameters for the product.

There are a lot of studies on physical and mechanical properties of some agricultural products such as different seeds and nuts (Aydin, 2002; Kashaninejad et al., 2006; Kabas and Ozmerzi, 2008; Nazari Galedar et al., 2009; Naderboldaji et al., 2008) and different fruits (Arora and Kumar, 2005; Masoudi et al., 2006; Goyal et al., 2007; Ozturk et al., 2010; Li et al., 2011). Despite an extensive search, limited information is available on physical and mechanical properties of peaches. Montevecchi et al. (2012) studied the physical characteristics such as color, weight and firmness for a Sicilian white flesh peach cultivar. They mentioned that this information is required for the definition of the quality scheme guaranteeing the standard of the product and the specifications of the production system.

Physical properties such as dimensions, weight, volume, sphericity, surface area and projected area are important in the development of mechanical, electronic and machine vision sorting equipment and packaging machinery. Also, physical data prepares useful information for modeling of fruits and vegetables. Mechanical properties such as friction and rolling resistance coefficients are useful parameters for selecting conveyor type and material and also affect the maximum inclination angle of conveyor.

Fruit firmness is one of the most widely used indicators of fruit quality (Wang et al., 2006). It is sometimes used to predict consumer responses and to assess ripeness, storage and shelf life (Jha et al., 2010). Also, firmness can be used as a criterion for sorting agricultural products into different maturity groups or for separating overripe and damaged fruits from good ones.

For most fruit types, bruising is the most common type of postharvest mechanical injury (Dintwa et al. 2008). Determining the impact conditions which can cause bruises are essential to improve harvesting, transporting, sorting procedure and equipment (Van Linden et al., 2006). Ahmadi et al. (2010) investigated the effect of impact by means of a pendulum on the bruising peach. They developed two bruise prediction models based on the bruise volume for the damage susceptibility of peach fruit. Most laboratory research used bruise volume as the bruise evaluation parameter, while in practice there is a greater interest in commercially significant bruise damage parameters such as the visible surface area or the threshold for visible bruising assessed negatively by the consumers (Lewis et al., 2007). Therefore, in this research both bruising area and volume were considered as the evaluation parameters. Studies of harvest and postharvest systems have shown that most bruising occurs as a result of impact against a variety of surfaces and different drop heights. In this work the focus was on bruising area and volume due to single impacts as this appeared to be the most prevalent.

The objectives of this study were to determine some physical and mechanical properties of two peach cultivars, and to investigate the effects of cultivar type, drop height and contact surface material on the bruise area and volume of damaged peaches.

2 Materials and methods

2.1 Materials

The experiments were carried out with two most common peach cultivars (Elberta and Spring time). Samples of the two cultivars were collected from the growing area of Sari, Mazandaran province in Iran during harvest season in 2012. The peaches were hand-harvested at 'ready-to-eat' ripening stage (30-40 N firmness) (Wang et al., 2006). Random samples (158 peaches) were drawn from a freshly harvested lot of fruits (3 boxes) at the time of harvest and then were transferred to the post-harvest laboratory of Sari Agricultural University. The fruit's surface was cleaned manually and tested within 24 h at room temperature and relative humidity (22±2ºC and 72%-78% RH).

2.2 Determination of physical properties

To determine the dimensions of peaches, 50 fruit were randomly taken from the bulk and their linear dimensions according to Figure 1 were measured using a digital caliper gage (DC- 515, Lurton Ltd., Taiwan) with an accuracy of 0.01 mm (Khoshnam et al., 2007; Kilickan et al., 2008). Fruit mass was measured by using a digital balance with a sensitivity of 0.01 g (Moreda et al., 2009). The volume was determined by using the toluene displacement method (Calisir et al., 2005).

The geometric mean diameter, sphericity and surface area values were calculated using the following relationships (Guner, 2007).

$$Geometric\ mean\ diameter = [(D]_i D_m H)^{1/3} \quad (1)$$

$$Sphericity = \frac{[(D]_i D_m H)^{1/3}}{D_m} \quad (2)$$

$$Surface\ area = \pi[(D]_i D_m H)^{2/3} \quad (3)$$

where, D_i, D_m and H are the main dimensions (mm) of peach (Figure 1). The projected area of peaches was determined from pictures taken by a digital camera (Sony W570, 14.2 Mpixels), and then the reference area was compared to a simple area using the Image Tool for Windows program (Ozturk et al., 2010).

