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FULL LENGTH ARTICLE

Physical properties and mathematical modeling of melon (*Cucumis melo* L.) seeds and kernels

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Abstract In the present research, some physical properties of Somsori and Varamin varieties of melon seeds and kernels were studied; three principal dimensions (length, width and thickness) of melon seeds and kernels were measured using image processing technique. Results indicated that mass of the Somsori and Varamin varieties seeds was equal to 0.043 and 0.052 g, respectively. The corresponding value for melon kernels was found to be 0.031 and 0.036, respectively. True density of the Somsori and Varamin varieties seeds was equal to 1182.612 and 1132.058 kg m^{-3}, respectively. The corresponding value for melon kernels was found to be 1479.731 and 1535.911 kg m^{-3}, respectively. Results showed that with increasing volume of container from 500 mL to 600 mL bulk density of the seeds increased. But with increasing volume of container from 600 mL to 1500 mL, bulk density of the seeds decreased. Also with increasing volume of container from 500 mL to 1000 mL bulk density of the kernels increased. But with increasing volume of container from 1000 mL to 1500 mL, bulk density of the kernels decreased. Values of coefficient of friction of seeds and kernels on rubber surface were more than the iron, galvanized and plywood surfaces, but values of coefficient of friction of seeds and kernels on galvanized surface were less the other surfaces. Comparison between three methods of measuring angle of repose showed that values based on pouring method and filling method were more and less than the other methods, respectively.
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1. Introduction

Melon (*Cucumis melo* L.) is a valuable cash crop grown throughout the world. It is a member of the genus *Cucumis*, in the family Cucurbitaceae. *C. melo* includes a diverse group of annual, trailing-vine plants. Melon is one of the popular fruits in the tropical countries. It originated from Iran and Pakistan, mostly grown in the warmer regions of the world (De Mello et al., 2001; Rashid et al., 2011).

In Iran, mainly in Isfahan, Tehran, Khorasan and Fars provinces, farmers grow local varieties of melon namely Somsori,

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Nomenclature

A_r	angle of repose, Degree	STD	standard deviation
D_A	arithmetic mean diameter, mm	T	thickness of the seeds, mm
D_G	geometric mean diameter, mm	t	thickness of the kernels, mm
E_R	elongation ratio	V	volume of the seeds or kernels, mm^3
F_R	flakiness ratio	W	width of the seeds, mm
H	height of the cone, mm	w	width of the kernels, mm
L	length of the seeds, mm	x_{avr}	mean seeds or kernels dimension, mm
l	length of the kernels, mm	x_i	midpoint of each class
n	number of occurrence	φ	sphericity of seeds or kernels,%
P_a	projected area of seeds or kernels, mm^2	ε	porosity of seeds or kernels,%
R	radius of the cone, mm	ρ_b	bulk density of seeds or kernels, kg m^{-3}
S_A	surface area of the seeds or kernels, mm^2	ρ_t	true density of seeds or kernels, kg m^{-3}

Varamin, etc. In addition to a good source of protein, melon seeds are a rich source of vegetable oil varying from 35% to 49% depending on varieties from different regions (De Mello et al., 2001; Mian-hao and Yansong, 2007; Rashid et al., 2011). Despite being a rich source of protein and oil, its seeds are still being classified as waste product (Mian-hao and Yansong, 2007). Several reports have been published on the composition of muskmelon seeds, as well as fatty acid profile showing higher linoleic acid contents, which, though are variety and genotype dependent (Yanty et al., 2008).

In Iran and Pakistan the melon seeds are generally discarded as an agro-waste and can economically be utilized to extract melon oil thus reducing the overall cost of muskmelon oil biodiesel production when compared with conventional vegetable oils (Rashid et al., 2011). In Iran, due to unavailability of suitable machinery for melon seeds post-harvesting operations such as shelling, sorting, sizing, drying, separating seeds and kernels, packing and oil extraction the melon seeds are discarded.

There are limited published literature about genetic, oil extraction, chemical properties and other scientific fields of melon seeds and kernels. The construction of a melon genetic map based primarily on AFLP markers using a backcross population was described (Wang et al., 1997).

Phenolic content and antioxidant activity of methanolic extracts from different parts of melon including leaf, stem, skin, seed and flesh were investigated (Ismail et al., 2010). Characterizations of some nutritional constituents of melon hybrid AF-522 seeds were studied (De Melo et al., 2000).

Mian-hao and Yansong (2007) cited that the seeds of melon hybrid ChunLi contained high percentages of lipids (35.36%) and proteins (29.90%). Hexane-extracted oil had acid, peroxide, iodine and saponification values of 1.51, 3.95, 89.5 and 226.73, respectively.

