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Evaluation of Engineering Properties in Almond Nuts

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Abstract

This study was conducted to evaluate different physical and mechanical properties in almond nuts of ten cultivars including dimensions, arithmetic and geometric mean diameters, sphericity, surface area, almond mass, bulk and true densities, porosity, angle of repose, projected area, coefficient of static friction and rupture force. Multi-linear models for the ten almond cultivars were developed and presented to predict the nut surface area. According to the results ‘Mamaei’ cultivar had highest length of nut and thickness and ‘Sahand’ cultivar had highest width than the other cultivars. Nut of ‘Mamaei’ cultivar was significantly heavier than the rest of cultivars. Similarly, it was found highest the arithmetic and geometric mean diameters, surface area, and projected area for ‘Mamaei’ nuts. Highest value of sphericity, true density, bulk density, porosity, angle of repose, and rupture force was found for the nuts of ‘V-9-17’, ‘Shahrood17’, ‘Shahrood17’, ‘V-3-16’, and ‘Sahand’ cultivars, respectively. On the plywood, glass, and galvanized iron sheet surfaces, the coefficient of static friction of the nuts of ‘Shahrood17’, ‘V-13’, and ‘V-3-16’ cultivars was significantly greater than that of the other cultivars.

Keywords: agricultural products, friction, mechanical behavior, Physical attributes, size distribution.

INTRODUCTION

Agricultural and food products have several unique characteristics which set them apart from engineering materials. Design of machines and process to harvest, handle and store agricultural materials and to convert these materials in to food and feed requires an understanding of their physical properties [1, 2]. In this sense, some studies have reported on the physical and mechanical properties of nuts, kernels, seeds and fruits in several species such as soya [3], sunflower [4], arecanut [5], hazelnuts [6], pigeon pea [7], pistachio [8, 9], simarouba [10], apricot kernels [11] and pits [12], cumin seed [13, 14] or rapeseed [15]. In fact, the output of agricultural and processing machines depends on these engineering properties [1].

In the case of almond [Prunus dulcis (Mill.) D.A.Webb; syn. P. amygdalus Batsch], after harvesting, nuts are subjected to different treatments, such as cracking almonds and removing the nuts. A significant proportion of almond production is used in the peeled form. The mechanical properties of almond nuts, like those of other fruits, grains and seeds, are essential for the design of equipment for harvesting, cracking, peeling, and processing of almond. The size and shape are important in designing of separating, harvesting, sizing and grading machines. In addition, bulk density and porosity affect the structural loads at silo. The angle of repose is important in designing of storage and transporting structures. The coefficient of friction of the almond against the various surfaces is also necessary in designing of conveying, transporting and storing structures. The development of satisfactory harvesting and processing methods are greatly influenced by the physical and mechanical properties of the product. However in this species there are few studies which did not show relevant information about mechanical characteristics of the nuts such as the physical and mechanical behavior under compression loading [16-18].

The objectives of this study were to determine physical and mechanical properties of almond nuts including dimensions, arithmetic and geometric mean diameters, sphericity, surface area, almond mass, bulk and true densities, porosity, angle of repose, projected area, coefficient of static friction and rupture force, to develop appropriate technologies for its processing.

MATERIAL and METHODS

Plant material

Nine Iranian almond cultivars including 'V-13', '9-17', '3-16', 'Shahrood15', 'Sahand', 'Mamaei', 'Yalda', 'Sefid', and 'Shahrood17' and an Italian cultivar 'Fragile' were included in the study (Figure 1). The almond nuts were obtained from the 2008 growing season at the experimental farm of the Plant and Seed Research Organization (PSRO) in Kamal Abad of Karaj (Iran). The almond nuts were cleaned in an air screen cleaner where all foreign matter such as stones and chaff as well as immature and broken nuts were removed. Then, they were stored in plastic buckets with cover and kept in cold storage at 5 °C. Finally, almond nuts were kept at room temperature of 20–25 °C for 3 h before making any measurement.

Determination of geometrical properties

Cross sectional areas (CSAs) in three perpendicular directions of the almond, using area measurement system Delta-T England. Dimensional characteristics obtained from this device are based on image processing. Captured images from a camera are transmitted to a computer card which worked as an analog to digital converter. Digital images are then processed in the software and the desired user needs are determined. Through three normal images of the almond nut (PA_1, PA_2 and PA_3 as first, second and third projected area in m^2), this device is capable for determining the minor, intermediate and major diameters of nuts as well as projected areas perpendicular to dimensions. Total error for these measurements is less than 2% [19]. The average projected areas (CPA), arithmetic mean diameter (D_a), geometric mean diameter (D_g), and the sphericity (ψ) were calculated using the following relationships [1]:

$$CPA = \frac{PA_1 + PA_2 + PA_3}{3}$$

$$D_a = \frac{L + W + T}{3}$$

$$D_g = (LWT)^{1/3}$$

$$\psi = \frac{(LWT)^{1/3}}{L}$$

where L is the major diameter (mm), W is the intermediate diameter and T is the minor diameter.