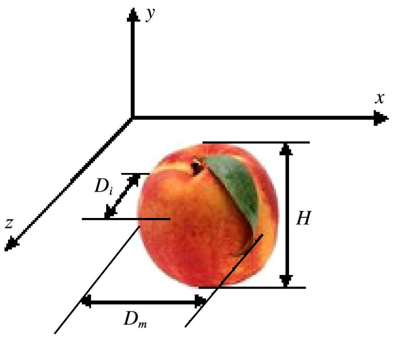


Figure 1 Representation of the three directions

2.3 Determination of mechanical properties

The friction and rolling resistance coefficients of peaches were determined on plywood, rubber and steel surfaces as shown in Figure 2a. First a material board on the test stand was fixed; the peach fruit was put on the surface and the plate was connected to the hook of a load cell with a cord. The static friction coefficient was calculated by dividing the maximum value of static friction force to the normal force between the surfaces, which is equal to the weight of tomato fruit (Altuntas and Sekeroglu, 2008).

The rolling resistance coefficient was determined by the mechanism shown in Figure 2b. The peach sample was placed on the surface and the slope increased following the rise of the load cell. The angle θ at which the initial movement of the peach was recorded and rolling resistance coefficient was calculated as the tangent of the angle θ. This method has been used by Kabas and Ozmerzi (2008) for tomato fruit.

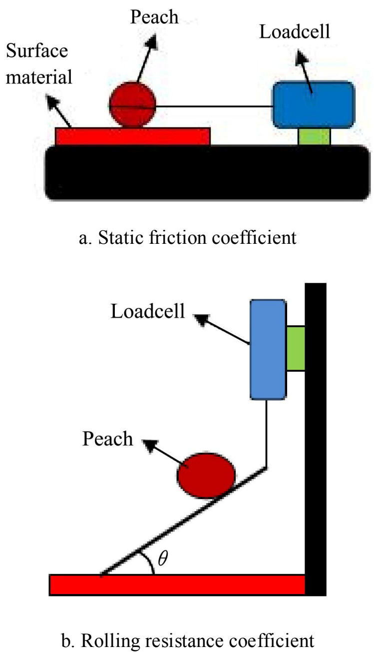


Figure 2 Test device used to determine the coefficients

Puncture testers based on the original Magness-Taylor pressure tester, also called Magness-Taylor fruit firmness tester, are used to measure firmness of numerous fruits and vegetables for postharvest evaluation of firmness (Zhou and Li, 2007). Firmness was measured by a Texture Analyzer (Stable Micro Systems, UK) to drive a 7.94 mm diameter probe with a radius of curvature of 5.16 mm at speed of 5 mm s^{-1} as referred by Peng and Lu (2006) and Jha et al. (2010). A random sample of 10 fruits having similar size from each cultivar was selected and firmness was measured as the maximum force recorded in a force-time curve. Each reported values of firmness represent the mean of two individual measurements on opposite sides taken on ten peach samples.

Compressibility was considered as the ratio of deformation to the dimension of the sample in the direction of compression force at the loading point (Sirisomboon et al., 2007). Peach fruit was set upon a flat base plate of a Texture Analyzer (Stable Micro Systems, UK) and probe carrier was fixed with a 65 mm diameter flat plate and brought in contact with the fruit. Compression force was applied at a speed of 1.5 mm s^{-1}

to compress the fruit for 10 mm from the contact point and the force- deformation curve was recorded (Singh and Reddy, 2006). The deformation was considered as any change in original dimension of the sample. The three compression axes were used (Figure 1).

2.4 Bruise measurement

Impact bruises were produced by dropping peaches from a measured drop height on a counter face surface. Bruise was measured as the procedure introduced by Lu et al. (2010). Peaches were left for 48 hours after dropping, for full development of bruises. Bruise area, BA (mm^2), was determined by measuring the widths (w_1 and w_2 in mm, Figure 3) using a digital caliper and assuming that they were elliptical. It is given by:

$$BA = \frac{\pi}{4} w_1 w_2 \tag{4}$$

Bruise volume, BV (mm^3), was calculated using the elliptical bruise thickness method (Mohsenin, 1986). It is given by:

$$BV = \frac{\pi d}{24(3w_1 w_2 + 4d^2)} \tag{5}$$

where, w_1 and w_2 (mm) are bruise widths along the major and minor axes, respectively; d (mm), bruise depth (Figure 3).