The physical, mechanical and morphological properties of seeds, grains, fruits, nuts or kernels must be known in order to design or modify the equipment of conveying, sorting, storing, sizing, oil extraction, drying, packing and other processes of agricultural products. Numerous researches have been conducted on physical, mechanical and chemical properties of agricultural products but there is no published literature about physical and mechanical properties of melon seeds and kernels.

Size and shape are important for separator and sorter and can be used to determine the lower size limits of conveyors. Furthermore, the characteristic dimensions allow a calculation of the surface area and volume of grains, important aspects for the modeling of drying and ventilation. Porosity affects the bulk density which is also a necessary factor in the design of dryer, storage and conveyor capacity while the true density is useful to design separation equipment (Sologubik et al., 2013). The angle of repose and coefficient of friction are considered by engineers as important properties for the design of seed containers and other storage structures and accessories. The static friction coefficient limits the maximum inclination angle of conveyor and storage bin. The amount of power requirement for conveyor depends on the magnitude of frictional force. Angle of repose is a useful parameter for the calculation of belt conveyor width and for designing the shape of storage (Sirisomboon et al., 2007).

Due to there is no published literature on physical properties of melon seeds and kernels, the aim of the present study was to (1) measure three principle dimensions and projected area of melon seeds and kernels for two varieties, namely Somsori and Varamin varieties, based on image processing technique and modeling length, width and thickness of seeds and kernels of the varieties, (2) calculate some dimensional properties including geometric mean diameter, arithmetic mean diameter, sphericity, volume and surface area for seeds and kernels of two varieties, (3) measure gravimetrical properties of the melon seeds and kernels including seeds, kernels and shell mass, 1000 seeds, kernels and shells mass, bulk density, true density and porosity of seeds and kernels and (4) measure frictional properties of melon seeds and kernels including coefficient of static friction and angle of repose based on pouring, filling and emptying methods for seeds and kernels of two varieties.

2. Materials and methods

2.1. Sample preparation

Two varieties of melons, namely Somsori and Varamin, which are widely cultivated in Iran, were used in the present work. The Somsori variety used in the present research was planted on late April 2012 in local farms of Porzan plain located on Shahreza, Isfahan Province, Iran. The Varamin variety was planted on late April 2012 in local farms of Ghezlagh plain located on Pakdasht, Tehran Province, Iran.

The melons were harvested manually in late July, after they were matured completely. Seventy melon fruits were selected randomly from each variety. The seeds of each melon fruit were extracted and wet seeds were left in the atmosphere to dry. After being dried in the atmosphere, the seeds were collected in order to measure their physical properties. The kernel was manually separated from the shell, in order to testing melon's kernel.

2.2. Dimensional properties

To determine the dimensions of the melon seeds and melon kernels, 50 seeds and kernels were selected from the bulk sample, randomly. For each seed, the three principal dimensions including length (*L and l*), width (*W and w*) and thickness (*T and t*) were measured using image processing technique. Some dimensional properties of seeds and kernels were calculated based on the length, width and thickness. Geometric mean diameter (D_G) and arithmetic mean diameter (D_A) were determined using Eqs. (1) and (2), as reported by Baryeh (2001) and Koocheki et al. (2007):

$$D_G = \sqrt[3]{LWT} \tag{1}$$

$$D_A = \frac{L + W + T}{3} \tag{2}$$

The sphericity (φ) of the grains, seeds, nuts, kernels or fruits is an index of its roundness. For non-spherical particles, the sphericity is calculated as the ratio of the surface area of equivalent sphere to the surface area (Jain and Bal, 1997; Mirzabe et al., 2013a). The sphericity of the seeds and kernels is determined using Eq. (3), as reported by Baryeh (2002) and Aydin (2003):

$$\varphi = \left(\frac{\sqrt[3]{LWT}}{L} \quad or \quad \frac{\sqrt[3]{lwt}}{l} \right) \times 100 \tag{3}$$

Surface area (*S*) and volume (*V*) of the particle scan were calculated using Eqs. (4) and (5):

$$S_A = \pi (D_G)^2 \tag{4}$$

$$V = \frac{\pi (D_G)^3}{6} \tag{5}$$

The shape parameters including flakiness ratio (F_R) and elongation ratio (E_R) of each single melon seeds and kernels were calculated using Eqs. (6) and (7), as reported by Mora and Kwan (2000):

$$F_R = \frac{\textit{Thickness of seed or kernel}}{\textit{Width of seed or kernel}} \tag{6}$$

$$E_R = \frac{\textit{Length of seed or kernel}}{\textit{Width of seed or kernel}} \tag{7}$$

