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Full Length Article

Engineering Properties and Susceptibility to Bruising Damage of Table Olive (*Olea europaea*) Fruit

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ABSTRACT

In this study, geometrical properties such as linear dimensions, sphericity, mass of fruit, projected area, surface area, true density, volume, hydrodynamic properties in water namely terminal velocity, drag force and buoyant force and bruising characteristics like as bruise area and bruise volume of two varieties of table olive fruit were determined. The values of length, width, geometric mean diameter, sphericity, mass of fruit, surface area, volume, gravitational force and buoyant force except projected area and true density terminal velocity and drag force were statistically significant between two varieties. The greatest values of bruise area and bruise volume were obtained with the stainless steel for both varieties. © 2011 Friends Science Publishers

Key Words: Table olive fruit; Geometric and hydrodynamic properties; Bruise area, Bruise volume

INTRODUCTION

The olive tree is an evergreen tree or shrub. It has been cultivated for olive oil fine wood, olive leaf, and the olive fruit and dining table consumption. The olive tree is native to the Mediterranean region and Western Asia, and spread to nearby countries from there. It is estimated the cultivation of olive trees began more than 7000 years ago in the Aegean and Mediterranean basin. It is a member of Oleaceae family (*Olea europaea* L.). The largest olive producer countries are Spain, Italy, Greece, Turkey, Syria, Tunisia, Morocco, Portugal, Egypt and Algeria (FAO, 2010). 900 million olive trees are grown on over areas of 10 million hectares in the world, and 98% of these olive trees are located in the countries of Mediterranean Basin (Sesli & Yeğenoğlu, 2009). Turkey is one of the countries that cultivate olives. There are totally 152 million olive trees, 106 million of which is bearing fruits in Turkey (TURKSTAT, 2010). According to the data of the last 10 years, olive fruit is grown on 630,000 ha areas in Turkey with a production rate of 1,310,000 t (FAO, 2010).

Most of the olive production is to obtain olive oil; however, a considerable proportion of it is processed for direct human consumption in various forms. Approximately 65-70% of olive produce in Turkey is processed to obtain oil olive; 30-35% is processed for table olive as in the world (RTMARA, 2006). The table olive is a food product which is usually consumed as an aperitif or in salads, which has a wide market in the Mediterranean countries. Olive is very different from other fruit species. After harvest, it is not consumed like other fruits. It is necessary to eliminate its bitterness before consumption. Table olives are a highly nutritious food with a balanced content of fats made up mainly of monounsaturated oleic acid. Eating olives also provide essential fatty acids, fiber, vitamins and minerals.

The main reason for the decreasing market values and quality of agricultural products is damage occurring between the point of harvesting and consumption. Fruits are susceptible to bruising when they impact each other or a hard surface during picking, packing, transportation, and retailing at stores and during other handling steps. Most research on the mechanical properties and bruising of fruit has focused on apples (Schoorl & Holt, 1980; Klein, 1987; Abbott & Lu, 1996; Aydın & Çarman, 1998; Vursavuş & Özgüven, 1999); pears (Garcia *et al*., 1995; Wang, 2004; Yurtlu & Erdoğan, 2005) and peaches (Vursavuş & Özgüven, 2003; Wang & Teng, 2006). However, these properties have not been reported extensively for olive in the literature. The table olives have to be treated carefully to maintain quality and avoid losses due to damage. The major contributing factor to such losses is bruising. This is defined as damage to, and discoloration fruit flesh such as apple, pear and quince, usually with no breach of the skin. Research into the damage susceptibility of apples requires the determination of the bruise size. The measurement of bruise volume is difficult and time consuming to achieve accurate data (Bollen *et al*., 1999).

Information with regard to some physical properties such as length, width, thickness, geometric mean diameter, sphericity, volume, true density, projected area etc. of olive fruit may have more importance for the proper design and constructing equipment and structures for handling, transporting, processing and sorting and also for assessing the product quality. For example, determining a relationship between mass, dimensions and projected areas is useful and applicable in weight sizing. Hydrodynamic properties are very important characters in hydraulic transport and handling as well as hydraulic sorting of agricultural products. The fruit sorting is to use the terminal velocity of fruit moving in a fluid that has a density above or below the fruit density. Fruit with different terminal velocities will reach different depths after flowing a fixed distance in a flume and may be separated by suitably placed dividers (Bollen *et al*., 1999).

