https://doi.org/10.17221/5/2018-RAE

An evaluation of the physical, dynamic and aerodynamic properties of olives

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Citation: Akbarnia A., Rashvand M. (2019): An evaluation of the physical, dynamic and aerodynamic properties of olives. Res. Agr. Eng., 65: 48–55.

Abstract: The determination of the physical and mechanical properties of agricultural products has always been considered as the basis for the design and fabrication of transmission, grading, and processing equipment for agricultural products. Due to the increasing production of olives and the foreign exchange earnings from its trade, the mechanisation of harvesting and processing operations is inevitable. Therefore, the aim of this study was to evaluate the physical, dynamic and aerodynamic properties of olive species in order to design and fabricate an olive oiling machine. In this research, four species of olives, namely the Manzanilla, Kalamata, Fishemi, and Oily, were used. The physical properties of the samples were completely different. The mean dimensions of the Manzanilla species are the largest and the Oily is smallest and were the inverse in relation to the sphericity index. To determine the mechanical properties of the samples, the test material was used at a speed of 8 mm·min^{-1}. The results showed that the maximum and minimum power and energy of rupture were allocated to the Manzanilla and Oily species, respectively. The Oily samples have the most mechanical sensitivity when compared to the other samples. The aerodynamic properties of the olive species were measured using a wind tunnel. The highest velocity and drag coefficient were assigned to the Oily sample and the lowest values were assigned to the Kalamata sample.

Keywords: drag coefficient; fracture energy; fruit; mechanical properties

An olive tree or shrub is a plant that was cultivated long ago in several countries, particularly, the countries around the Mediterranean (Hoshyarmanesh et al. 2017). Because of the significant amount of oil and unsaturated fatty acids olives have come to humanity's attention (Herrera-Cáceres et al. 2017). The varieties which are special for making olive oil are, at first, pale in colour then proportionally get darker with the rate of ripening, this act causes the time when the olive is harvested to be different when considering the type of consumption (González et al. 2012). The weight of each olive grain with the proper oiling is almost 2–12 g (Sadeghi 2000). Olive plants are cultivated as a strategic product in countries that have favourable weather (El-Soaly 2008).

Inappropriate harvesting of the olive causes irreparable damage, like low fertility of this product, in the years to come (Zipori et al. 2014). To mechanise the mentioned operations, the olive's physical, mechanical and aerodynamic properties should be analysed. Overall, the determination of the physical and mechanical properties of the agricultural production as a basis to design and fabricate transmission machines, grading and product processing has been considered (Tavakoli et al. 2010; Rahim et al. 2017).

Studies on the mechanical properties of the agriculture production has long been the subject of

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discussion and critique of scientific circles and has attracted the attention of many researchers. Ghamary et al. (2010) have undertaken research about the mechanical properties of two kinds of olive, the Yellow and Oily varieties. For every olive, three dimensions including the width, diameter and volume were measured and based on that, the physical properties like the geometric diameter and sphericity were determined. They reported the appropriate angle for cutting both kinds of olive is 27.7° and the average hardship for the olive flesh is 2.392 N and for the olive core is 265.8 N (Ghamary et al. 2010).

Also, in regard to other agriculture production, a great deal of research has been undertaken. Laurier (2004), in the design of a watermelon dewatering system, investigated how breaking the watermelon skin is possible. Furthermore, the amount of the watermelon skin's shear force of 500 N was reported (Laurier 2004). In this research, in order to design and fabricate an oiling machine and investigate the efficiency parameters on the quality and quantity of machine, the power needed for chopping and crushing olive seeds, the following goals were followed: (*i*) the determination and investigation of the physical properties consist of the dimensions, the geometric diameter mean, the volume and the area of four types of olive - Oily, Fishemy, Manzanilla and Kalamata, (*ii*) the determination and investigation of the gravity properties consist of the density and real density, (*iii*) the force needed to rupture, chop and crush the four types of olive.

MATERIAL AND METHODS

Physical properties. In this research, the physical, mechanical and aerodynamic properties of four types of olive named Oily, Fishemi, Manzanilla and Kalamata were studied. The samples were obtained from the Ministry of Agriculture research station of Rudbar, located in the Gilan province. Four trees from each type were randomly selected and almost 1 kg of olives was harvested from different areas of each tree. Then, in order to determine the uniformity of the olive's moisture, the olives were transferred to the laboratory of mechanical properties. After 24 h, the samples were taken out from a refrigerator (Inferico AGN602MIX; Inferico, United Kingdom) and its moisture content was calculated using a standard oven-drying method by repeating the experiment three times for each type at 75°C, in an oven (SHCI55; Azmiran,Iran) for 24 hours. In this research, the data was analysed by a factorial experiment based on a completely random block plan. Also, the description of the symbols and abbreviations in Eqs 1–8 is reported in Table 1.

