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Comparison of Geometrical Properties of Sunflower Seeds and Kernels Cultivars

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Abstract: The knowledge of geometrical properties such as shape and size is essential for the design of processing equipment including separating, handling, sizing, drying and dehulling. In this research, geometrical properties of three varieties of Iranian oil and confectionary sunflower seed and its kernel (Shahroodi, Fandoghi and Azargol known as confectionary, semi-oil and oil varieties respectively) were investigated as a function of size and variety in the range of moisture contents from 3% to 14% (d.b.). The range of seed length for Fandoghi, Azargol and Shahroodi varieties at 7 %(d.b) were 11.03 - 12.10, 13.79 -15.13 and 13.31-14.54 mm, respectively. Moreover, these values for the corresponding kernels at 7 %(d.b) were 8.75 - 9.22, 10.48 - 10.96 and 10.67- 11.45 mm, respectively. The results showed that all main dimensions (length, width and thickness), sphericity, surface area, equivalent, geometric and arithmetic mean diameters of seed and its kernel linearly increased with increasing moisture content in all varieties and sizes. The minimum and maximum equivalent diameter of seeds among all varieties and sizes were 5.44 and 9.14 mm respectively. These values for kernels were 4.29 and 5.96 mm, respectively. Among all studied varieties, Shahroodi had Maximum surface area for both seed and kernel. On the other hand, Fandoghi had minimum surface area for both seed and kernel.

Key words: Geometrical properties · Sunflower seed · Variety · Moisture content · Size

INTRODUCTION

Sunflower (*Helianthus annuus L.*) seed is one of the most important oilseed crops due to its highly nutritious oil in large quantity [1]. According to Iranian government statistical data of 2005, over 35 varieties of sunflower are cultivated in Iran. The production of sunflower seed in the country is aimed for oil production and fresh consumption with 90 and 10%, respectively [2].

The knowledge of geometrical properties including shape, size (dimensions), geometric mean diameter, arithmetic mean diameter, equivalent diameter, sphericity and surface area is essential for the design of separating, handling, sorting, sizing, drying, dehulling and processing equipment. For example, the size and shape of seeds are important for either their electrostatic separation from undesirable materials or the development of sizing and sorting machinery. The identification of seed shape could also be important for an analytical prediction of its drying behavior [3].

Despite extensive researches which have been carried out on sunflower seed so far, a limited research has been conducted on the geometrical properties of sunflower seed and its kernel. In this regard some physical properties of sunflower seeds (Modern variety of sunflower) as a function of moisture content have been reported by Gupta and Das [4]. Arithmetic mean diameter, geometric mean diameter, surface area and volume as function of size and variety have not been investigated yet. The results indicated that the length of seed is closely related to its thickness and width while there was less association between mass of seed and its dimensions. However, the length of kernel is closely related to its width but not with either thickness or mass. Isik and Izli [5] have also investigated some moisture-dependent properties of sunflower for only the Turkey variety of sunflower seed. They have revealed an increase in geometric mean diameter when moisture content varies from 10.06 to 27.06%. Beside, physical properties of high oleic sunflower seeds at 5.6% moisture content (dry basis) were investigated by Santalla and Mascheroni [6].

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Similar researches on different seeds including soybean [7]. cotton [8] oilbean [9] wheat [10] and lentil [11] as a function of moisture content have been carried out. Olajide and Clarke [12] determined geometric mean diameter, volume and surface area for cashew nuts. Aviara *et al.* [13] reported the average of length, width, thickness and surface area for guna seeds. Joshi *et al.* [14] measured dimensions of pumpkin seed and kernel. They reported a close relationship between the width and length of the pumpkin seed, while the thickness and mass have less association with the length of the seed. Baümler *et al.* [15] investigated the effect of moisture content on some physical properties of safflower seeds typically cultivated in Argentina. They exhibited that volume, equivalent diameter and the sphericity increased linearly with the increase of the seed moisture content. Gupta and Parkash [16] reported that the variation of moisture content has no significant effect on sphericity of safflower seed.