The objective of this study was to determine selected geometric and hydrodynamic properties in water such as terminal velocity, drag force and buoyant force of Memecik and Domat varieties of table olive fruit. In addition it was investigated the effects of varieties, drop heights and selected impact surfaces on bruise area and bruise volume. The selected geometric properties examined were linear dimensions, sphericity, mass, projected area, surface area, true density, and volume of fruit. The results provide useful data to be used by engineers in the design of suitable harvest and post-harvest equipment and machines.

MATERIALS AND METHODS

Two olive cultivars, namely, Memecik and Domat, planted varieties in Turkey were randomly hand-picked in 2009 winter season from an orchard located in Aydın, Turkey. The Memecik is a variety having a wide geographic distribution in Turkey; its tree grows strongly under good maintenance conditions. Its fruits are large and oval, transversely symmetric shaped; it is processed for oil production and as table olives. The Domat variety's tree is strong, broad and large. Its fruit is large, cylindrical and symmetric; its yield is quite good. It is consumed as stuffed or seeded green olives (Sesli & Yeğenoğlu, 2009).

Samples of 600 fruits of each harvested variety were transferred to the laboratory in polyethylene bags to reduce water loss during transport. The initial moisture content of fruits was determined as 63.87 g/100 g sample for Memecik variety and 51.02 g/100 g sample for Domat variety by drying the samples to a constant weight in a 70°C oven (Akinci *et al*., 2004). The remaining material was kept in cold storage at 4ºC until use. All of the analyses were carried out at room temperature.

To determine the average size of the fruit, one hundred fruits were selected at random. Their two linear dimensions, namely length, *L*, width, *W* (=thickness, *T*), and the projected area were determined from pictures taken with a digital camera (Canon IXUS 40), and then comparing to reference area to a sample area by using the Image Tool 3.0 image processing software (Fig. 1). Many researchers have described and worked on the determination of the fruit properties by using image processing (Sadrnia *et al*., 2007; Rashidi & Gholami, 2008).

The geometric diameter (D_g), sphericity (ϕ) and surface area (S) were calculated by using the following relationship (Mohsenin, 1986; Varnamkhasti *et al*., 2007):

$$D_g = (L \cdot W \cdot T)^{\frac{1}{3}} \tag{1}$$

$$\phi = \frac{(L \cdot W \cdot T)^{\frac{1}{3}}}{L} \tag{2}$$

$$S = \pi \cdot (D_g)^2 \tag{3}$$

The average true density was determined using the water displacement method. The volume of water displaced was found by immersing a weighed quantity of olive fruit in the water (Mohsenin, 1986). The fruit mass was determined with an electronic balance of 0.01 g accuracy. The volume, V, of a single fruit was determined from the following relationship:

$$V = \frac{m}{\rho_t} \tag{4}$$

Where, m is the mass of fruit in kg, and ρ_t is the true density in kg m^{-3}.

To determine some hydrodynamic properties of olive fruits, a 1500 x 400 x 400 mm^3 glued glass column was constructed (Fig. 2). The column was filled with tap water to a height of about 1200 mm. Each fruit was placed on the top of the column with hand and then released and if any bubble appearing on them, it was removed by rubbing the fruit. Fruit was then positioned flat (i.e., with their largest two dimensions oriented horizontally) on the top of column. A digital camera, SONY with 25 frames per second, recorded the movement of fruits, simultaneously. Video to frame software was used to convert the video film to individual images and subsequently, to calculate coming up times and terminal velocities of fruits by knowing the fact that each picture takes 0.04 s.

Considering olive fruits in water, the forces acting on the sample will be the gravitational force (F_g) acting downward, buoyant force (F_b) acting upward, and drag force (F_d) acting opposite to the direction of motion. These forces were calculated using the following equations (Mohsenin, 1986; Kheiralipour *et al*., 2010):

$$F_g = m \cdot g \tag{5}$$

$$F_b = \rho_w \cdot V \cdot g \tag{6}$$

$$F_d = C \cdot A_p \cdot \frac{\rho_w \cdot v_t^2}{2} \tag{7}$$

Where, m is the mass of fruit in kg, g is gravitational acceleration in m s^{-2}, ρ_w is water density in kg m^{-3}, V is fruit volume in m^3, C is the dimensionless drag coefficient, A_p is projected area of the fruit, which is perpendicular to the direction of motion in m^2 and v_t is terminal velocity in m s^{-1}. Drag coefficient was calculated from the following relationship (Mohsenin, 1986):

$$C = \frac{2 \cdot m \cdot g \cdot (\rho_f - \rho_w)}{v_t^2 \cdot A_p \cdot \rho_f \cdot \rho_w} \quad (8).$$

Where, ρ_f is the true density of the fruit in kg m^{-3}.