Nut surface area (S) was calculated using the formula stated by Jain and Bal [20]:

$$S = \frac{\pi L^2 \sqrt{WT}}{(2L - \sqrt{WT})}$$

Determination of gravimetrical properties

Almond nut mass was measured by weighing them in an electronic balance to an accuracy of 0.001 g. The average bulk density (ρ_b) of the almond was determined using the standard test weight procedure [13] by filling a container of 500ml with the almond nuts from a height of 150mm at a constant rate, weighting the content and use the following formula:

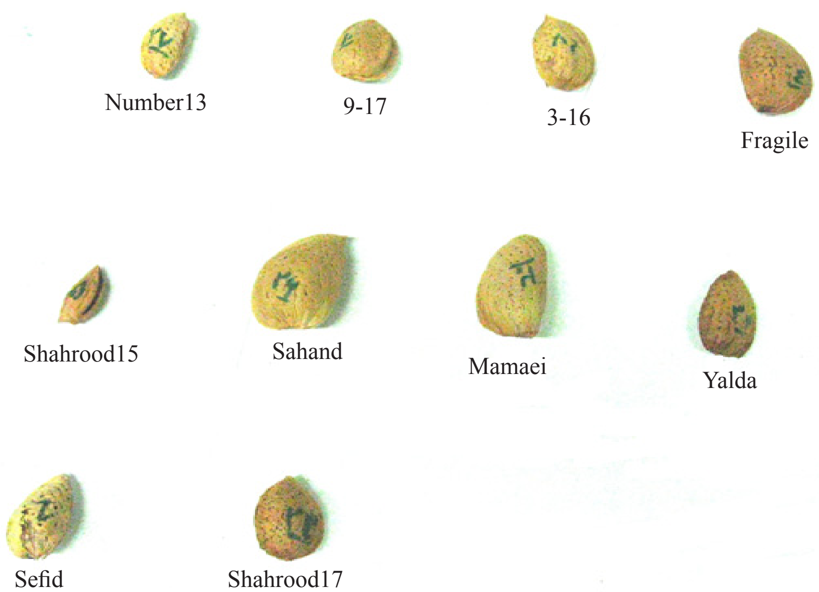

Figure 1. Ten different species of almond cultivars

$$\rho_b = \frac{W_s}{V_s}$$

where W_s is the mass of the sample (kg) and V_s is the volume occupied by the sample (m^3).

The average true density was determined using the toluene displacement method. The volume of toluene displaced was found by immersing a weighed quantity of almond in the toluene [14, 15]. Porosity (ε) was calculated from the values of bulk (ρ_b) and true (ρ_t) densities using the following relationship:

$$\varepsilon = (1 - \frac{\rho_b}{\rho_t}) \times 100$$

Determination of repose angle and frictional properties

The method of Mollazade et al. [14] was adopted to determine the angle of repose. Used device was consisting of a plywood box and two plates: fixed and adjustable. The box was filled with the sample and then the adjustable plate was inclined gradually allowing the almond nuts to follow and assume a natural slope. Coefficient of static friction was measured by a frictional device with the galvanized iron, glass, and plywood surfaces. For this measurement, the material was placed on the surface and it was gradually raised by the screw. Slip angle was read from the gauge of device when the material started sliding over the surface and then, using the tangent value of the angle so that the coefficient of friction was found.

Determination of rupture strength properties

The rupture strength was tested to know the magnitude of the force that was required to break the almond nuts when the almonds are an axial dimension. Rupture forces were measured using an Instron Universal Testing Machine (Model Santam STM-5) with 250N capacity. The loading velocity of the machine was constant at 10 mms^{-1} during measurements. For each test, a single almond nut was placed on its intermediate diameter axes on a flat steel washer and then compressed with a plate probe.

Statistical analysis

Variance analysis (ANOVA) was carried out on the cultivars, and the difference between the mean values was investigated by using the Duncan's multiple range tests [21]. Mean values were reported with the standard deviation. Correlation coefficients between almond dimensions and surface area were determined by Pearson correlation matrix method using SPSS 17.0 for Windows.

RESULTS and DISCUSSION

Size distribution and physical properties of cultivars

Figures 2 to 4 show the frequency distribution curve of major, intermediate, and minor diameter of almond cultivars, respectively. The frequency distribution curve of major diameter of the 'V-13', 'Shahrood15', 'Sefid', and 'Sahand' showed a trend towards a normal distribution. Normal distribution trend in the intermediate diameter was seen for 'V-13', 'Shahrood15', 'Yalda', 'Sefid' and 'Shahrood17'. Figure 4 also shows that 'V-3-16', 'Shahrood15', 'Sahand', 'Yalda', 'Sefid', and 'Shahrood17' have a trend towards a normal distribution in their minor diameter. A similar trend is reported by Unal et al [15] for three different cultivars of rapeseeds.

On the other hand, Table 1 shows the size distribution of almond cultivars. Longitudinal dimension (L) ranged from 12.71 to 42.25 mm. The majority of almond nuts (about 100% of 'V-13', 88% of 'V-9-17', 100% of 'V-3-16', 66% of 'Fragile', 100% of 'Sefid' and 98% of 'Shahrood17') were medium-sized (18-32 mm). Also the majority of nut from 'Sahand' (94%), 'Mamaei' (98%), and 'Yalda' (60%) cultivars were large-sized (>32 mm) and the majority of 'Shahrood15' (82%) cultivar was small sized (<18 mm) based on major diameter