The current study was conducted to investigate the effect of moisture content, size and variety on geometrical properties of three varieties of sunflower seed and its kernel commonly cultivated in Iran. The properties including size, geometric mean diameter, arithmetic mean diameter, equivalent diameter, sphericity, aspect ratio and surface area were determined at various moisture contents ranged from 3-14% d.b.

Nomenclature

D_a Arithmetic mean diameter, mm
D_e Equivalent diameter, mm
D_g Geometric mean diameter, mm
L Length, mm
W width, mm
W_i Initial mass of the sample, kg
M_i Initial moisture content, % d.b
Q Mass of water added, kg
R_a Aspect ratio
S Surface area, mm²
T Thickness, mm
M_f Final moisture content, % d.b
ö Sphericity, %

MATERIALS AND METHODS

The three varieties of oil and confectionary sunflower seeds namely Shahroodi, Fandoghi and Azargol (confectionary, semi-oil and oil varieties respectively) were obtained from three regions of Khorasan Razavi province, Iran, during autumn season in 2008 (Fig. 1). A mass of 20 kg from each variety was weighted and transported to the lab.

The seeds were manually cleaned to get rid of foreign matters, broken and immature seeds. To get whole kernels, the seeds were manually dehulled. The initial moisture of both seeds and kernels were determined using the standard hot air oven method with a temperature setting of 105±1°C for 24 h [4, 17, 18]. The initial moisture contents of seeds for Shahroodi, Fandoghi and Azargol were 7.9% 6.8% and 7.2% d.b., respectively. That level of moisture content for kernel of Shahroodi, Fandoghi and Azargol were obtained to be 5.9% 5.6% and 5.4% d.b., respectively. To study the effect of seed size and its kernel on geometrical properties, the seeds of each variety were graded into three size categories (small, medium and large) using 5.5, 6.5 and 8 mesh sieves (Fig.2). All the geometrical properties of the seeds were measured for three levels of moisture content (3, 7 and 14% d.b) that is a usual range since harvesting, transportation, storage and processing operations of sunflower seed. To get the seeds and kernels with the desired moisture contents, sub-samples of both seeds and kernels of each variety and size category (small, medium and large), each weighing 0.5 kg, were drawn form the bulk sample and dried (by putting them in the oven at 75°C for 2 h) or adding the calculated

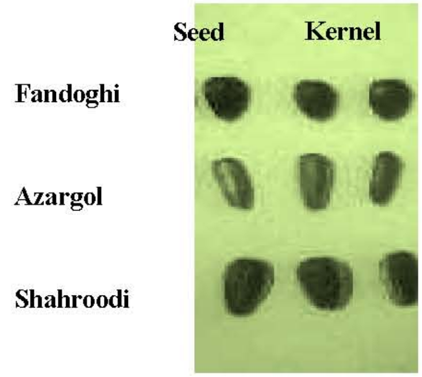

Fig. 1: The illustrated view of seed and kernel of three varieties of sunflower

Fig. 2: Classification of sunflower seed into three size categories

Fig. 3: Measuring dimensions of the sunflower seed

quantity of water to the samples. The required amount of water for the samples was determined using the following equation [18]:

$$Q = \frac{W_i(M_f - M_i)}{100 - M_f}$$

where Q, Wi, Mi and Mf are the mass of added water, kg, the initial mass of sample in kg, the initial moisture content of sample in d.b.% and the final moisture content of sample in d.b.%, respectively.

The pre-determined quantity of water was added to the sub-samples and then they were kept in a double-layered low-density polyethylene bags of 90μm thickness, sealed and stored at low temperature (5°C in a refrigerator) to avoid the growth of microorganisms and allowing to uniformity of moisture distribution. Before starting the tests, the required quantities of seed and kernel was taken out of the refrigerator and allowed to warm with room temperature for approximately 2 h [4, 14].

To determine the size and shape of seed and kernel for revealing the interrelations of length, width and thickness, totally 50 seeds and kernel of each sub-samples were randomly selected and labeled for easy identification. This method of random sampling was similar to Baryeh [19]. Baümler *et al.* [15] and Saiedirad *et al.* [20]. Finally, three main dimensions namely length, width and thickness for both seed and kernel were carefully measured using a digital caliper (Diamond, China) with an accuracy of ±0.02 mm as shown in Figure 3.