One by-product of mechanization in production and handling of agricultural products has been mechanical damage to the crop during harvesting and subsequent handling. It is observed that olive fruits drop various heights on different surfaces in this process. Hence, the impact tests were conducted at drop heights of 0.5, 1.0, 1.5, 2.5, 3.5 and 4.5 m on three different structural materials, namely wood, rubber and stainless steel to determine of bruising damage of olive fruit. The tests were conducted with three replications for each height and surface.

The fruits were left for 24 h after dropping for the bruises to develop fully. The bruise areas (A_b in mm^2) were then determined by measuring the widths (w_1 & w_2, as shown in Fig. 3) and assuming they were elliptical (Lewis *et al*., 2007):

$$A_b = \frac{\pi}{4} \cdot w_1 \cdot w_2 \quad (9).$$

Where, w_1 and w_2 are bruise width along the major and minor axes in mm, respectively. Bruise volumes (V_b in mm^3) were calculated by the following equation (Lewis *et al*., 2007):

$$V_b = \frac{\pi \cdot d}{24} \cdot (3 \cdot w_1 \cdot w_2 + 4 \cdot d^2) \quad (10).$$

Where, d is bruise depth in mm. These bruise parameters were measured with digital callipers with accuracy of 0.01 mm.

All data were subjected to statistical analysis using the analysis of variance (ANOVA) test. Duncan's multiple range tests was performed to determine the effects of drop height and impact surfaces on bruise area and bruise volume.

RESULTS AND DISCUSSION

Selected geometric properties and hydrodynamic properties in water of Memecik and Domat varieties of olive were presented in Table I. The most of the fruit characteristics of the different olive varieties were found no significant as statistically. But the main feature that distinguishes the fruits of Memecik variety is the prominence in the end of fruit. The dimensional characteristics were found for Memecik variety with means of 28.37 and 21.99 mm length and width respectively, whereas these values were 28.13 and 21.59 mm for Domat variety. The geometric mean diameter (23.93 & 23.57 mm) and the mean values of fruit mass (6.97 & 6.61 g) of the Memecik and Domat varieties, respectively were recorded in this experiment. Ozturk *et al*. (2009) reported the fruit masses values of Butko, Kara Sati and Kizil Sati olive cultivars were 2.46, 2.41 and 3.13 g, respectively. The mean values of projected area and surface area were 5.12 and 18.01 cm^2 for Memecik variety and 4.82 and 17.46 cm^2 for Domat variety, respectively. The analysis of variance revealed that projected area and true density were significant ($p < 0.05$) between two varieties. Al-Widyan *et al*. (2010) reported the largest projected area, surface area, and sphericity of four olive varieties were obtained as 5.13 cm^2, 26.81 cm^2, and 0.75 for Spanish variety, 5.40 cm^2, 23.42 cm^2, and 0.60 for Black Spanish variety, 2.86 cm^2, 10.82 cm^2, and 0.72 for Improved Nabali variety, and 2.25 cm^2, 8.50 cm^2, and 0.61 for Nabali Baladi variety, respectively. Also, Saglam and Aktas (2005) reported the average length, width, volume, and sphericity of two olive varieties were obtained as 19.05 mm, 15.22 mm, 2.84 cm^3, and 0.80 for Ayvalik variety, 22.28 mm, 16.97 mm, 4.16 cm^3, and 0.77 for Memecik variety, respectively.

According to the results of analysis of variance, the values of terminal velocity were significant ($p < 0.01$)

Table I: Several physical and hydrodynamic properties of two olive varieties

Parameters	Memecik	Domat	Significance
Length (mm)	28.37±1.64	28.13±117	ns
Width (mm)	21.99±1.01	21.59±0.79	ns
Geometric mean diameter (mm)	23.93±1.09	23.57±0.73	ns
Sphericity (%)	0.84±0.03	0.84±0.03	ns
Mass of fruit (g)	6.97±0.91	6.61±0.60	ns
Projected area (cm^2)	5.12±0.49	4.82±0.35	**
Surface area (cm^2)	18.01±1.62	17.46±1.09	ns
True density (kg m^{-3})	1100.90±60.29	1051.75±51.58	**
Volume (cm^{-3})	6.37±1.00	6.30±0.67	ns
Terminal velocity (m s^{-1})	0.10±0.01	0.06±0.01	*
Drag coefficient	2.70±1.96	3.67±2.74	*
Gravitational force (N)	0.07±0.01	0.06±0.01	ns
Buoyant force (N)	0.06±0.01	0.06±0.01	ns
Drag force (N)	0.006±0.003	0.005±0.003	*