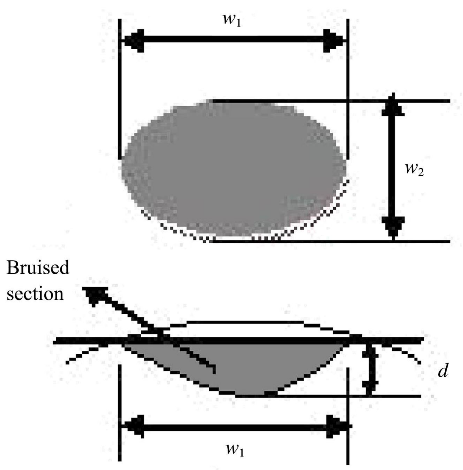


Figure 3 Bruise determination

2.5 Statistical analysis

Mean values of physical and mechanical properties for two peach cultivars were expressed as means± standard deviation for each determination. Differences at $p<0.05$ were considered to be statistically significant. Also, bruise evaluation was performed by a Completely Randomized Design (CRD) with factorial test at two cultivars (Spring time and Elberta), three levels of drop height (50, 100 and 150 mm) and three contact surface materials (fruit, rubber and steel). Tests were conducted at three replications with 54 treatments. The data were analyzed using analysis of variance and the means were separated at 5% level applying Duncan multiple range test in SAS software (SAS Version 8.2, The SAS Institute Inc., Cary, NC, USA).

3 Results and discussion

3.1 Physical properties

Table 1 shows the physical properties of two peach cultivars in the test. All the dimensions of cultivar Elbert was higher than that of Spring time. The sizes of Spring time and Elberta cultivars vary within the dimensions ranges of 49.2-57.4 mm and 51.9-62.2 mm, respectively. The type of cultivar had a significant effect on the major, intermediate and geometric mean diameter ($p<0.01$) and minor diameter ($p<0.05$). Li et al. (2011) reported that the cultivar had a significant effect on the dimensions of tomato and the same results were reported by Kilickan and Guner (2008) for two olive cultivars. There was no meaningful difference between sphericity of two cultivars but the sphericity of cultivar Spring time (94.12%) was a little higher than that of Elberta (93.43%). The sphericity values indicate that fruit shape is approximately close to sphere.

The volume and unit masses of Spring time and Elberta cultivars had significant difference ($p<0.01$) and were 168.3 cm^3-105.4 g, and 173.5 cm^3-132.1 g, respectively. The surface area for Elberta cultivar was larger than that of cultivar Spring time by 6.1%. Also, the two cultivars had almost the same projected area. These data can help to design or adjust the sorting, conveying and packaging mechanisms based on shape, weight and volume either in new designed or in available systems. In general, physical properties determination is necessary in the food industry, to meet the requirements of some processing machines and also it can provide useful information for suitable working of internal quality sensors.

Table 1 Means and standard deviations of the physical and mechanical properties of two peach cultivars

Properties	Cultivar		Significant test
	Spring time	Elberta	
Major diameter, mm	57.4 (0.43)	62.2 (0.52)	**
Intermediate diameter, mm	52.7 (0.61)	56.7 (0.89)	**
Minor diameter, mm	49.2 (0.57)	51.9 (0.64)	*
Geometric mean diameter, mm	52.5 (0.15)	56.1 (0.22)	**
Sphericity, %	94.12 (3.4)	93.43 (2.6)	ns
Mass, g	105.4 (18.2)	132.1 (21.7)	**
Volume, cm^3	168.3 (12.1)	173.5 (17.3)	*
Surface area, cm^2	144.8 (19.8)	154.2 (24.6)	**
Projected area, cm^2	43.04 (4.1)	44.11 (7.3)	ns
Static friction coefficient			
Plywood	0.434 (0.006) A	0.438 (0.005) A	ns
Rubber	0.511 (0.003) B	0.513 (0.004) B	ns
Steel	0.430 (0.005) A	0.436 (0.007) A	ns
Rolling resistance coefficient			
Plywood	0.641 (0.004) A	0.646 (0.006) A	ns
Rubber	0.673 (0.006) B	0.689 (0.008) B	*
Steel	0.580 (0.007) C	0.585 (0.003) C	ns
Firmness, N	31.2 (2.41)	26.7 (3.17)	**
Compressibility, %			
x-axis	14.54 (1.57) A	17.96 (2.15) A	**
y-axis	15.62 (1.08) B	18.08 (2.78) A	**
z-axis	13.11 (1.39) C	15.26 (1.35) B	**