The average of seed and kernel diameter were computed using geometric mean, arithmetic mean and equivalent diameters of the three axial dimensions. The geometric mean diameter, Dg, arithmetic mean diameter, Da and equivalent diameter, De, were calculated using the following equations [21]:

$$D_g = (LWT)^{1/3} \quad (2)$$

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

$$D_e = \left[L \frac{(W + T)^2}{4} \right]^{1/3} \quad (4)$$

Where L is the length, W is width and T is the thickness.

The criterion used to describe the shape of sunflower seed and its kernel was sphericity. The sphericity, ö, of seed and kernel was determined using the following formula [21]:

$$\varphi = \frac{(LDT)^{1/3}}{L} \quad (5)$$

The aspect ratio, Ra, was calculated using the following relationship [22]:

$$R_a = \frac{W}{L} \quad (6)$$

The surface area of the seeds and kernels was determined by similarity with a sphere of the same geometric mean diameter, using the following expressions [8, 17, 21]:

$$S = \pi D_g^2 \quad (7)$$

The tests were carried out with five replications for all levels of moisture content, varieties, categories and the average values were reported. Average, minimum, maximum, standard deviations, correlation coefficients of dimensions and regression equations were computed using Microsoft Excel software (2003).

RESULTS AND DISCUSSION

Seed and Kernel Dimensions: The variation of length, width and thickness of the sunflower seed and its kernel at different levels of moisture content for all varieties and size categories are shown in Tables 1 and 2. It can be found that for all varieties and size categories of seed and kernel the main dimensions (length, width and thickness) have linearly increased with increase in moisture content. This indicates that during the moisture absorption process, the studied varieties of sunflower seed and its kernel will simultaneously expand in all dimensions. Deshpande *et al.* [7] reported similar results for soybean. For the studied range of moisture content (3-14% d.b.) and in all varieties of sunflower seed, the highest average

Table 1: Variation of dimensions of sunflower seed with moisture content, size and variety

			Moisture content (% d.b.)		
Variety	Dimensions	Size	3	7	14
Fandoghi	Length	Big	11.90 ± 0.58	12.09 ± 0.64	12.55 ± 0.55
		Average	10.858 ± 0.73	11.53 ± 1.12	11.96 ± 0.54
		Small	10.26 ± 0.76	11.03 ± 0.96	11.53 ± 0.50
	Width	Big	7.91 ± 0.52	8.19 ± 0.66	8.53 ± 0.54
		Average	6.17 ± 0.37	6.31 ± 0.40	6.42 ± 0.43
		Small	4.66 ± 0.58	5.08 ± 0.56	5.35 ± 0.29
	Thickness	Big	5.25 ± 0.46	5.33 ± 0.61	5.76 ± 0.41
		Average	4.08 ± 0.55	4.14 ± 0.43	4.69 ± 0.31
		Small	3.27 ± 0.43	3.64 ± 0.53	3.89 ± 0.23
Azargol	Length	Big	14.49 ± 0.91	15.13 ± 1.13	15.98 ± 0.89
		Average	13.87 ± 1.14	14.27 ± 0.97	15.18 ± 1.02
		Small	13.32 ± 0.99	13.79 ± 0.78	14.13 ± 0.89
	Width	Big	7.24 ± 0.29	7.35 ± 0.44	7.50 ± 0.46
		Average	6.33 ± 0.24	6.34 ± 0.39	6.51 ± 0.38
		Small	5.02 ± 0.39	5.31 ± 0.44	5.52 ± 0.35
	Thickness	Big	4.27 ± 0.32	4.28 ± 0.38	4.36 ± 0.41
		Average	3.81 ± 0.29	3.83 ± 0.38	4.13 ± 0.29
		Small	3.12 ± 0.38	3.39 ± 0.47	3.59 ± 0.29
Shahroodi	Length	Big	14.13 ± 0.58	14.54 ± 0.82	15.06 ± 0.67
		Average	14.24 ± 0.43	14.53 ± 0.49	14.73 ± 0.59
		Small	13.27 ± 0.43	13.31 ± 0.58	13.49 ± 0.37
	Width	Big	8.94 ± 0.47	9.15 ± 0.54	9.26± 0.58
		Average	8.09 ± 0.17	8.13 ± 0.30	8.25 ± 0.32
		Small	7.87 ± 0.25	7.93 ± 0.32	8.22 ± 0.29
	Thickness	Big	4.78 ± 0.48	4.81 ± 0.66	4.94 ± 0.58
		Average	4.07 ± 0.20	4.13 ± 0.57	4.42 ± 0.69
		Small	3.88 ± 0.34	4.17 ± 0.64	4.38 ± 0.29