At first, the intact olives were separated from the unhealthy olives, and to measure the fruit dimensions from every type, 20 olives were selected randomly. The fruit mass and dimensions of the fruit were sequentially measured with a digital scale (KIA220; Kia, Iran) and digital callipers (Guanglu HB 101-111; Guanglu, China). The diameter of the arithmetic and geometric mean was obtained from Eqs 1 and 2:

$$D_{\mathrm{a}} = \frac{a+b+c}{3} \tag{1}$$

where: D_{a} – arithmetic mean diameter of the sample; a – length of the sample; b – width of the sample; c – thickness of the sample

$$D_{\mathrm{g}} = \left(abc\right)^{\frac{1}{3}} \tag{2}$$

where: D_{g} – geometric mean diameter of the sample

Generally, the factor used to describe the shape of the fruit is the spherical coefficient which was calculated from Eq. 3 (Mohsenin 1986):

$$\emptyset = \frac{D_{\mathrm{g}}}{a} \times 100 \tag{3}$$

where: $\emptyset$ – sphericity coefficient of the olive

Also, the schematic of the dimensions of the olive fruit is shown in Fig. 1.

According to Eq. 4, the liquid displacement method was used to calculate the olive's volume in order to the determine the olive's density:

$$p_{\mathrm{t}} = \frac{m_{\mathrm{t}}}{V_{\mathrm{t}}} \tag{4}$$

where: p_{t} – true density of the olive; m_{t} – mass unit of the olive; V_{t} – unit volume of the olive

To measure the density of the olive pile, an empty cylinder was filled with a certain volume of olives and then the pile density was obtained by dividing the mass pile by the volume pile (Eq. 5):

$$p_{\mathrm{b}} = \frac{m_{\mathrm{b}}}{V_{\mathrm{b}}} \tag{5}$$

where: p_{b} – bulk density of the samples; m_{b} – bulk mass of the samples; V_{b} – volume mass of the samples

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Table 1. The average physical properties of the olive samples

Property	Fishemi	Kalamata	Manzanilla	Oily
Length (mm)	20.55	24.25	23.14	21.40
Width (mm)	17.40	17.25	18.65	16.84
Thickness (mm)	17.10	16.63	17.12	16.05
Arithmetic mean diameter (mm)	16.28	18.54	17.87	18.47
Geometric mean diameter (mm)	18.97	18.33	19.14	18.02
Volume (mm^3)	3.22	4.55	4.12	4.84
Mass (g)	3.84	3.39	4.43	4.58
Moisture (%)	61.48	60.41	62.65	64.30
Sphericity coefficient (%)	78.55	76.54	75.65	81.25
True density (kg·m^{-3})	1,038.89	1,035.47	29.54	1,039.11
Density (kg·m^{-3})	539.74	538.39	535.41	540.50
Porosity (%)	46.87	46.10	46.59	46.30
Area (cm^2)	10.86	11.71	11.56	11.07

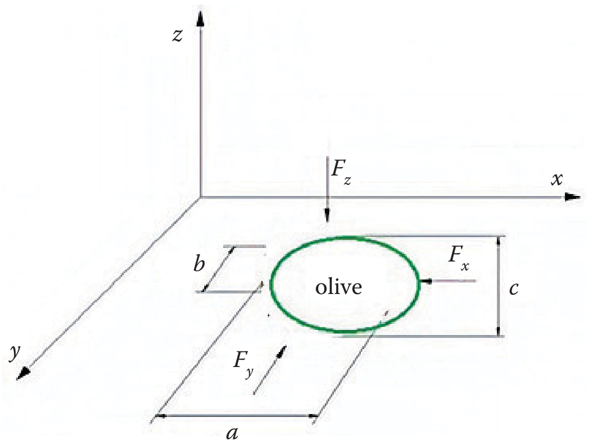

Fig. 1. The schematic of the dimensions of the olive fruit

a – length of the sample; *b* – width of the sample; *c* – thickness of the sample; F_x – longitudinal force; F_y – transverse force; F_z – external force of the device