Note: **, * significant at 5% and 1% probability level; ns, not significant.
The values in parentheses show standard deviation.
A, B and C letters indicate the statistical difference among each property in columns.

3.2 Mechanical properties

The mechanical properties of peach cultivars including static coefficient of friction, rolling resistance coefficient, firmness and compressibility are presented in Table 1. Cultivar type had no significant effect on the static friction coefficients on all surfaces studied. The plywood and steel showed no significant differences in the static coefficient of friction for both cultivars, but there was a significant difference ($p<0.05$) between the static friction coefficient of rubber surface with two other materials. This was because the rubber surface has higher frictional properties which made fruit difficult to move on.

The mean value of static friction coefficient of Spring time was less than Elberta cultivar. The highest static friction coefficient was obtained on the rubber surface for Elberta cultivar (0.513) and the lowest value was found for the Spring time cultivar (0.430) on the steel surface. It can be due to the frictional properties of surfaces (Ozguven and Vursavus, 2005) and lower sphericity of Elberta cultivar in the obtained physical parameters. Some researchers have reported coefficient of friction for Iranian apricot (Janatizadeh et al., 2008), tomato fruits (Kabas and Ozmeri, 2008) and sweet cherry (Naderiboldaji et al., 2008) on different surface materials. They reported that different varieties of fruit due to the morphological differences and surface material types affect the friction coefficients.

The rolling resistance coefficients for two cultivars on the plywood, rubber and steel as the contact surface materials were in the ranges of 0.580-0.689 (Table 1). There was a significant difference ($p<0.05$) between rolling resistant coefficient of two cultivars on the rubber surface, while the steel and plywood showed no significant differences in rolling resistance coefficient for two cultivars. On the other hand, surface material type had a significant effect on the rolling resistance coefficient for both cultivars. The mean values of rolling resistance coefficient for Elberta cultivar were higher than those for Spring time cultivar, and this might be due to the effect of sphericity. In general, having information on the static friction and rolling resistance coefficients of peaches are needed to design the conveying and sorting systems.

Table 1 shows that the cultivar had a significant effect on the firmness ($p<0.01$). The mean values of firmness for Spring time and Elberta cultivars were 31.2 and 26.7 N, respectively. Montevecchi et al. (2012) reported that peach firmness is related to the variety type.

Statistical analysis showed that the cultivar had a significant effect ($p<0.01$) on the compressibility of peach at three loading directions (Table 1). Cultivar Elberta had higher compressibility at all loading directions than those of cultivar Spring time. Also, along the y-axis it was the highest (18.08%) than those along the other two axes. In both cultivars the least compressibility was observed along the z-axis. Li et al. (2011) found that the compressibility of tomato fruits was depended on the loading direction and the tissue resistance along axes can affect the compressibility. In order to tolerate more pressure especially during packaging it is better to put peaches along its y-axis.

3.3 Bruise area

Table 2 shows the analysis of variance related to the cultivar, drop height and contact surface material and their interactions on the bruise area and volume of peach. The effect of cultivar on the bruise area was not significant, while contact surface material and drop height significantly affected bruise area (P<0.01). Also, the interactions of the parameters on the bruise area were not significant.