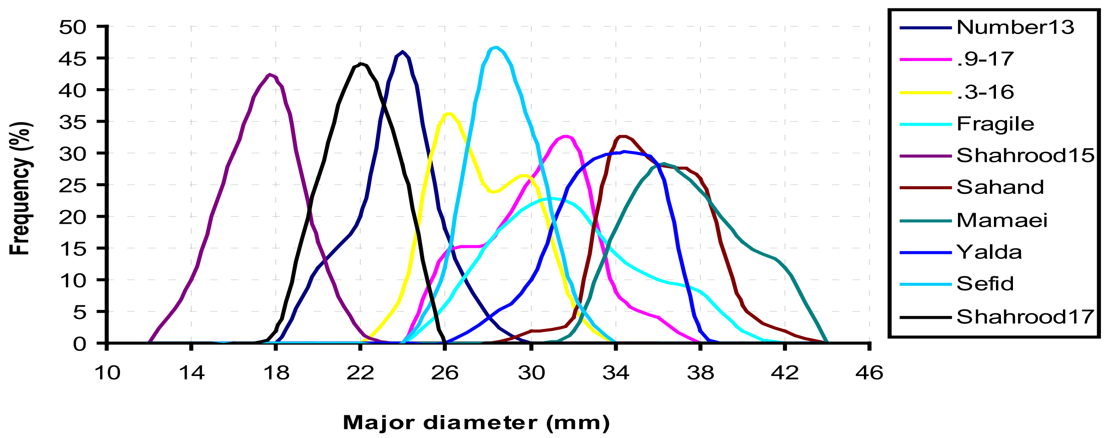

Figure 2. Frequency distribution curve of major diameter of almond cultivars

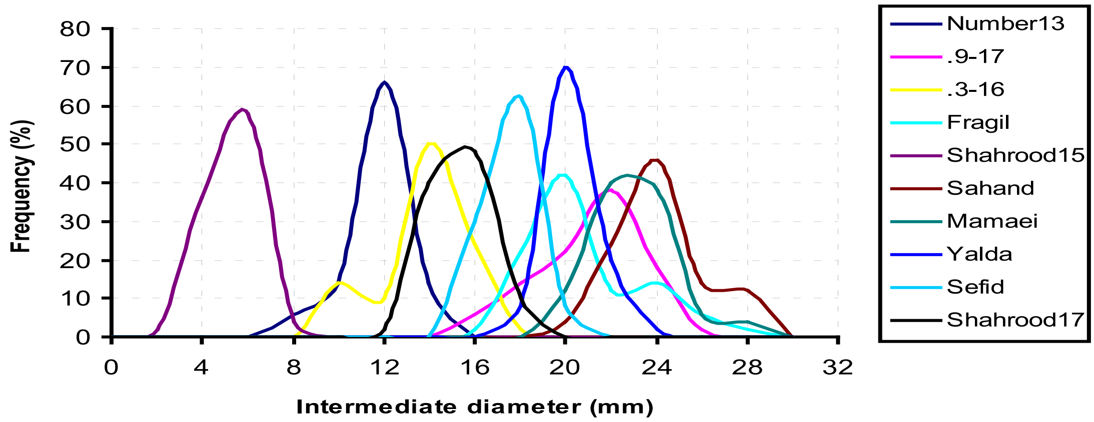

Figure 3. Frequency distribution curve of Intermediate diameter of almond cultivars

Table 1. Size distribution of nuts of the almond cultivars assayed based on major, intermediate, and minor diameters.

Size category				Cultivar
Large*	Medium*	Small*	Ungraded*	
>32 mm	18-32 mm	<18mm		Major diameter
-	18.63-27.99 (100)	-	18.63-27.99 (100)	'V-13'
32.00-34.13 (12)	24.04-31.83 (88)	-	24.04-34.13 (100)	'V-9-17'
-	23.28-31.39 (100)	-	23.28-31.39 (100)	'V-3-16'
32.11-39.21 (34)	24.65-31.83 (66)	-	24.65-39.21 (100)	'Fragile'
-	18.16-20.60 (18)	12.71-17.99 (82)	12.71-20.60 (100)	'Shahrood15'
32.39-42.25 (94)	29.36-31.94 (6)	-	29.36-42.25 (100)	'Sahand'
32.30-41.97 (98)	31.37-31.83 (2)	-	31.37-41.97 (100)	'Mamaei'
32.07-36.47 (60)	27.84-31.38 (40)	-	27.84-36.47 (100)	'Yalda'
-	24.40-30.91 (100)	-	24.40-30.91 (100)	'Sefid'
-	19.05-23.46 (98)	17.34-17.92 (2)	17.34-23.46 (100)	'Shahrood17'
32.00-42.25 (298)	18.16-31.94 (618)	12.71-17.99 (84)	12.71-42.25 (1000)	Total
>19 mm	7-19 mm	<7 mm		Intermediate diameter
-	7.60-13.33 (98)	6.25-6.93 (2)	6.25-13.33 (100)	'V-13'
19.02-24.60 (80)	15.50-17.48 (20)	-	15.50-24.60 (100)	'V-9-17'
-	8.53-16.20 (100)	-	8.53-16.20 (100)	'V-3-16'
19.14-26.14 (50)	15.58-18.80 (50)	-	15.58-26.14 (100)	'Fragile'
-	-	1.98-6.32 (100)	1.98-6.32 (100)	'Shahrood15'
19.35-27.84 (100)	-	-	19.35-27.84 (100)	'Sahand'
19.38-27.91 (98)	18.53-18.56 (2)	-	18.53-27.91 (100)	'Mamaei'
19.05-23.29 (64)	16.86-18.95 (36)	-	16.86-23.29 (100)	'Yalda'
-	14.96-18.46 (100)	-	14.96-18.46 (100)	'Sefid'
-	11.88-16.58 (100)	-	11.88-16.58 (100)	'Shahrood17'
19.02-27.91 (392)	7.60-18.80 (506)	1.98-6.93 (102)	1.98-27.91 (1000)	Total
>16 mm	5-16 mm	<5 mm		Minor diameter
-	5.03-11.18 (84)	3.31-4.75 (16)	3.31-11.18 (100)	'V-13'
16.05-17.35 (20)	9.86-15.88 (80)	-	9.86-17.35 (100)	'V-9-17'
-	5.02-7.51 (46)	2.77-4.97 (54)	2.77-7.51 (100)	'V-3-16'
-	6.13-14.25 (100)	-	6.13-14.25 (100)	'Fragile'
-	-	0.68-3.89 (100)	0.68-3.89 (100)	'Shahrood15'
16.03-21.11 (36)	13.86-16.00 (64)	-	13.86-21.11 (100)	'Sahand'
16.09-19.71 (58)	12.98-15.97 (42)	-	12.98-19.71 (100)	'Mamaei'
-	10.73-14.26 (100)	-	10.73-14.26 (100)	'Yalda'
16.01-16.06 (4)	12.11-15.92 (96)	-	12.11-16.06 (100)	'Sefid'
-	6.4-11.28 (100)	-	6.4-11.28 (100)	'Shahrood17'
16.01-21.11 (118)	5.02-16.00 (712)	0.68-4.97 (170)	0.68-21.11 (1000)	Total