Also, the percentage of the porosity pile was obtained by the pile density and solid density, using Eq. 6 (Tavakoli 2006):

$$\varepsilon = \left(1 - \frac{p_b}{p_t}\right) \times 100 \qquad (6)$$

where: ε – porosity of the olives

The olive stand friction angle was measured on three different friction surfaces including a galvanized sheet, an aluminium sheet and a steel plate. The angle of the slope surface was increased gradually with the screw mechanism of the machine and as soon the olives commenced sliding, the slope of the device was measured with an accuracy of 1° and the coefficient of the static friction angle was calculated using Eq. 7:

$$M_s = \tan(\alpha) \qquad (7)$$

where: M_s – stationary coefficient of friction; α – angle of the plate

Mechanical and aerodynamic properties. In order to measure, evaluate and determine the dynamic behaviour of the olive samples, the test material was used in a single axial compressive test in a Santam SMT-20 (Santam, Iran) and a 500 N Load Cell (Sensy, Belgium). The purpose of the single-axial pressure test is to draw the force-deformation curves of the olive between two plates at 8 mm·min^{-1} (Vursavuş, Özgüven 2004). The device consists of three main parts: a fixed jaw, a moving jaw, and a screen. Performing the test with 20 samples of each type, which were randomly selected was undertaken.

In order to obtain the limit speed, information obtained from a wind tunnel was used. The flow of air was transmitted through a tube of 70 mm in diameter. For measuring the air's speed, an AM-4206 (Lutron Electronic Enterprise Co., Ltd., Taiwan) with an accuracy of 0.01 m·s^{-1} was used. Also, the drag coefficient, which was required for the transfer and the separation of the pneumatic material, was obtained from Eq. 8:

$$C_d = \frac{2mg}{P_{aV_t^{2A}}} \qquad (8)$$

where: C_d – drag coefficient of the sample; m – mass; g – gravity; P_a – density of air; V_t – limit speed; A – area

https://doi.org/10.17221/5/2018-RAE

RESULTS AND DISCUSSION

Evaluation of the physical properties

Table 1 shows the results for the physical properties of four olive varieties. According to Table 1, the Manzanilla has a larger average size than the other varieties.

In Table 2, the mean values of the variance and skewness for each type of olive were determined. According to the results of Tables 1 and 2, it can be concluded that the standard deviation which was related to the length, width, arithmetic mean diameter, geometric mean diameter, mass and volume of the Fishemi variety were 1.11, 1.01, 1.44, 1.71, 0.725 and 0.645, respectively, which shows less dispersion than the average in comparison with the other varieties. Also, the standard deviation of the thickness and the area of the Oily sample with 1.04 and 0.887, had less discrepancy than the average. Furthermore, in regard to the result of Kalamata, 3.782 and 0.003 indicate the moisture and porosity factors, respectively.

Regarding the results of the variance of the physical properties of olive, the effect of the variety on the length, geometric mean diameter, mass, and volume were significant at the 1% level and only the density index was significant at the 0.05% level. The results that were derived in the table of variance of

Table 2. The mean values of the variance and skewness for each type of olive

Property	Fishemi		Kalamata		Manzanilla		Oily	
	SD	skewness	SD	skewness	SD	skewness	SD	skewness
Length (mm)	1.11	–0.185	1.36	–0.152	1.24	–0.177	1.19	–0.191
Width (mm)	1.01	–0.142	1.10	–0.151	1.08	–0.146	1.02	–0.128
Thickness (mm)	1.05	–0.168	1.09	–0.185	1.07	–0.177	1.04	–0.169
Arithmetic mean diameter (mm)	1.44	–0.331	1.69	–0.353	1.57	–0.348	1.52	–0.339
Geometric mean diameter (mm)	1.71	–0.485	1.87	–0.496	1.80	–0.490	1.73	–0.488
Volume (mm^3)	0.645	0.005	0.770	0.014	0.684	0.010	0.745	0.12
Mass (g)	0.725	0.002	0.741	0.018	0.802	0.026	0.855	0.0244
Moisture (%)	3.981	–1.254	3.782	1.169	3.989	–1.275	4.005	–1.367
Sphericity coefficient (%)	4.722	–1.865	4.539	–1.608	4.341	–1.432	4.852	–1.900
True density ($kg \cdot m^{-3}$)	96.254	–0.194	101.874	–0.208	108.245	–0.231	105.685	–0.211
Density ($kg \cdot m^{-3}$)	35.452	–0.201	34.121	–0.182	33.886	–0.199	37.255	–0.214
Porosity (%)	2.365	–0.388	2.119	–0.326	2.315	–0.301	2.245	–0.271
Area (cm^2)	0.944	0.003	0.936	0.003	0.904	0.003	0.887	0.002