The projected area (P_A) is an important parameter to determine aerodynamic properties. This parameter was calculated based on Eq. (8), as reported by Ebrahimzadeh et al. (2013):

$$P_A = \frac{\pi LW}{4} \quad or \quad \frac{\pi lw}{4} \tag{8}$$

2.3. Image processing setup

The image processing system consisted of a camera (Canon, IXY 600F, Japan) with 3X IS lens capable of filming up to 120 frames per second (fps) and 12.1 megapixels, USB connection, four white-colored fluorescent lamps (32 W) and a laptop computer (VAIO, VPCEG34FX, Japan) equipped with Matlab R2012a software package. The camera was mounted on an image processing box (Mansouri et al., 2015). Each melon seed or kernel was placed at the center of the camera's field of view and three metal spheres with the same and identified diameters were placed at the side (three different positions) of the melon seed or kernel; then two RGB color images were captured from up view and front view of melon seed and kernel. The original color image of each melon seed or kernel and each metal sphere was converted to an eight-bit grayscale image. Eight-bit grayscale intensity represents 256 different shades of gray from black (0) to white (255). The eight-bit grayscale images were digitized to binary image by using binary transformation on the basis of all the pixels with a brightness level which was the average of the brightness levels of the three channels (Uozumi et al., 1993). From the grayscale image of Somsori variety, pixel values less than 150 for seeds and 180 for kernels were converted to 0 (black) and pixel values higher than 150 for seeds and 180 for kernels were converted to 255 or white (Koc, 2007). The threshold level of Varamin variety seeds and kernels grayscale image is chosen 115 and 180 respectively. The threshold value of seeds and kernels was determined experimentally (Koc, 2007). The holes and noise of binary images are filling by morphological closing and opening (Li et al., 2012). The pixels showing the melon seed and kernel boundary had the value of 0 and the remainder of the pixels in the image had the value of 255. Examples of the original, grayscale, binarized and boundary images of a melon seed or kernel are shown in Fig. 1. The number of pixels representing the length (*L and l*), width (*W and w*) and thickness (*T and t*) of the melon seeds and kernels was also measured on the captured images using Matlab R2012a software package.

2.4. Gravimetric properties

2.4.1. Mass and thousand seeds mass

To determine the mass of a single melon seed, kernel and shell, 100 seeds, kernels and shells from the bulk sample were selected. Mass of the selected sample was measured by a digital balance (KERN, PLS 360-3, Germany) with an accuracy of 0.001 g. To determine 1000 melon seeds, kernels and shells mass, 50 seeds, kernels and shells were selected; the weight of 50 seeds, kernels and shells was measured. Then the weight of 50 seeds, kernels and kernels was multiplied by 20 to determine 1000 seeds, kernels and shells mass. Measuring the 1000 melon seeds, kernels and shells was done with 5 repetitions for each variety.

2.4.2. True density

Mass of the samples of melon seeds and kernels was measured by a digital balance (KERN, EMB600-2, Philippines) with an accuracy of 0.01 g and volume of the samples of melon seeds and kernels was calculated based on the water displacement method; toluene (C_7H_8) was used instead of water, because

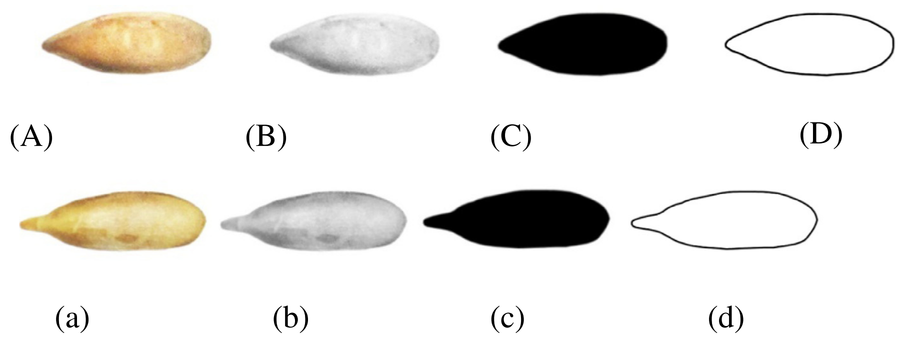

Figure 1 Images of a melon seed and kernel (A and a) Original RGB color image, (B and b) eight-bit grayscale image, (C and c) two-bit binary image and (D and d) outline image.

its absorption by seeds and kernels is less than water; also its surface tension is low, so that it fills even shallow dips in a seed and its dissolution power is low (Milani et al., 2007). Finally the true density (ρ_t) of seeds and kernels was determined based on ratio of the mass to volume. The seeds and kernels true density was measured with 5 repetitions.