* Range and frequency (%) in parentheses.

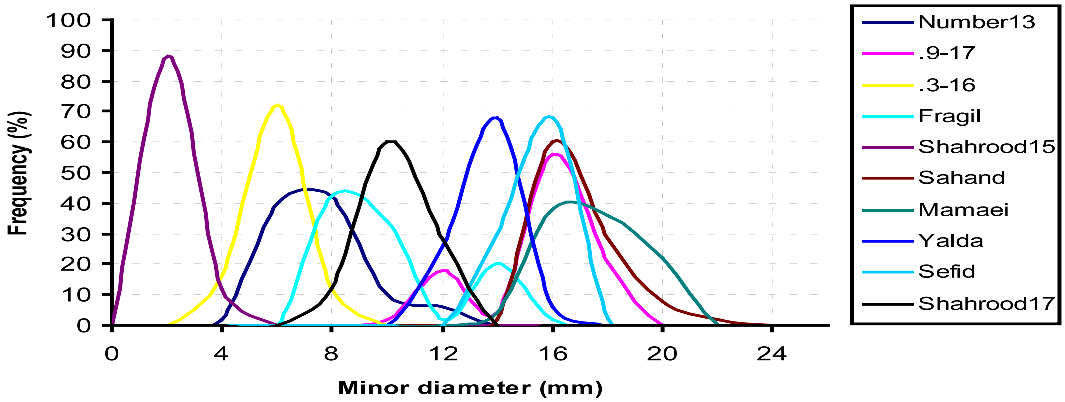

Figure 4. Frequency distribution curve of minor diameter of almond cultivars

Table 2. Physical and mechanical properties of the nuts of the almond cultivars assayed.