*1% significant level, **5% significant level, ns: no significant

Table II: The Duncan grouping of bruise area and bruise volume for drop heights and counterface materials for Memecik and Domat varieties

Characters		Memecik		Domat	
		A_b (mm^2)	V_b (mm^3)	A_b (mm^2)	V_b (mm^3)
Drop height (m)	4.5	189.88^f	3450.02^f	91.07^c	2318.80^d
	3.5	122.09^e	2426.56^e	82.07^c	1895.98^{cd}
	2.5	95.20^d	1961.46^d	55,37^b	1513.14^{bc}
	1.5	68.01^c	1517.50^c	40.59^{ab}	971.46^{ab}
	1.0	49.53^b	1179.55^b	26.06^a	627.50^a
	0.5	36.36^a	631.98^a	-	-
Counterface materials	Steel	103.69^b	2138.33^b	77.50^b	1993.35^b
	Rubber	85.01^a	1684.13^a	53.20^a	1475.43^a
	Wood	88.83^a	1766.55^a	52.82^a	1609.79^a

Fig. 1: Three linear dimensions of the fruit on the digital image

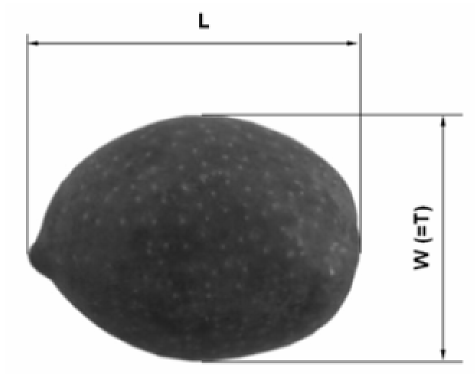


Fig. 2: Water column and camera setting

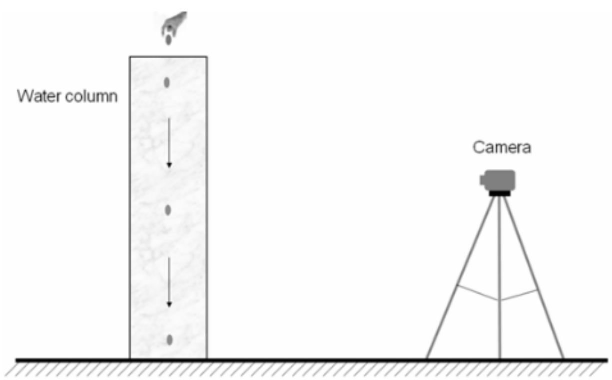
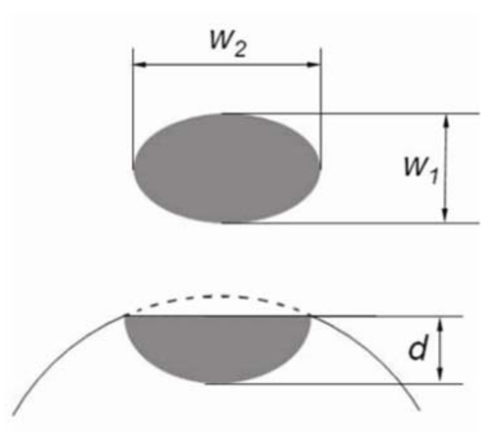


Fig. 3: Elliptical bruise thickness method for bruise determination



between two varieties. The mean values of terminal velocity of Memecik and Domat fruits were found to be 0.10 and 0.06 m s^{-1}, respectively. In comparison terminal velocity of these varieties, with considering other characters, can be concluded that terminal velocity increased with increasing of true density and decreasing of geometric mean diameter. For Memecik and Domat varieties the effective factor on

Fig. 4: Relationship between bruise areas and drop heights for olive impacts against different materials; stainless steel (○), rubber (□), wood (Δ)