Table 2: Variation of dimensions of sunflower kernel with moisture content, size and variety

			Moisture content (% d.b.)		
Variety	Dimensions	Size	3	7	14
Fandoghi	Length	Big	9.082 ± 0.431	9.216 ± 0.630	9.347 ± 0.452
		Average	8.956 ± 0.778	9.099 ± 0.857	9.316 ± 0.659
		Small	8.641 ± 0.649	8.752 ± 0.676	8.980 ± 0.534
	Width	Big	4.894 ± 0.431	5.018 ± 0.434	5.159 ± 0.292
		Average	4.193 ± 0.303	4.329 ± 0.322	4.561 ± 0.230
		Small	3.559 ± 0.315	3.747 ± 0.359	3.976 ± 0.320
	Thickness	Big	2.928 ± 0.290	3.059 ± 0.273	3.185 ± 0.221
		Average	2.618 ± 0.349	2.767 ± 0.381	2.896 ± 0.173
		Small	2.490 ± 0.268	2.646 ± 0.339	2.809 ± 0.226
Azargol	Length	Big	10.814 ± 0.908	10.963 ± 0.955	11.179 ± 0.743
		Average	10.494 ± 0.599	10.517 ± 0.707	10.656 ± 0.654
		Small	10.315 ± 0.666	10.481 ± 0.749	10.578 ± 0.634
	Width	Big	4.580 ± 0.242	4.792 ± 0.336	4.935 ± 0.258
		Average	4.143 ± 0.309	4.446 ± 0.372	4.533 ± 0.332
		Small	3.445 ± 0.225	3.744 ± 0.330	3.823 ± 0.268
	Thickness	Big	2.417 ± 0.206	2.558 ± 0.277	2.872 ± 0.205
		Average	2.371 ± 0.220	2.451 ± 0.244	2.609 ± 0.166
		Small	2.304 ± 0.205	2.429 ± 0.262	2.429 ± 0.262
Shahroodi	Length	Big	11.304 ± 0.592	11.453 ± 0.679	11.573 ± 0.619
		Average	11.233 ± 0.746	11.376 ± 0.765	11.511 ± 0.718
		Small	10.535 ± 0.656	10.675 ± 0.693	10.827 ± 0.641
	Width	Big	5.399 ± 0.249	5.573 ± 0.462	5.729 ± 0.350
		Average	4.956 ± 0.361	5.085 ± 0.377	5.22 ± 0.343
		Small	4.995 ± 0.278	5.121 ± 0.369	5.214 ± 0.256
	Thickness	Big	2.508 ± 0.210	2.715 ± 0.408	2.837 ± 0.209
		Average	2.357 ± 0.178	2.489 ± 0.234	2.827 ± 0.199
		Small	2.319 ± 0.183	2.461 ± 0.258	2.622 ± 0.194

Table 3: Regression models and coefficients of determination achieved for dimensions of studied sunflower seed varieties as a function of moisture content (3 - 14% d.b.) and size.