Characteristics	Replic.	'V-13'	'V9-17'	'V-3-16'	'Fragile'	'Shahrood15'	'Sahand'	'Mamaei'	'Yalda'	Sefid	'Shahrood17'	Level
Moisture (% d.b.)	3	1±0.3 e	2.5±0.5 a	1.3±0.3 bc	4±0.1 d	6±0.1 f	3±0.2 d	2.5±0.4 a	2.2±0.2 a	1.1±0.3 c	1.5±0.3 b	*
Major diam. (mm)	100	22.96±1.5 h	30.30±1.27 e	27.05±1.67 g	30.58±4.1 d	15.00±1.04 j	35.78±2.41 b	36.05±2.57 a	31.75±2.01 c	27.48±2.31 f	20.7±0.59 i	*
Interm. diam. (mm)	100	10.38±1.2 g	20.87±1.97 c	13.24±2.32 f	20.64±3.21 c	4.05±0.99 h	24.18±2.50 a	22.99±1.40 b	19.25±0.81 c	16.98±1.32 d	13.9±0.71 e	*
Minor diameter (mm)	100	6.65±1.2 e	15.32±0.95 b	5.34±0.64 f	9.69±2.72 d	1.18±0.47 g	16.54±1.29 a	17.32±1.42 a	12.48±0.68 c	13.94±1.71b	9.77±0.37 d	*
G. mean diam. (mm)	100	11.66±1.5 f	20.29±2.17 b	11.86±1.37 f	17.66±2.83 d	4.64±0.71 g	23.49±1.58 a	23.67±1.58 a	19.81±1.06 b	18.76±0.86 c	13.9±0.97 e	*
A. mean diam. (mm)	100	13.40±1.4 e	21.19±2.07 b	14.79±1.36 d	19.89±2.70 c	7.33±0.81 f	24.73±1.65 a	25.03±1.63 a	21.37±1.19 b	19.58±90 c	14.7±0.92 d	*
Sphericity (%)	100	51±5 f	70±5 a	45±4 g	57±4 e	28±4 h	67±2 b	65±3 c	61±2 d	68±2 b	67±4 b	*
Surface area (mm^2)	100	372.2±95 g	1108.9±226 b	393.52±85 g	848.4±281 e	69.8±18.60 h	1465.6±202 a	1486±200 a	1038.3±111 c	933.6±85.7 d	520±72.3 f	*
Almond mass (g)	100	1.74±0.74 b	3.80±0.38 a	1.42±0.48 b	4.16±0.59 a	0.67±0.07 b	4.18±1.09 a	4.37±0.84 a	2.13±0.31 b	1.51±0.64 b	1.97±0.30 b	**
Bulk density (kg/m^3)	10	280±10 d	480±20 a	290±10 d	460±30 a	320±20 c	390±10 b	370±20 b	290±10 d	280±20 d	320±10 c	*
True density (kg/m^3)	10	1010±40 d	1080±30 b	1040±20 c	880±10 e	1060±30 bc	870±20 e	1040±10 c	790±10 f	860±20 e	1260±40 a	*
Porosity (%)	10	72±2 b	55±1 e	72±1 b	48±3 f	70±2 b	56±2 e	65±1 cd	63±3 d	67±2 c	75±1 a	*
Rupture force (N)	10	54.1±12.7 d	893.7±134.2 b	58.42±18.61 d	420.4±44.0 c	15.11±6.81 d	1265.2±172 a	704.6±28.3 b	182.0±9.1 d	86.4±2 d	195.6±1 d	*
Angle of repose (deg)	10	38±2 cd	32±5 e	53±3 a	42±1 bc	40±1 bc	35±1 de	40±1 bc	32±3 e	43±2 b	36±3 de	*
First proj. area (mm^2)	10	230.1±77 d	361.1±59.1 a	215.9±77.1 e	314.4±13.2 b	156.7±72.1 f	338.7±96.2 b	412.9±43.6 a	227.1±29.8 d	216.2±59 de	277.1±7.9 c	*
2° proj. area (mm^2)	10	372.5±91 d	472.8±79.7 c	371.0±85.6 d	475.9±52.7 c	193.0±30.6 f	508.1±100.7 b	645.6±39.6 a	371.7±5.6 d	348.9±29.2 e	372.3±14 d	*
3° proj. area (mm^2)	10	465.6±59d	610.7±52.8 c	602.9±223.6 c	833.9±28.9 b	278.5±35.2 f	737.5±200 bc	946.7±219 a	582.4±35.7 c	382.1±63.9 e	382.1±63 e	*
Crit. proj. area (mm^2)	10	331.6±52 f	472.94±49.2 c	361.04±58 e	531.51±64 b	192.39±28 g	567.22±78.1 a	576.96±80 a	407.72±42.7 d	316.84±32.8 f	364.9±35 e	*
Coeff. static friction on												
Plywood	10	0.445±0.052 bA	0.325±0.017 cA	0.424±0.052 bB	0.286±0.035 c	0.487±0.052 bA	0.305±0.017 c	0.305±0.017 cB	0.466±0.035 bA	0.249±0.035 cB	0.509±0.017 aA	*
glass	10	0.404±0.035 aAB	0.325±0.017bA	0.344±0.017bB	0.286±0.035 c	0.267±0.017 cC	0.286±0.017 c	0.305±0.017 cB	0.364±0.035 abB	0.404±0.017aA	0.404±0.017aB	*
galvanized iron	10	0.325±0.035 cdeB	0.249±0.035 eB	0.509±0.052 aA	0.325±0.035 cde	0.305±0.017 cdeB	0.267±0.035 e	0.364±0.017 cdA	0.445±0.017 bA	0.383±0.035 cA	0.404±0.035 bB	*
Significant level	10	**	*	**	Ns	**	Ns	*	**	**	*	

Ns: not significant. Standard deviation values are in ±. a-j letters indicate the statistical difference in rows.
A–C letters indicate the statistical difference in columns for coefficient of static friction.
* Significant level at 5%. ** Significant level at 1%.

dimensions.

Furthermore, latitudinal dimension (W) of almonds ranged from 1.98 to 27.91 mm. The five of cultivars (about 98% of 'V-13', 50% of 'Fragile', and 100% of 'V-3-16', 'Sefid', and 'Shahrood 17') were medium-sized (7-19 mm), while the 'V-9-17' (80%), 'Fragile' (50%), 'Sahand' (100%), 'Mamaei' (98%), and 'Yalda' (64%) cultivars were large-sized (>19 mm) and only 'Shahrood15' cultivar (100%) was small-sized (<7mm). Vertical dimension (T) of almonds ranged from 0.68-21.11 mm. The majority of almonds (about 84% of Number 13, 80% of 9-17, 100% of Fragile, 64% of Sahand, 100% of Yalda, 96% of Sefid, and 100% of Shahrood 17 by number) were medium-sized (5-16 mm). The two of cultivars (about 54% of 3-16 and 100% of Shahrood15) were smaill-sized (<5mm) and mamaei cultivar (58%) was large-sized (>16 mm) (Table 1).

Stroshine [2] reported that the particle size distributions of agricultural products influence their handling, storage and utilization characteristics. Also, when agricultural materials such as oilseeds, almond, and hazelnut are ground in mills, the distribution of particle sizes must be known in order to achieve desirable properties without unnecessary expenditure of energy.