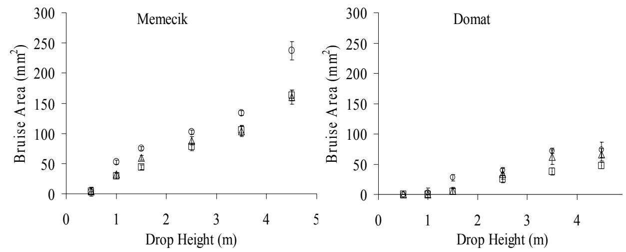
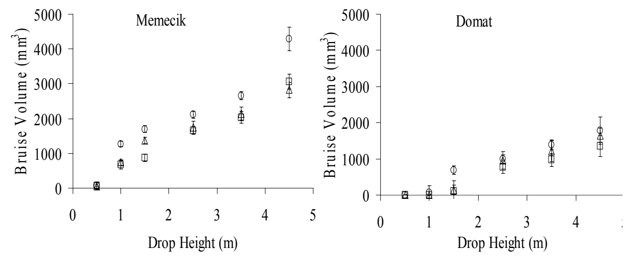


Fig. 5: Relationship between bruise volumes and drop heights for olive impacts against different materials; stainless steel (○), rubber (□), wood (Δ)



terminal velocity was true density, because of little difference in geometric mean diameter (varied from 23.93 to 23.57 mm) compare with difference in true density (varied from 1100.90 to 1051.75 kg m^{-3}). Similar results were found by Mirzaee *et al*. (2009) for tree apricot cultivars (Rajabali, Ghavami & Nasiry). However, Kheiralipour *et al*. (2008) reported a reverse relationship for terminal velocity of apple fruit. The buoyant and drag force were 0.06 and 0.006 N for Memecik variety, and 0.06 and 0.005 N for Domat variety, respectively. The analysis of variance revealed that drag force was significant ($p < 0.01$) between two varieties. The same statistical relationship has been noted by Mirzaee *et al*. (2009) for tree apricot cultivars.

Average olive bruise areas and volumes after impacts against three impact surfaces at varying drop heights for two varieties are shown in Figs. 4-5, respectively. In the case of fruit dropping on the three impact surfaces, the bruise area and bruise volume increased with the drop height. The greatest values of bruise area and bruise volume were obtained with the stainless steel. The bruise areas were 3.0, 52.4, 75.1, 102.3, 133.9 and 237.3 mm^2 for Memecik variety and 0.0, 2.6, 27.7, 39.7, 72.2 and 74.1 mm^2 for Domat variety impacts against stainless steel surface from drop height of 0.5, 1.0, 1.5, 2.5, 3.5, and 4.5 m, respectively.

In the case of fruit dropping on the three impact surfaces, good linear relationship were found between bruise area and drop height. For Memecik variety the coefficients of determination (R^2) for the wood, rubber, and stainless steel were 0.97, 0.99, and 0.94, respectively. For Domat variety R^2 for the wood, rubber, and stainless steel were 0.95, 0.97 and 0.95, respectively. Similar trends were obtained for bruise volume for Memecik and Domat varieties impacts against stainless steel surface from drop height of 0.5, 1.0, 1.5, 2.5, 3.5 and 4.5 m, respectively.

According to trade standard applying to table olives, which reported by International Olive Oil Council, blemished fruit is described as olives with marks on the skin that are more than 9 mm^2 in surface area and that may or may not penetrate through to the flesh (IOOC, 2009). It can be determined at what drop height this is exceeded for each of the surface materials, which is very useful information when designing equipment for harvesting and sorting or packaging media. On this study, the threshold (9 mm^2) has been exceeded for Memecik variety impacts against all surfaces for drop heights of more than 0.5 m. However, the limit heights were determined for the stainless steel as 1.0 m and for the wood and rubber as 1.5 m for Domat variety. The bruising has not observed at drop height of 0.5 m onto the all surfaces for Domat variety.

Impact surface materials, varieties and drop heights affected significantly bruise areas and volumes at $p < 0.01$ significance level. The changes of the bruise area and bruise volume due to drop height were found significantly different ($p < 0.01$) between stainless steel and others for both varieties (Tables II). These data show that bruises differ for the different impact surfaces from the same drop height, due to the different buffer capacities of the impact materials.

CONCLUSION

There were no significant differences in length, width, geometric mean diameter, sphericity, mass of fruit and surface area except projected area and true density between two varieties. The terminal velocity value of Memecik variety was 67% greater than that of Domat variety, whilst that drag force was also significant ($p < 0.01$) between two varieties. The highest bruise area and volume were obtained with stainless steel. The changes of the bruise area and bruise volume due to drop height were found significantly between stainless steel and others for both varieties.

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