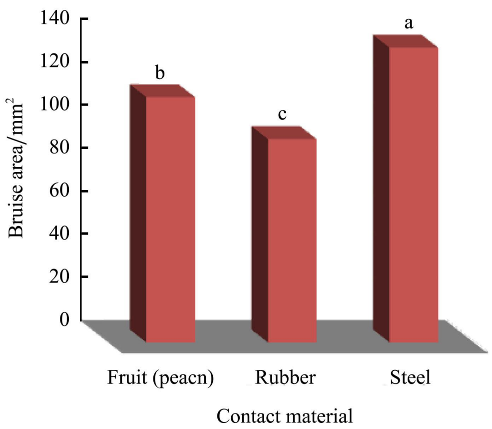
Table 2 Analysis of variance related to the bruise area and volume of peach

Mean square		df	Source of variation
Bruise volume	Bruise area		
6064.045^{ns}	2147.327^{ns}	1	Cultivar (A)
49848.137*	23254.233**	2	Drop height (B)
67176.51*	64356.014**	2	Contact material (C)
1013.942^{ns}	336.821^{ns}	2	A×B
247.231^{ns}	56.452^{ns}	2	A×C
522.396^{ns}	25.361^{ns}	4	B×C
421.852^{ns}	108.475^{ns}	4	A×B×C
		36	Error
		53	Total

Note: **, * significant at 5% and 1% probability level; ns, not significant.
A, B and C letters indicate the statistical difference among each property in columns.

Mean comparison of data using Duncan's test showed that the bruise area among the three contact surface materials was significantly different (Figure 4). The mean value of bruise area for the rubber (94.5 mm^2) was lower than industry threshold for bruise area (100 mm^2) reported by Pang et al. (1994), while the bruise area on the fruit (114.7 mm^2) and steel (137.4 mm^2) was higher than industry threshold criteria. The reason can be due to the higher energy absorbing properties of rubber than two other contact surfaces. Also, the depth of damage at harder surfaces is more and it could be resulted in development of the bruised area.

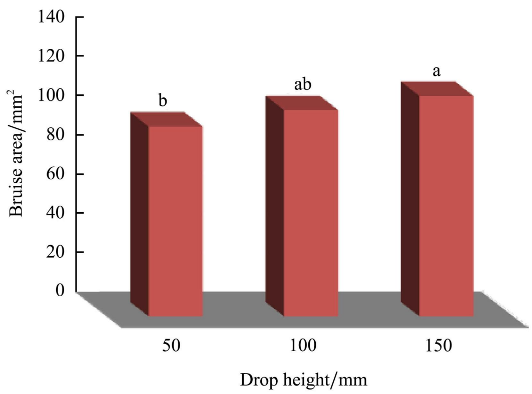
This result indicates that one way for reducing the bruise area of peach is using soft and more elastic material such as rubber when designing sorting, conveying or packaging media. Lewis et al. (2007) reported that when apple dropped on different counter face materials such as steel, wood, rubber and perspex, only rubber surface had bruise area less than industry threshold. Since bruise area is relatively easy to measure, this could be a useful approach to large scale rapid experimental estimation of bruise susceptibility.



Note: a, b and c show significant difference at 5% probability level

Figure 4 Main effect of contact material on the bruise area of peach

The average value of peach bruise area (calculated using Equation (1)) after dropping from different heights against three contact surface materials are shown in Figure 5. As can be seen the bruise area differs significantly between levels of 50 and 150 mm drop height. Increasing the drop height from 50 to 150 mm considerably increased the bruise area. Mean value of bruise area increased approximately 15% when the drop height increased from 50 to 150 mm. Fruit drop from higher heights may release more potential energy and accelerates the intensity of contact and resulted in more bruised area. The bruised area was less than industry threshold only when fruit dropped from 50 mm. Therefore, drop heights can be reduced to levels below



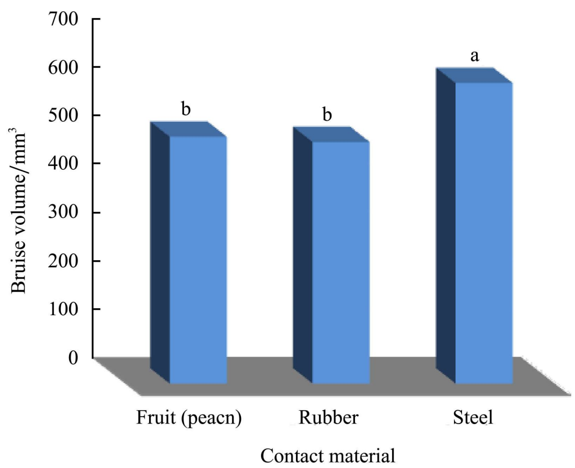
Note: Similar letters show no significant difference at 5% probability level

Figure 5 Main effect of drop height on the bruise area of peach those that could give a bruise area over the industry threshold. Tabatabaekoloor et al. (2012) found similar results for apple bruising. They found that increasing drop height from 10 to 30 cm increased bruise area about 23%.