Variety	Size	Length	R^2	Width	R^2	Thickness	R^2
Fandoghi	Big	L= 0.0597Mc + 11.71	0.99	W= 0.0553Mc + 7.77	0.99	T= 0.0481Mc + 5.06	0.95
	Average	L= 0.0953Mc + 10.87	0.92	W= 0.0221Mc + 6.12	0.95	T= 0.0581Mc + 3.84	0.93
	Small	L= 0.1102Mc + 10.06	0.93	W= 0.06Mc + 4.549	0.92	T= 0.0539Mc + 3.17	0.92
Azargol	Big	L= 0.1336Mc + 14.13	0.99	W= 0.0233Mc + 7.18	0.99	T= 0.0113Mc + 4.22	0.94
	Average	L= 0.1203Mc + 13.48	0.99	W= 0.0169Mc + 6.26	0.91	T= 0.0305Mc + 3.68	0.92
	Small	L= 0.071Mc + 13.18	0.93	W= 0.0443Mc + 4.93	0.94	T= 0.0415Mc + 3.04	0.93
Shahroodi	Big	L= 0.0837Mc + 13.91	0.99	W= 0.0278Mc + 8.89	0.91	T= 0.0179Mc + 4.71	0.95
	Average	L= 0.0433Mc + 14.154	0.93	W= 0.0325Mc + 7.75	0.96	T= 0.0436Mc + 3.80	0.95
	Small	L= 0.0212Mc + 13.19	0.96	W= 0.0144Mc + 8.04	0.99	T= 0.0333Mc + 3.94	0.96

Table 4: Regression models and coefficients of determination achieved for dimensions of studied sunflower kernel varieties as a function of moisture content (3 - 14% d.b.) and size.

Variety	Size	Length	R^2	Width	R^2	Thickness	R^2
Fandoghi	Big	l= 0.0235Mc + 9.03	0.97	w= 0.0236Mc + 4.84	0.99	t= 0.0228Mc + 2.87	0.97
	Average	l= 0.0326Mc + 8.86	0.99	w= 0.0334Mc + 4.09	1	t= 0.0245Mc + 2.56	0.96
	Small	l= 0.031Mc + 8.542	0.99	w= 0.0373Mc + 3.46	0.99	t= 0.0283Mc + 2.42	0.98
Azargol	Big	l= 0.0329Mc + 10.72	0.99	w= 0.0309Mc + 4.52	0.93	t= 0.0418Mc + 2.28	0.99
	Average	l= 0.0153Mc + 10.43	0.95	w= 0.0338Mc + 4.11	0.91	t= 0.0218Mc + 3.68	0.99
	Small	l= 0.9109Mc + 10.28	0.91	w= 0.0317Mc + 3.42	0.91	t= 0.0274Mc + 2.23	0.99
Shahroodi	Big	l= 0.0236Mc + 11.25	0.95	w= 0.0292Mc + 5.33	0.96	t= 0.0285Mc + 2.46	0.91
	Average	l= 0.0246Mc + 11.18	0.97	w= 0.0191Mc + 4.96	0.94	t= 0.027Mc + 2.25	0.99
	Small	l= 0.026Mc + 10.47	0.98	w= 0.0235Mc + 4.90	0.98	t= 0.024Mc + 2.30	0.98

expansion was along the length and the lowest along the thickness, but for all varieties of sunflower kernel the highest and lowest average expansion was along the width and along the length, respectively. Deshpande *et al.* [7] found that the expansion rate of soybean seeds to be the largest along their thickness in comparison with their other two principal axes. This could be as a result of the different cell arrangements, environmental and growth conditions for the seeds and their kernels. Among the varieties studied, Shahroodi cultivar had greater values in all main dimensions than other two varieties for both seed and kernel.

The range of length for Fandoghi, Azargol and Shahroodi sunflower seed at 7 % (d.b) were 11.03 - 12.10, 13.79 -15.13 and 13.31-14.54 mm, respectively. The range of length for Fandoghi, Azargol and Shahroodi sunflower kernel at 7% (d.b) were 8.75 - 9.22, 10.48 - 10.96 and 10.67- 11.45 mm, respectively. Gupta and Das [4] reported the ranges of 8.92 - 9.52 and 7.23 - 8.28 mm for the length of an modern variety of sunflower seed and kernel at 6.2 %(d.b) respectively. They also reported the ranges of 3.92 - 5.12 and 2.52 - 3.27 mm for width and thickness of this variety of sunflower seed , in same way they reported 3.59 - 4.09 and 2.09 - 2.43 mm for width and thickness of this variety of sunflower kernel at 6.2 %(d.b) respectively. In aother study, the average length, width and thickness of a sunflower seed were indicated as 7.79, 7.12 and 4.18 mm at a moisture content of 10.06% d.b., respectively (Isik and Izli, 2007). Santalla and Mascheroni [6] showed an average length, width, thickness of 11.53, 5.01 and 2.81 mm respectively. Corresponding values for the kernel were found 8.80,3.89 and 1.91 mm respectively by them.