SD – standard deviation

Table 3. The results of the variance of the physical properties of the olive

Variable	Degree of freedom	Length	Arithmetic mean diameter	Geometric mean diameter	Mass	Volume	Density
Sample	3	169.27**	14.20**	7.351**	4.28**	2.69**	587.75*
Error	109	1.36	0.711	0.742	28.64	0.257	173.9

**significant at the 1% level; *significant at the level of 0.05%

Table 4. The results of the friction coefficient of the olive species on the different surfaces

Sample	Surface type		
	aluminium sheet	galvanized sheet	steel plate
Manzanilla	26.5	27.8	22.4
Kalamata	26.10	26.25	24.75
Fishemi	19.85	20.45	17.25
Oily	22.1	22.5	20.85

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the olive present that several indexes such as the length, arithmetic mean diameter, geometric mean diameter, mass, volume and density had an effect on the physical properties of the olive (Table 3).

The static friction angle of the olive was measured on three different friction surfaces including a galvanized sheet, an aluminium sheet and a steel plate. According to Table 4, it can be concluded that the olive varieties on the galvanized sheet need less force for moving than the aluminium and the steel sheet. Due to the amount of significance that was gained at 0.001, it can be concluded that the sphericity coefficient of all the varieties are affected by the friction coefficient.

Evaluation of the mechanical and aerodynamic properties

In order to obtain the dynamic properties, the samples were prepared separately and put into an wind tunnel and the samples aerodynamic properties were investigated. The limit speed and drag coefficient are directly related to the mass of the product. Therefore, according to Table 5 and Fig. 2, the Oily and Kalamata variety have the highest and the lowest average limit speed among the varieties with the values of 23.59 and 21.47 $m \cdot s^{-1}$, respectively. Due to the fact that the amount of oil in the Oily sample was higher than the other varieties, it had a significant effect on the grain weight. The Kalamata's olive texture weighed less because of its low meat content than the other samples, which indicate the speed limit was low.

Table 5. The average results of the aerodynamic properties of the olive species

Sample	Aerodynamic property	
	limit speed ($m \cdot s^{-1}$)	drag coefficient
Manzanilla	22.93	0.58
Kalamata	21.47	0.49
Fishemi	21.84	0.54
Oily	23.59	0.63

The rupture force was measured for all the olive samples. With reference to Fig. 3a, it can be concluded that there was a direct relationship between the thickness of the olive and the rupture force. The highest rupture force was observed in the Manzanilla sample with a thickness of 19.75 mm and a force of 181.36 N and the lowest in the Oily sample with a thickness of 14.24 mm and a force of 70.55 N.

Also, the rupture energy was obtained by calculating the level below the graph. In regard to the relationship between the rupture energy and the rupture force, the failure energy also increased when increasing the diameter. According to Fig. 3b, the Manzanilla, Fishemi, Kalamata and Oily varieties had the highest to the lowest rupture energies.

The mean rupture force, rupture energy and toughness are shown in Table 6. The Fishemi and Oily varieties showed the highest and lowest toughness with the values of 0.081 and 0.045 $J \cdot mm^{-3}$, respectively. Also, according to Table 6, the results of the comparison of the mean energy, force, and toughness in the different varieties were different.

In comparison to the research that was performed outside of Iran on the varieties of olives, it can be concluded that the results of this research were slightly different from the other studies. Kılıçkan and Güner (2008) reported 25.25 mm, 18.06 mm,