3.4 Bruise volume

Analysis of variance related to the effects of cultivar, contact material and drop height on the bruise volume is shown in Table 2. The effect of cultivar on the bruise volume was not obvious. The results showed that contact material and drop height had a significant effect (P<0.05) on the bruise volume.

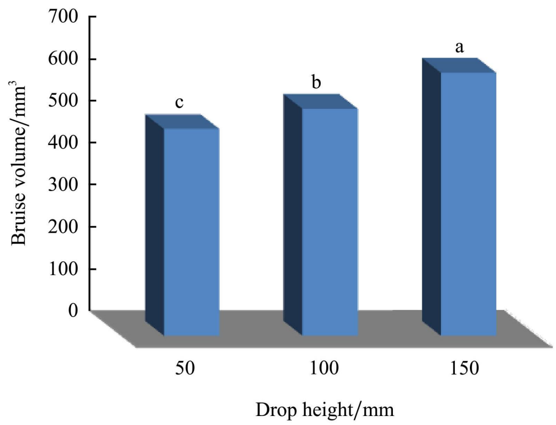
Figure 6 shows the bruise volume for peach impact against different materials. No significant difference was observed between bruise volume of peach due to drop on the rubber and fruit. As the Equation (5) shows, the roll of bruise depth in bruise volume is complicated and it is not clear how it exactly affect the bruise volume. Also, the bruise volume for this two contact materials was less than that of steel. This was expected because using counter-face materials with a higher energy absorbing capacity (rubber and fruit) led to smaller peach bruises. Lewis et al. (2008) found a strong correlation between bruise volume and energy absorbed by the contact material. Tabatabaekoloor et al. (2012) reported that type of counter-face material significantly affected the bruise volume and the minimum and maximum values of bruise volume were obtained on cardboard and steel materials, respectively.



Note: Similar letters show no significant difference at 5% probability level

Figure 6 Main effect of contact material on the bruise volume of peach

Figure 7 shows the mean values of peach bruise volume from varying drop heights. By increasing the drop heights from 50 to 100 mm, 100 to 150 mm, and 50 to 150 mm the bruise volume increased about 9%, 14% and 22%, respectively. Initial observations showed that the shape of most bruised areas was generally ellipsoidal, and so the bruise volume was related to the major and minor diameters and depth of bruised section (Equation (2)). Therefore, an increase in drop height increased the bruise contact area and depth and resulted in a higher bruise volume. Pang et al. (1992) experimentally showed that bruise volume of apple increased by increasing the drop height. Although bruise volume has been calculated in this work, it is probably bruise area that is more important as it is visible and used to define the threshold used.



Note: a, b and c show significant difference at 5% probability level

Figure 7 Main effect of drop height on the bruise volume of peach

4 Conclusion

The following conclusions are derived from this research and some recommendations are given to enrich the future works.

1) Among physical properties of two varieties, no significant difference was observed between sphericity and projected area.

2) The firmness, compressibility and rolling resistance on rubber were significant for two varieties.

3) The effect of cultivar on the bruise area and volume was not significant. Drop height and contact material had significant effects on the bruise area (p<0.01)

and bruise volume ($p<0.05$). The least damage to the fruit happened on rubber and from 50 mm drop height.

It is recommended that more levels of drop heights and some other contact materials such as wood, cardboard and perspex were considered as treatments. Also, it is suggested to investigate the effect of forward speed of fruit before drop (conveyor speed) and point of contact on damage to the fruit.

Acknowledgement

The author would like to acknowledge the Research Fund of Sari Agriculture University. Also, thanks to Atena Gholampor and Sehre Ebragimi for their valuable assistance in experiments.

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