Tables 3 and 4 shows the regression models and coefficients of determination (R^2) achieved by fitting the dimension values for each variety of sunflower seed and its kernel as a function of moisture content and size. It can be observed that all dimensions of different varieties of sunflower seed and its kernel increased linearly with increase in moisture content. In all cases, very high correlation was found between the main dimensions and moisture content. These linear behaviors are in accordance with results reported in the literature for almond [23], millet [19], coffee bean [24], soybean [7], pumpkin seed [14], cotton seed [8], white lupin [25] and cumin seed [26].

Equivalent, Geometric and Arithmetic Mean Diameters: Figures 4-12 show the variation of equivalent, geometric and arithmetic mean diameters as a function of moisture content for all size categories of the investigated varieties of sunflower seed and its kernel.

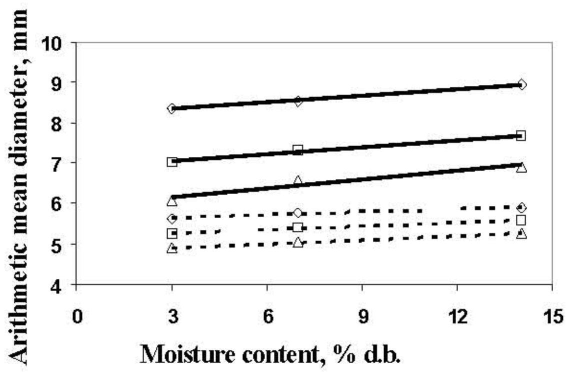

Fig. 4: Effect of moisture content and size on arithmetic mean diameter of Fandoghi variety of sunflower seed and kernel (◊, big; □, average; Δ, small; -, seed; - - -, kernel.)

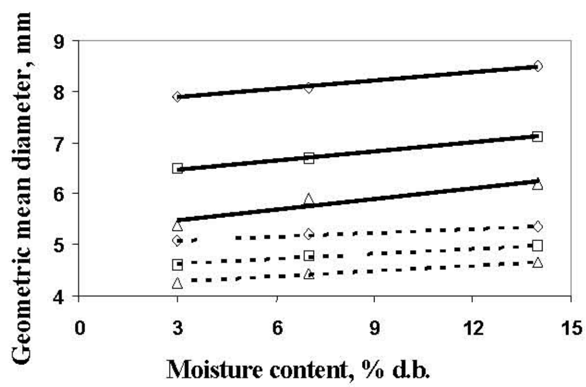

Fig. 7: Effect of moisture content and size on geometric mean diameter of Fandoghi variety of sunflower seed and kernel (◊, big; □, average; Δ, small; -, seed; - - -, kernel.)

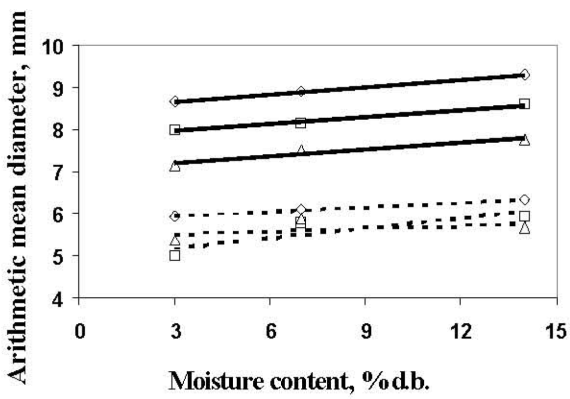

Fig. 5: Effect of moisture content and size on arithmetic mean diameter of Azar gol variety of sunflower seed and kernel (◊, big; □, average; Δ, small; -, seed; - - -, kernel.)