2.4.3. Bulk density

In order to determine bulk density of seeds and kernels, they were put into 4 cylindrical containers with known weights and volumes of 500, 600, 1000 and 1500 mL with a constant height of 150 mm (Dash et al., 2008; Mirzabe et al., 2013a). Bulk densities (ρ_b) were calculated from the mass of bulk material divided by volume containing the mass. The seeds and kernels bulk density was measured with 5 repetitions.

The porosity (ε) of the seeds and kernels was calculated based on bulk and true density, using Eq. (9), as reported by Fathollahzadeh et al. (2008):

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \tag{9}$$

2.5. Frictional properties

2.5.1. Angle of friction

The coefficient of external static friction was determined using plywood, iron sheet and galvanized iron sheet. A top and bottomless metallic box was put on the surface. The box was filled with seeds and kernels samples. The surface was gradually raised by a screw (Fig. 3). When the glides of the seeds and kernels on the surface were started, the angle between the frictional surface and horizon was photographed and coefficient of friction was calculated using image processing technique and Auto Cad 2007 software package.

2.5.2. Angle of repose

When bulk granular materials are poured onto a horizontal surface, a conical pile will form. The internal angle between the surface of the pile and the horizontal surface is known as the angle of repose. Material with a low angle of repose forms flatter piles than material with a high angle of repose. Angle of repose is related to the density, surface area and shapes of the particles, the coefficient of friction of the material and gravity-dependent (Kleinhans et al., 2011). There are different methods to measure the angle of repose including pouring, filling (charging), empting (discharging), piling, submerging and rotating drums methods.

2.5.2.1. Pouring angle of repose. Static angle of repose was measured using pouring method. The angle of repose of seeds and kernels sample was determined using a top and bottomless metallic cylinder of 200 mm height and 150 mm diameter (Mirzabe et al., 2013b). The cylinder was placed on horizontal surface and was filled with seeds and kernels; then, the cylinder was raised very slowly (Fig. 4). The height and radius of the cone were measured using a digital caliper. The static angle of repose was determined using following Eq. (10), as reported by Milani et al. (2007):

$$A_r = \tan^{-1}\left(\frac{H}{R}\right) \tag{10}$$

where A_r was angle of repose; H was height of the cone; and R was radius of the cone.

2.5.2.2. Filling and empting angle of repose. In order to measure filling and empting angle of repose, seeds and kernels were filled to wooden box of 200 mm height, 200 mm width and 100 mm thickness. There was a discharge valve at the bottom of the wooden box. With opening the discharge valve the seeds and kernels discharged from the wooden box and the filling and empting angle of repose were formed. The camera was placed at opposite of the front view of the wooden box and then photographed from filling and empting angle of repose. The filling and empting angles were calculated with Auto Cad 2007 software package.

2.6. Statistical analysis

Statistical indices including maximum, minimum, mean and standard deviation (STD) for three principal dimensions, dimensional properties and mass of single seed, kernel, and shell and kernel ratio were calculated using Microsoft Office Excel 2010. Skewness and kurtosis are two statistical indices which were calculated so that the reader would better understand the probability density distribution data. The skewness and kurtosis were calculated using Eqs. (11) and (12), respectively (Lucian, 2006; Khazaei et al., 2008):

$$Skewness = \frac{n}{(n-1)(n-2)}\sum_{i=1}^{n}\left(\frac{x_i - x_{ag}}{\text{STD}}\right)^3 \tag{11}$$

$$Kurtosis = \left\{ \frac{n(n-1)}{(n-1)(n-2)(n-3)} \sum_{i=1}^{n} \left(\frac{x_i - x_{ag}}{\text{STD}} \right)^4 \right\} - \frac{3(n-1)^2}{(n-2)(n-3)} \quad (12)$$

where n is the number of occurrence; STD is the standard deviation; x_{avg} is mean seeds or kernels dimension (length, width, thickness and dimensional properties); x_i is midpoint of each class interval in metric.

3. Results and discussion

3.1. Dimensional properties

Length, width, thickness and dimensional properties of seeds and kernels of Somsori variety are shown in Table 1. The length, width, and thickness of melon seeds were ranged from 6.60 mm to 8.61 mm, 3.10 mm to 4.21 and 0.65 mm to 1 mm, respectively. The comparable values for melon kernels were found to be 5.91 mm to 7.93 mm, 3.03 mm to 4.11 mm and 0.60 mm to 0.93 mm, respectively.

The mean values of sphericity, geometric mean diameter, arithmetic mean diameter, surface area, volume, flakiness ratio, elongation ratio and projected area of Somsori seeds were found to be 36.85%, 2.84 mm, 4.07 mm, 25.49 mm^2, 12.17 mm^3, 0.22, 2.11 and 22.31 mm^2, respectively (Table 1). The analogous values for melon kernels were found to be 37.47%, 2.67 mm, 3.82 mm, 22.44 mm^2, 10.06 mm^3, 0.21, 2.00 and 20.01 mm^2, respectively.