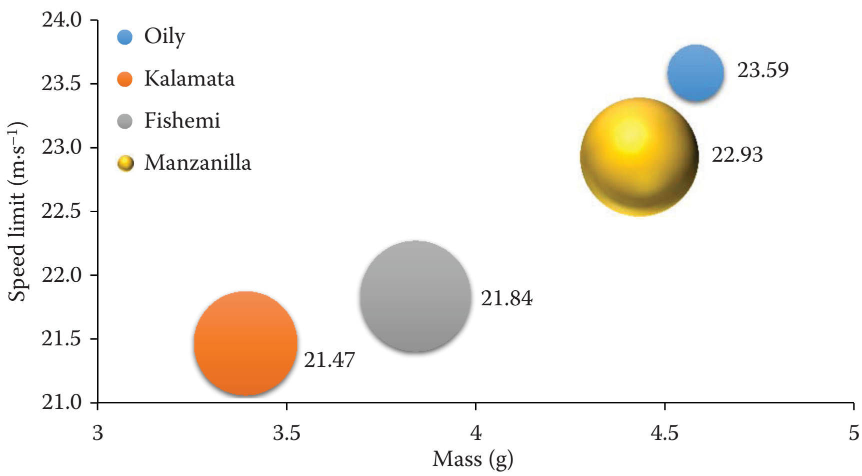

Fig. 2. The effect of the sample mass on the speed limit

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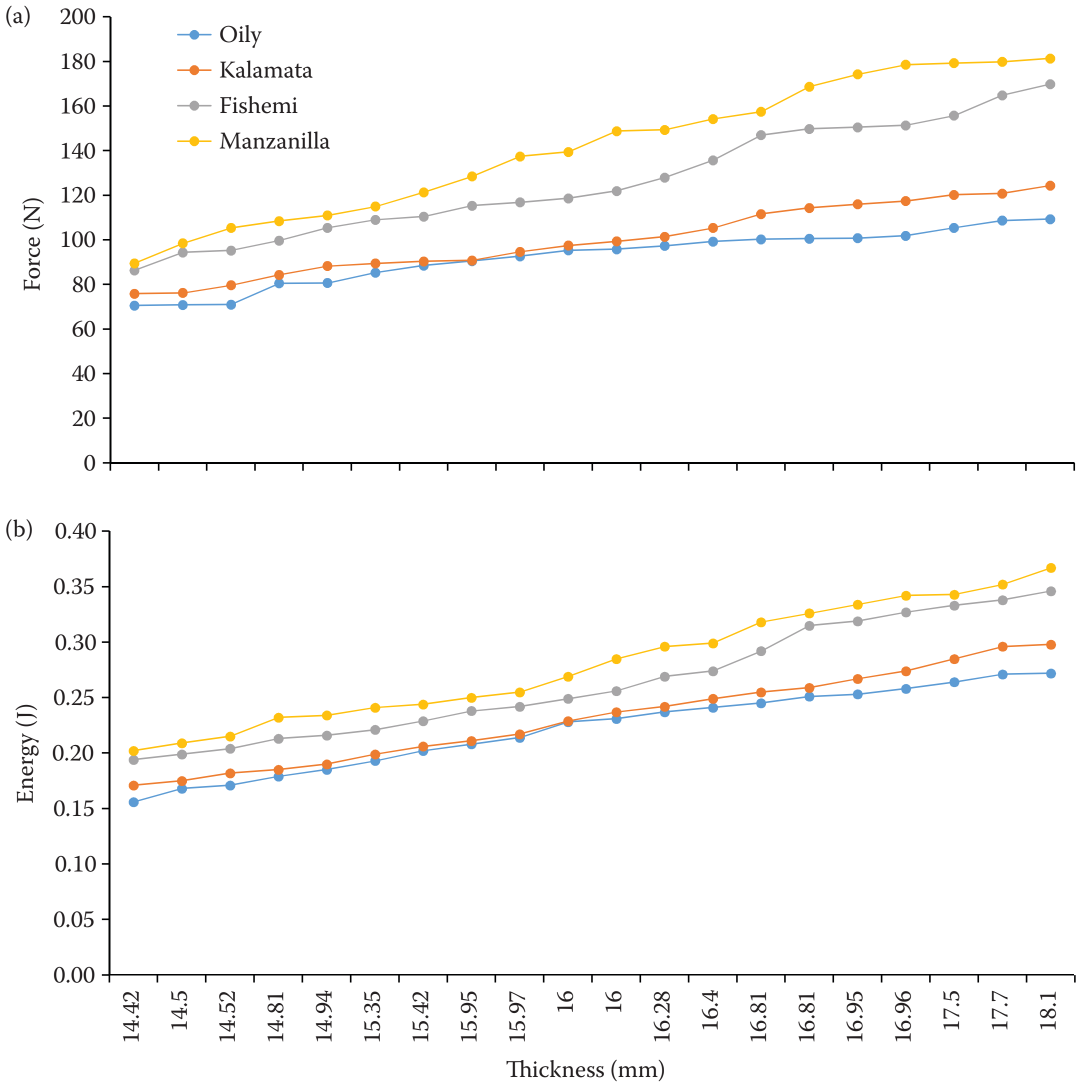