As seen in Table 2, all of the physical and mechanical properties of the cultivars considered in the current study were found to be statistically significant at the different probability levels (5% and 1%). These significant findings can be attributed to the result of individual properties of almonds. Differences between major diameter of cultivars was significant and 'Mamaei', 'Sahand', and 'Yalda' have bigger major diameter than that of the other cultivars ($p<0.05$). According to Duncan's multiple range tests, 'Sahand' and 'Shahrood15' cultivars had a biggest and lowest value of intermediate diameter and the differences of this value between 'V-9-17', 'Fragile', and 'Yalda' cultivars was not significant at the 5% probability level. Results showed that the differences between minor diameters of 'Sahand' and 'Mamaei', and 'V-9-17' and 'Sefid' cultivars was not significant ($p<0.05$). The geometric and arithmetic mean diameter of each almond cultivar resulted in different means, varying from 4.64 to 23.67, and 7.33 to 25.03 mm, respectively. 'V-9-17' and 'Shahrood15' cultivars were more and less sphericity than the other cultivars, respectively. The surface area of cultivars was found to be statistically significant and the surface area of the nuts of 'Sahand' cultivar (1465.65 mm^2) was significantly greater than those of the other cultivars at the 5% probability level. According to the results obtained, the highest PA_1–PA_3 values were found for 'Mamaei' cultivar with means of 412.90, 645.46, and 946.71 mm^2, respectively. 'Shahrood15' had the lowest projected areas, so that average values of PA_1, PA_2, and PA_3 were found within 156.57, 193, and 278.56 mm^2, respectively. The results about projected area are due to the difference in dimensional characteristics values, because 'Mamaei' and 'Shahrood15' had the highest and the lowest dimensional characteristics and projected areas, respectively.

According to the Nazari Galedar et al [8] the average length, width and thickness of wild pistachio nut at 5.83% moisture content (w.b.) were 13.98, 8.76 and 7.25 mm. This shows that the intermediate and minor diameter of Iranian almond cultivar is close to those of the wild pistachio nut. On the other hand, Pliestic et al [18] reported that the average length, width, thickness, and equivalent diameter of almond (cv. 'Fra Giulio Grande') nuts were 36.77 mm, 26.70 mm, 19.01 mm, and 26.51 mm, respectively at a moisture content of 9.74% wet basis (w.b.). This results show that this Croatian cultivar of almond is bigger than the Iranian cultivars studied in this research.

Correlation relationship of dimensional properties of cultivars

Correlation coefficients among dimensions, sphericity and surface area of almond cultivars are presented in Table 3. Using the ten cultivars as an example, the surface areas of the almonds were closely related to geometric mean diameter, but less associated with sphericity of almonds. Thus, the best dimension to estimate the surface area of the almond is geometric mean diameter. Further, the best dimension to estimate the sphericity of the almond for 'V-13', 'V-9-17', 'V-3-16', 'Fragile', 'Shahrood15', 'Mamaei', 'Sefid', and 'Shahrood17' cultivars was found to be minor diameter of almonds and for Yalda cultivar was found to be major diameter of almonds. Finally, for 'Sahand' cultivar, none of the dimension properties was capable to estimate the sphericity.

To investigate the relationship between the almond surface area (S) and the dimensional properties such as major diameter (L), intermediate diameter (W), minor diameter (T), geometric mean diameter (D_g), arithmetic mean diameter (D_a), and sphericity (ψ) of the almond cultivars a multiple linear regression model was fitted to the experimental data. According to the result of stepwise regression analysis, the best fit model yielded the following equations for cultivars:

Table 3. Correlation coefficients among dimensions, sphericity and surface area of nuts of the almond cultivars.