The dimensional parameters of Varamin seeds are shown in Table 2. The length, width, and thickness of melon seeds were ranged from 6.90 mm to 9.07 mm, 2.49 mm to 4.09 mm and 0.73 mm to 1.68 mm, respectively. The analogous values for melon kernels were found to be 6 mm to 8.27 mm, 2.39 mm to 3.93 mm and 0.67 mm to 1.54 mm, respectively.

The mean values of sphericity, geometric mean diameter, arithmetic mean diameter, surface area, volume, flakiness ratio, elongation ratio and projected area of Varamin seeds were found to be 40.31%, 3.13 mm, 4.11 mm, 31.01 mm^2, 16.35 mm^3, 0.36, 2.34 and 20.50vmm^2, respectively (Table 1). The corresponding values for melon kernels were found to be 41.18%, 2.91 mm, 3.80 mm, 26.82 mm^2, 13.15 mm^3, 0.35, 2.22 and 17.92 mm^2, respectively.

Comparison between three principle dimensions of the seeds and kernels of two varieties indicated that length and thickness of Varamin seeds were more than the comparable values of Somsori variety, but the width of Somsori seeds was more than the corresponding values of Varamin variety. Length, and width values of Somsori kernels were more than the analogous values of Varamin variety, but the thickness of Varamin seeds was more than the similar values of Somsori variety.

Analogy between sphericity of the seeds and sphericity of the kernels pointed out that for both varieties, the mean values of the kernels sphericity were more than the sphericity of the seeds. Also, sphericity of Varamin variety was more than Somsori samples.

Results of statistical analysis of dimensional properties of seeds and kernels of the Somsori variety denoted that the values of the skewness and kurtosis in most cases were negative. For dimensional properties of Varamin seeds and kernels, the skewness and kurtosis in half cases had negative value.

3.2. Gravimetric properties

3.2.1. Mass and kernel ratio

Average mass of the Somsori and Varamin varieties seeds was equal to 0.043 and 0.052 g, respectively. The corresponding value for melon kernels and shells was found to be 0.031 and 0.036 for kernels and 0.012 and 0.016 g for shells, respectively (Table 3). Results indicated that the mean value of seeds, ker-

Table 1 Calculated statistical indices of dimensions and dimensional properties of melon seeds and kernels for Somsori variety.

Material	Parameter	Unit	Max	Min	Mean	STD	Skewness	Kurtosis
Seed	L	mm	8.61	6.40	7.72	0.49	−0.32	−0.34
	W	mm	4.21	3.10	3.67	0.25	−0.26	−0.34
	T	mm	1.00	0.65	0.81	0.09	0.06	−0.70
	φ	%	42.12	33.44	36.85	1.80	0.82	1.45
	D_G	mm	3.19	2.42	2.84	0.18	−0.33	−0.58
	D_A	mm	4.42	3.47	4.07	0.23	−0.46	−0.41
	S_A	mm^2	31.97	18.46	25.49	3.25	−0.20	−0.63
	V	mm^3	17.00	7.46	12.17	2.30	−0.07	−0.64
	F_R	–	0.28	0.18	0.22	0.02	0.40	−0.57
	E_R	–	2.48	1.82	2.11	0.15	0.27	0.19
	P_a	mm^2	26.49	16.85	22.31	2.46	−0.36	−0.61
Kernel	l	mm	7.93	5.91	7.13	0.44	−0.34	−0.31
	w	mm	4.11	3.03	3.57	0.24	−0.23	−0.36
	t	mm	0.93	0.60	0.75	0.09	0.12	−0.71
	φ	%	42.94	33.83	37.47	1.93	0.63	1.14
	D_G	mm	3.00	2.28	2.67	0.17	−0.23	−0.65
	D_A	mm	4.14	3.26	3.82	0.21	−0.45	−0.37
	S_A	mm^2	28.29	16.33	22.44	2.89	−0.11	−0.69
	V	mm^3	14.15	6.21	10.06	1.92	0.02	−0.68
	F_R	–	0.26	0.17	0.21	0.02	0.35	−0.32
	E_R	–	2.35	1.72	2.00	0.14	0.35	0.45
	P_a	mm^2	23.84	15.16	20.04	2.19	−0.35	−0.59

Table 2 Calculated statistical indices of dimensions and dimensional properties of melon seeds and kernels for Varamin variety.