Fig. 3. Changes in the rupture force (a), rupture energy (b) in the olive cultivars

21.57 mm, 4.15 g and 0.854% for the length, thickness, geometric mean diameter, mass, and spherical coefficient of an olive fruit sample, respectively. The amount of the force and rupture energy for the olive fruit were reported to be 57.38 N and 0.257 J, respectively, and for the olive kernel were 320 N and 1.53 J, respectively. Also, Lavasani et al. (2008) studied the Mari and Oily variety and obtained the maximum force, maximum energy and toughness at a significant 1% level. They obtained the highest amount of the rupture force, fracture energy and toughness for the Oily sample of 60.91 N, 152.181 J and 0.053 J·mm^{-3}, respectively, at the time of 6 days after harvest, and the lowest amount of the rupture force, fracture energy and toughness was reported for Mari sample (Lavasani et al. 2008). Hezbavi et al. (2009) performed a study of the physical and mechanical properties of a sample of olive and its core. Based on the findings of this study, the highest static friction coefficient for the olive fruit on the rubber surface and for the olive core was found to be 5.31 and 8.32, respectively, the lowest static friction co-

Table 6. The mean and comparison of the average effect of the sample on the mechanical properties of the olive species

Sample	Rupture energy (J)	Rupture force (N)	Toughness (J·mm^{-3})
Manzanilla	0.280^{A}	141.315^{A}	0.067^{A}
Kalamata	0.231^{c}	99.900^{B}	0.050^{B}
Fishemi	0.263^{B}	126.294^{c}	0.081^{C}
Oily	0.221^{B}	92.264^{A}	0.045^{C}

In each column, the averages with a common letter do not have a significant difference

https://doi.org/10.17221/5/2018-RAE

efficient was found to be 3.91 and 7.85 for the olive fruit and for its core on the rubber surface, respectively. The average failure force, rupture strength and toughness were 221 N, 297 J and 0.071 J·mm^{-3} for the olive fruit and 589 N, 394 J and 0.214 J·mm^{-3} for the olive core, respectively (Hezbavi et al. 2009). According to results of the Hezbavi et al. (2009) experiment, it can be concluded that the physical and mechanical properties of the olive sample that was used in that experiment were similar to Manzanilla olive and also, compared to all of the samples in this experiment, it has higher values. Also, according to Saracoglu et al. (2011), the drag coefficient of the Memecik and Domst samples were 2.7 and 3.6, respectively. Whereas the drag coefficient in this experiment was below this for all of the samples (Saracoglu et al. 2011). In this research, compared to other research, four different olives with a high consumption proportion were used. In order to obtain the coefficient of friction of the samples, three different levels were used. Usually, the levels used in this study are used in olive processing machines. In addition, the speed limit of the olive samples was measured using a wind tunnel. Due to the use of pneumatics in some processing units, the aerodynamic properties were also studied.

CONCLUSION

The evaluation of the physical properties was shown that the length, width, thickness, mass and volume have a direct relationship with the geometric mean diameter and have an inverse relationship with the density and spherical coefficient. In other words, as the size of the olive increased, the density and spherical coefficient decreased. The results of the aerodynamic properties indicated that the speed limit had a direct relationship with the mass and moisture content of the olive species. Olive oil, in contrast to the higher susceptibility to other species, had the lowest power and failure energy, had the highest speed and drag coefficient. Awareness of the mechanical properties of olives has a paramount role in the design and fabrication of machines such as olive harvesting machines or oiling machines. In Iran, the use of these species was widely used. Recently, due to the large amount of olive cultivation, engineers are designing and evaluating devices in accordance with the mechanical properties of olives. In this research, we have tried to provide useful information to engineers as well as future researchers in order to evaluate the properties of olives.

Acknowledgement

The authors would like to thank to the Machine Design and Mechatronics Department, the Institute of Mechanics, the Iranian Research Organization for Science and Technology for their contribution to this study.

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Received for publication January 17, 2018
Accepted after corrections November 12, 2018