Cultivar		W (mm)	T (mm)	D_g (mm)	D_a (mm)	ψ (%)	S (mm2)
V-13[a]	L (mm)	0.439*	0.242ns	0.544**	0.794**	-0.184ns	0.583**
	W (mm)	1	0.544**	0.808**	0.797**	0.572**	0.785**
	T (mm)		1	0.899**	0.727**	0.850**	0.891**
	D_g (mm)			1	0.938**	0.714**	0.993**
	D_a (mm)				1	0.441*	0.949**
	ψ (%)					1	0.667**
V-9-17[a]	L (mm)	0.629**	0.630**	0.729**	0.853**	-0.012Ns	0.773**
	W (mm)	1	0.893**	0.944**	0.924**	0.712**	0.952**
	T (mm)		1	0.958**	0.924**	0.746**	0.959**
	D_g (mm)			1	0.994**	0.598**	0.998**
	D_a (mm)				1	0.509**	0.990**
	ψ (%)					1	0.617**
V-3-16[a]	L (mm)	0.625**	0.234Ns	0.650**	0.875**	-0.032ns	0.694**
	W (mm)	1	0.298Ns	0.780**	0.872**	0.477**	0.783**
	T (mm)		1	0.804**	0.521**	0.844**	0.783**
	D_g (mm)			1	0.913**	0.736**	0.996**
	D_a (mm)				1	0.425*	0.932**
	ψ (%)					1	0.690**
Fragile[a]	L (mm)	0.836**	0.793**	0.892**	0.942**	0.374ns	0.886**
	W (mm)	1	0.913**	0.964**	0.960**	0.757**	0.959**
	T (mm)		1	0.975**	0.939**	0.844**	0.977**
	D_g (mm)			1	0.991**	0.751**	0.998**
	D_a (mm)				1	0.660**	0.987**
	ψ (%)					1	0.751**
Shahrood15[a]	L (mm)	0.493**	0.170ns	0.582**	0.928**	-0.138Ns	0.676**
	W (mm)	1	0.204ns	0.712**	0.722**	0.446*	0.712**
	T (mm)		1	0.782**	0.408*	0.807**	0.733**
	D_g (mm)			1	0.824**	0.720**	0.987**
	D_a (mm)				1	0.215ns	0.882**
	ψ (%)					1	0.617**
Sahand[a]	L (mm)	0.666**	0.662**	0.877**	0.921**	-0.309ns	0.866**
	W (mm)	1	0.574**	0.872**	0.868**	0.360ns	0.868**
	T (mm)		1	0.857**	0.807**	0.345ns	0.869ns
	D_g (mm)			1	0.993**	0.184ns	0.999**
	D_a (mm)				1	0.081ns	0.989**
	ψ (%)					1	0.205Ns
Mamaei[a]	L (mm)	0.534**	0.480**	0.816**	0.892**	-0.387ns	0.808**
	W (mm)	1	0.307ns	0.762**	0.768**	0.303ns	0.766**
	T (mm)		1	0.792**	0.704**	0.458*	0.792**
	D_g (mm)			1	0.986**	0.216ns	0.999**
	D_a (mm)				1	0.065ns	0.984**
	ψ (%)					1	0.228ns
	Yalda[a]						
	L (mm)	0.679**	0.588**	0.894**	0.949**	-0.603**	0.849**
	W (mm)	1	0.467*	0.832**	0.834**	-0.014ns	0.834**
	T (mm)		1	0.816**	0.728**	0.166ns	0.814**
	D_g (mm)			1	0.987**	-0.183ns	0.999**
	D_a (mm)				1	-0.327ns	0.987**
	ψ (%)					1	-0.187ns
Sefid[a]	L (mm)	0.714**	0.238ns	0.794**	0.886**	-0.573**	0.775**
	W (mm)	1	0.391ns	0.862**	0.869**	-0.015ns	0.864**
	T (mm)		1	0.724**	0.609**	0.586**	0.737**
	D_g (mm)			1	0.985**	0.042ns	0.999**
	D_a (mm)				1	-0.130ns	0.979**
	ψ (%)					1	0.071Ns
Shahrood17[a]	L (mm)	0.404*	0.293ns	0.608**	0.747**	-0.352ns	0.601**
	W (mm)	1	0.703**	0.885**	0.862**	0.601**	0.891**
	T (mm)		1	0.892**	0.794**	0.744**	0.890**
	D_g (mm)			1	0.977**	0.527**	0.999**
	D_a (mm)				1	0.354ns	0.978**
	ψ (%)					1	0.533**

ns, not significant. a 98 degrees of freedom, * Significant level at 5%, ** Significant level at 1%.

‘V-13’: $S = 27.92 - 2.19L + 23.27W + 40.98T + 24.94D_g - 815.16\psi, R^2 = 0.998$

‘V-9-17’: $S = -376.51 + 35.94L + 94.71W + 125.31T - 127.78D_g - 960.70\psi, R^2 = 0.998$

‘V-3-16’: $S = 181.23 - 13.99L + 8.94W + 21.73T + 79.58D_g - 1306.01\psi, R^2 = 0.999$

‘Fragile’: $S = 1702.90 - 46.86L + 44.06W + 105.43T + 73.04D_g - 4435.30\psi, R^2 = 0.999$

‘Shahrood15’: $S = 35.33 - 4.45L + 0.91W + 2.48T + 43.61D_g - 361.14\psi, R^2 = 0.996$

‘Sahand’: $S = -819.10 + 50.73W + 90.27T - 77.86D_g + 88.22D_a - 1026.14\psi, R^2 0.999$

‘Mamaei’: $S = -1088.23 + 18.81W + 22.75T + 109.02D_g - 15.09D_a - 646.12\psi, R^2 = 0.998$

‘Yalda’: $S = -884.54 + 6.67L + 19.37W + 29.63T + 56.36D_g - 250.15\psi, R^2 = 0.999$

‘Sefid’: $S = -841.37 - 0.438L + 10.67W + 10.79T + 82.34D_g - 133.24\psi, R^2 = 0.999$

‘Shahrood17’: $S = -171.96 + 13.54L + 48.05W + 72.64T - 42.06D_g - 533.08\psi, R^2 = 0.999$

These models have been analyzed and showed that the parameters L, T, W, D_g, and ψ in the ‘V-13’, ‘V-9-17’, ‘V-3-16’, ‘Fragile’, ‘Shahrood15’, ‘Yalda’, ‘Sefid’, and ‘Shahrood17’ cultivars and the parameters L, T, W, D_g, and D_a in the ‘Sahand’ and ‘Mamaei’ cultivars explain 100% of the total variation in the almond surface area. Unal et al [15] have done similar tasks for three different cultivars of rapeseeds.