Material	Parameter	Unit	Max	Min	Mean	STD	Skewness	Kurtosis
Seed	L	mm	9.07	6.90	7.79	0.50	0.06	−0.42
	W	mm	4.09	2.49	3.34	0.30	−0.26	1.09
	T	mm	1.68	0.73	1.20	0.19	0.16	−0.10
	φ	%	47.02	34.94	40.31	2.88	0.48	0.15
	D_G	mm	3.56	2.47	3.13	0.22	−0.39	0.73
	D_A	mm	4.53	3.55	4.11	0.23	−0.34	−0.37
	S_A	mm^2	39.80	19.18	31.01	4.19	−0.15	0.32
	V	mm^3	23.61	7.90	16.35	3.27	0.08	0.12
	F_R	–	0.52	0.24	0.36	0.07	0.44	−0.52
	E_R	–	2.82	1.99	2.34	0.20	0.64	−0.13
	P_a	mm^2	26.15	13.74	20.50	2.65	−0.07	0.09
Kernel	l	mm	8.27	6.00	7.10	0.47	−0.08	−0.18
	w	mm	3.93	2.39	3.21	0.29	−0.28	1.00
	t	mm	1.54	0.67	1.10	0.18	0.16	−0.13
	φ	%	49.48	35.70	41.18	3.05	0.58	0.51
	D_G	mm	3.32	2.28	2.91	0.20	−0.40	0.91
	D_A	mm	4.20	3.26	3.80	0.22	−0.36	−0.36
	S_A	mm^2	34.58	16.33	26.82	3.65	−0.14	0.46
	V	mm^3	19.12	6.20	13.15	2.65	0.10	0.22
	F_R	–	0.49	0.24	0.35	0.07	0.42	−0.60
	E_R	–	2.68	1.86	2.22	0.20	0.56	−0.05
	P_a	mm^2	22.94	12.05	17.92	2.37	−0.10	−0.01

nels and shells mass for Varamin variety was more than Somsori variety.

Kernel ratio of the Somsori and Varamin varieties seeds was found to be 72.803 and 69.832%, respectively; therefore kernel ratio of Somsori variety was more than Varamin variety. Shell ratio of the Somsori and Varamin varieties seeds was found to be 27.193 and 30.168%, respectively. Shell ratio of Somsori variety was less than Varamin variety because kernel ratio of Somsori variety was more than the Varamin variety.

3.2.2. Seeds mass, 1000 kernels mass, 1000 shell mass and true density

1000 seeds and kernels mass and true density of seeds and kernels for both varieties are illustrated in Table 4. Results indicated that the mean value of 1000 seeds, kernels and shell mass of Varamin variety was more than Somsori variety. Also results showed that the true density value of Somsori seeds was more than the Varamin variety, but the true density of Varamin kernels was more than the true density of the Somsori variety.

3.2.3. Bulk density and porosity

The bulk density values of melon seeds and kernels are illustrated in Fig. 2 and 3. Results showed that with increasing volume of container from 500 mL to 600 mL bulk density of the seeds of two varieties increased. But with increasing volume of container from 600 mL to 1500 mL, bulk density of the seeds of two varieties decreased. Bulk density of seeds of Somsori variety was more than Varamin variety, in all cases (Fig. 2).

Results showed that with increasing volume of container from 500 mL to 1000 mL bulk density of the kernels of two varieties increased. But with increasing volume of container from 1000 mL to 1500 mL, bulk density of the kernels of two varieties decreased. Bulk density of kernels of Somsori variety was less than the Varamin variety, in all cases (Fig. 3).

The porosity value of melon seeds and kernels is shown in Figs. 4 and 5. Results indicated that with increasing volume of

Table 3 Statistical analysis for mass of melon seed, kernel, shell, kernel ratio and shell ratio.

Parameter	Variety	Max	Min	Mean	STD	Skewness	Kurtosis
Seed	Somsori	0.061	0.029	0.043	0.006	0.624	0.597
	Varamin	0.066	0.035	0.052	0.007	−0.170	−0.474
Kernel	Somsori	0.044	0.022	0.031	0.005	0.445	−0.170
	Varamin	0.045	0.024	0.036	0.005	−0.340	−0.718
Shell	Somsori	0.017	0.007	0.012	0.002	0.144	−0.369
	Varamin	0.023	0.007	0.016	0.004	0.024	−0.523
Kernel ratio,%	Somsori	79.070	60.526	72.803	4.166	−0.675	0.483
	Varamin	81.579	55.102	69.832	5.559	−0.183	0.256
Shell ratio,%	Somsori	39.474	20.930	27.197	4.166	0.675	0.483
	Varamin	44.898	18.421	30.168	5.559	0.183	0.256

Table 4 Thousand particle mass and true density of melon seeds and kernels.