Gravimetrical properties of cultivars

The sample mass of almonds had different means, and these values varied from 0.67 to 4.37 g. Also, ‘Mamaei’ and ‘Shahrood15’ cultivars had more and less mass than that the other cultivars, respectively. This property may be useful in the separation and transportation of the fruits by hydrodynamic means. The bulk density ranged from 280 kgm^{-3} for Number13 cultivar to 480 kgm^{-3} for 9-17 cultivar (Table 2). The bulk density could be used as an indication of quality during storage for almond. Decrease in bulk density is an indication of reduced overall quality of the fruit. Factors which commonly affect bulk density are insect infestation, excessive foreign matter and high percentage moisture content. The true density ranged from 790 kgm^{-3} for ‘Yalda’ cultivar to 1260 kgm^{-3} for ‘Shahrood17’ cultivar. Significant differences ($p<0.05$) exist among the cultivars in true density. ‘Yalda’ nuts were significantly lower in bulk density than the others. The true density indicates that the fruits are heavier than water and this characteristic can be used to design separation or cleaning process. According to the results, the mean porosity value of Shahrood17 (75%) and Fragile (48%) was highest and lowest value between almond cultivars, respectively.

According to the Aydin [16], in the moisture range from 2.77 to 24.97 d.b., studies on re-wetted a Turkish variety of almond nut showed that the bulk density decreased from 655 to 525 kgm^{-3}, true density increased from 1015 to 1115 kgm^{-3}, and porosity increased from 35.32% to 53.21%. In comparison with the results of Aydin [16], the results of this study indicate this fact that Iranian almonds have more porosity than that of this Turkish variety of almond and this must be considered when almond is stockpiled in the silos. Also because porosity allows fluid to pass through the bulk, it is useful in the calculation of rate of aeration and cooling, drying and heating and the design of heat exchangers and other similar equipment.

Frictional and angle of repose properties of cultivars

As shown in Table 2, the static coefficient of friction on the examined surfaces was found to be statistically significant at the 5% probability level. On the plywood surface, the coefficient of static friction of the ‘Shahrood17’ and ‘Sefid’ cultivars was found to be the highest and the lowest coefficients with means of 0.509 and 0.249, respectively. On the glass surface, the coefficient of static friction of the ‘V-13’, ‘Sefid’, and ‘Shahrood17’ cultivars, with mean of 0.404, was significantly greater than that of the other cultivars. On the galvanized iron sheet, the highest coefficient of static friction was obtained for 3-16 cultivar with a mean of 0.509 while the corresponding value was 0.2449 for 9-17 cultivar as the lowest coefficient. These data can be used in designing of the almond conveying systems. For ‘V-13’, ‘V-9-17’, ‘Shahrood15’, ‘Sahand’, ‘Yalda’, and ‘Shahrood17’ cultivars, the static coefficient of friction was greatest against plywood and for ‘V-3-16’, ‘Fragile’, ‘Sahand’, and ‘Mamaei’ cultivars, greatest value of the static coefficient of friction was against galvanized iron sheet. For ‘Sefid’ cultivar greatest and lowest value of coefficient of friction was obtained on glass (0.404) and plywood (0.249), respectively. Comparison of results of this study and results of Ahmadi et al. [12] show that the value of coefficient of friction of almond nuts on the glass and galvanized iron sheet surfaces is higher and on the plywood surface is lower than that of apricot pit.

Tables 2 shows that significant differences ($p<0.05$) existed in angle of repose among the cultivars and this property varied between 32° (for 9-12 and Yalda cultivars) and 53° (for 3-16 cultivar). The angles of repose for almond nuts was considerably higher than that reported for wild pistachio [8], Iranian wild pistachio [9], and Simarouba fruit [10]. The surfaces of the wild pistachio, Iranian wild pistachio, and simarouba fruit may be comparatively smoother or have a higher sphericity thus enabling them to slide more easily on one another, resulting in a lower value of angle o

Rupture strength properties of cultivars

Rupture strengths of cultivars were investigated and given in Table 2. Results showed that the rupture properties of cultivars are statistically significant

($p<0.05$). In almond cultivars; the force applied for Sahand and Shahrood15 cultivars was highest and lowest, respectively. The mean values of the rupture force for the 'Sahand' and 'Shahrood15' cultivars were 1265.23 and 15.11 N, respectively. This difference may be attributed to physical properties of almond cultivars.

Khazaei [21] reported that the required force for fracture of Mamaei cultivar of almond in the loading rate of 5 mm/s and moisture content of 6.3% w.b. is about 673 N. This value is close to our findings. On the other hand, Khazaei et al. [17] also reported that the variation range of rupture force of almond 'Tegzas' variety, grown in the Saveh area of Iran, is between 139-1526 N when moisture content increased from 6.46% to 20.24% d.b. Know of this property is useful in the optimal design of postharvest equipments such as mills that prepare the almond for further operations in food industries.

CONCLUSIONS

All physical and mechanical nut properties considered in the current study were found to be statistically significant between the almond cultivars assayed. Nuts of 'Mamaei' almond cultivar are longer while nuts from 'Shahrood15' are shorter in diameter. The 'Mamaei' cultivar had nuts with higher mass, arithmetic and geometric mean diameters, surface area, and projected area when compared with the other cultivars. In the case of 'V-9-17', 'Sahand', 'Sefid', and 'Shahrood17' cultivars nut showed higher sphericity than 'Mamaei'. In general, large almonds had higher geometric mean diameters, projected area and surface area than small almonds. 'V-13' and 'Sefid' cultivars were significantly lower in bulk density of nuts than the others. But, 'Shahrood17' was significantly higher in true density and porosity than the others. On the other hand, the angle of repose of 'V-3-16' and rupture force of 'Sahand' was higher than that of the other cultivars. Finally, the developed multi-linear models to predict the almond surface area based on the dimensional properties showed the high correlation coefficient.

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