Material	Variety	1000 particle mass, g	ρ_t, kg m^{-3}
Seed	Somsori	40.664	1182.612
	Varamin	49.576	1132.058
Kernel	Somsori	30.632	1479.731
	Varamin	35.836	1535.911
Shell	Somsori	11.464	–
	Varamin	15.556	–

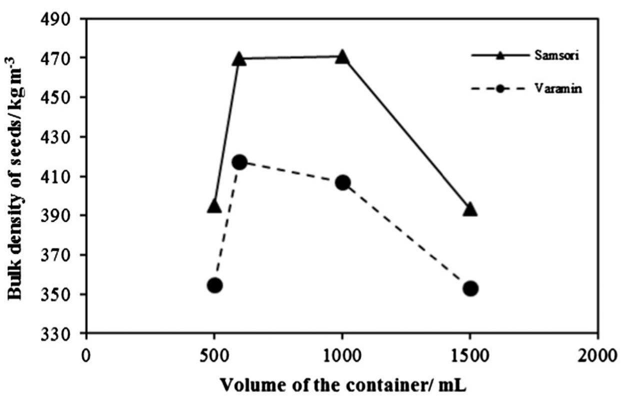

Figure 2 Effect of the volume of the container on bulk density of melon seeds.

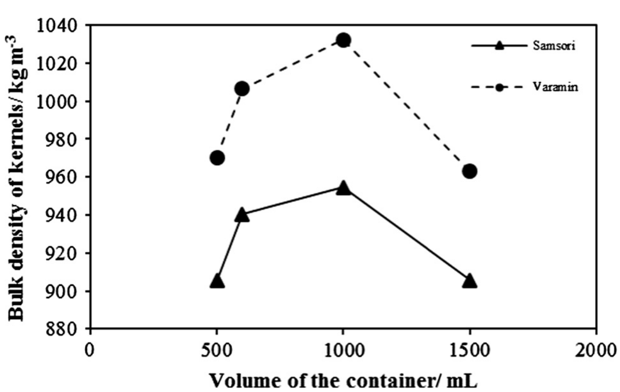

Figure 3 Effect of the volume of the container on bulk density of melon kernels.

container from 500 mL to 600 mL, porosity of the seeds for both varieties decreased. But with increasing volume of container from 600 mL to 1500 mL, porosity value of the seeds for both varieties increased. Porosity value of Somsori seeds was less than the Varamin variety, in all cases (Fig. 4).

Results indicated that with increasing volume of container from 500 mL to 1000 mL, porosity of the kernels for both varieties decreased. Although with increasing volume of container from 1000 mL to 1500 mL, porosity value of kernels for both varieties increased. Porosity value of Somsori kernels was more than the Varamin variety, in all cases (Fig. 5).

So as to measure bulk density and porosity of the olive fruits the bulk material was put into 4 cylindrical containers with known weights and volumes of 500, 1000, 1500 and 2000 mL with a constant height of 150 mm (Mirzabe et al., 2013a). Their results showed that with increasing volume of the container from 500 to 2000 mL, value of the bulk density and porosity were increased and decreased, respectively.

3.3. Frictional properties

3.3.1. Static coefficient of friction

The results of the static coefficient of friction of melon seeds and kernels are presented in Table 5. For both varieties the coefficient of friction values for seeds and kernels on rubber surface was more than the iron, galvanized and plywood surfaces. Also on all surfaces, the coefficient of friction values

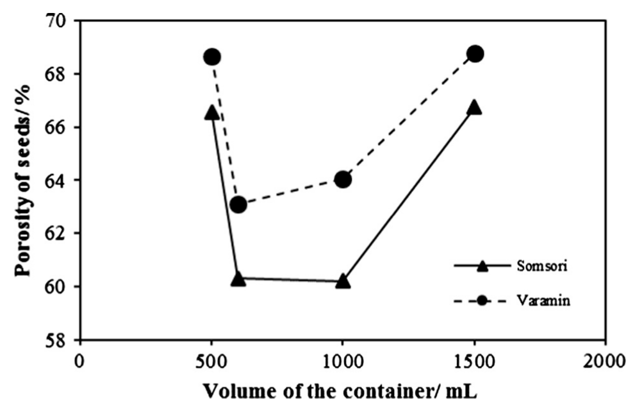

Figure 4 Effect of the volume of the container on porosity of melon seeds.

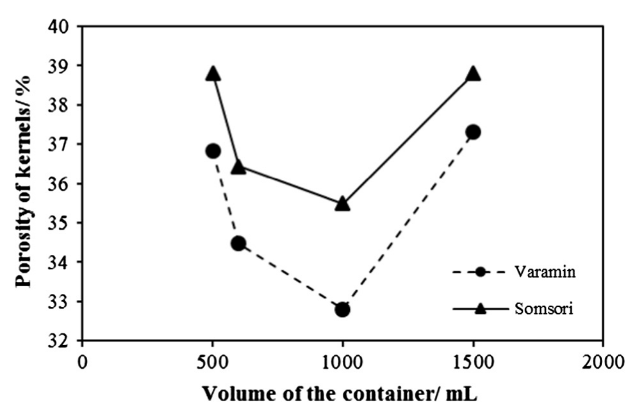

Figure 5 Effect of the volume of the container on porosity of melon kernels.

Table 5 Values of static coefficient of friction of melon seeds and kernels.

Material	Variety	Iron	Plywood	Galvanized	Rubber
Seeds	Somsori	19.53	20.58	14.33	23.64
	Varamin	23.92	30.06	15.41	32.01
Kernel	Somsori	23.67	25.53	22.12	34.85
	Varamin	25.74	26.67	23.63	35.42

Table 6 Angle of repose of melon seeds and kernels based on different methods.

Material	Variety	Filling method	Empting method	Pouring method		
				Iron	Plywood	Galvanized
Seeds	Somsori	27.23	33.64	38.64	41.23	36.16
	Varamin	33.74	37.18	41.75	43.79	39.11
Kernels	Somsori	31.66	37.64	43.42	44.89	38.13
	Varamin	35.41	39.86	44.79	45.93	40.43

for seeds and kernels of Varamin variety was more than the Somsori variety.

The least static coefficient of friction may be owing to the smoother and more polished surface of the galvanized sheet than the other materials used. Wood also offered the maximum friction for tef seed (Zewdu and Solomon, 2007), jatropha fruit (Pradhan et al., 2009) and almond (Mirzabe et al., 2013b; Aydin, 2003), but the galvanized iron had higher coefficient of friction than plywood for Roselle seeds (Sánchez-Mendoza et al., 2008) and lentil seeds (Amin et al., 2004).

3.3.2. Angle of repose

The results of the pouring angle of repose (Ar) of melon seeds and kernels for both varieties are presented in Table 6. For both varieties, value of angle of repose of seeds and kernels on plywood sheet was more than the iron, galvanized surfaces because values of friction coefficient on plywood sheet were more than the iron and galvanized surfaces.

Results of the pouring, filling and empting angle of repose showed that based on three methods values of angle of repose for Varamin variety were more than the Somsori variety, in all cases. Also for both varieties of angle of repose values for kernels were more than the corresponding values for seeds.

Comparison between three methods of measuring angle of repose showed that values of angle of repose of seeds and kernels of both varieties based on the pouring method and filling method were more and less than the other methods respectively. The angle of repose was obtained from emptying method was greater than that of filling method for wild pistachio (Fadavi et al., 2013), but the reverse results were shown for jatropha (Karaj and Müller, 2010; Sirisomboon et al., 2007).

4. Conclusions

In the present study, some physical properties of two varieties of melon seeds and kernels, namely, dimensional properties, gravimetric properties and frictional properties were investigated. According to the measured and calculated properties:

(1) Length and thickness of seeds of Varamin variety were more than the corresponding values of Somsori variety, but width of seeds of Somsori variety was more than the corresponding values of Varamin variety.
(2) Unit mass of the Somsori and Varamin varieties seeds was equal to 0.043 and 0.052 g, respectively. The corresponding value for kernels and shells was found to be 0.031 and 0.036 for kernels and 0.012 and 0.016 g for shells, respectively.
(3) With increasing volume of container from 500 mL to 600 mL bulk density of the seeds increased. But with increasing volume of container from 600 mL to 1500 mL, bulk density of the seeds decreased.
(4) With increasing volume of container from 500 mL to 1000 mL bulk density of the kernels increased. But with increasing volume of container from 1000 mL to 1500 mL, bulk density of the kernels decreased.
(5) With increasing volume of container from 500 mL to 600 mL, porosity of the seeds decreased. But with increasing volume of container from 600 mL to 1500 mL, porosity of the seeds increased.
(6) With increasing volume of container from 500 mL to 1000 mL, porosity of the kernels decreased. But with increasing volume of container from 1000 mL to 1500 mL, porosity of the kernels increased.
(7) On all surfaces, values of coefficient of friction of seeds and kernels of Varamin variety were more than the Somsori variety
(8) Results of the pouring, filling and empting angle of repose showed that based on three methods values of angle of repose of Varamin variety were more than the Somsori variety, in all cases. Also for two varieties the value of angle of repose of kernels was more than the corresponding values for seeds.

Conflict of interest

The author(s) declare(s) that there is no conflict of interests regarding the publication of this article.

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