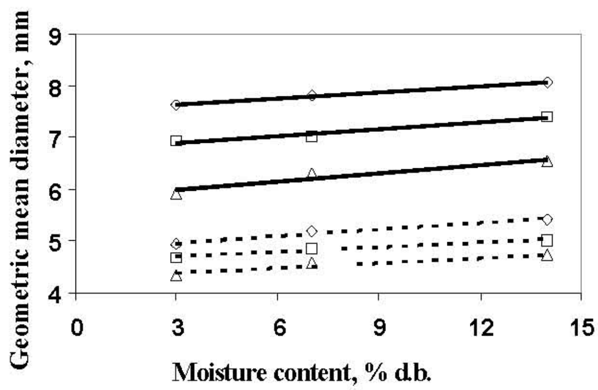

Fig. 8: Effect of moisture content and size on geometric mean diameter of Azar gol variety of sunflower seed and kernel (◊, big; □, average; Δ, small; -, seed; - - -, kernel.)

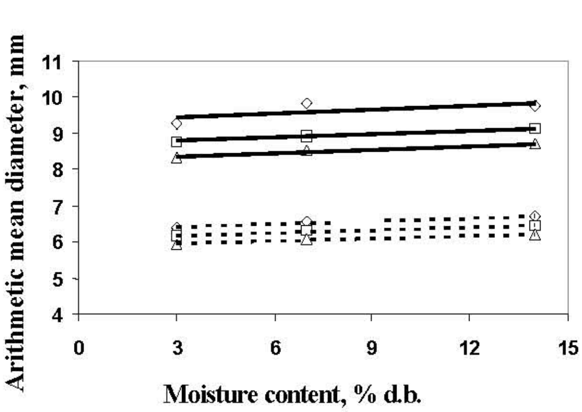

Fig. 6: Effect of moisture content and size on arithmetic mean diameter of Shahroodi variety of sunflower seed and kernel (◊, big; □, average; Δ, small; -, seed; - - -, kernel.)

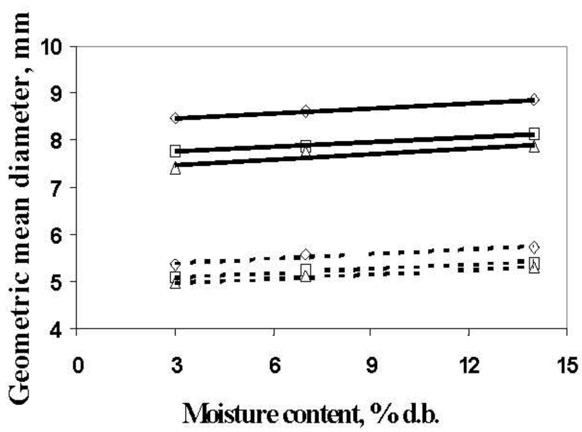

Fig. 9: Effect of moisture content and size on geometric mean diameter of Shahroodi variety of sunflower seed and kernel (◊, big; □, average; Δ, small; -, seed; - - -, kernel.)

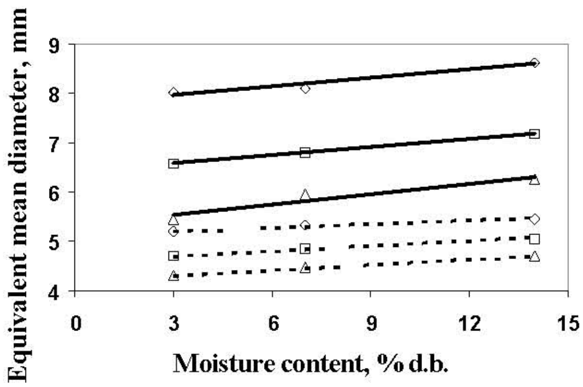

Fig. 10: Effect of moisture content and size on equivalent mean diameter of Fandoghi variety of sunflower seed and kernel (◊, big; □, average; Δ, small; -, seed; - - -, kernel.)

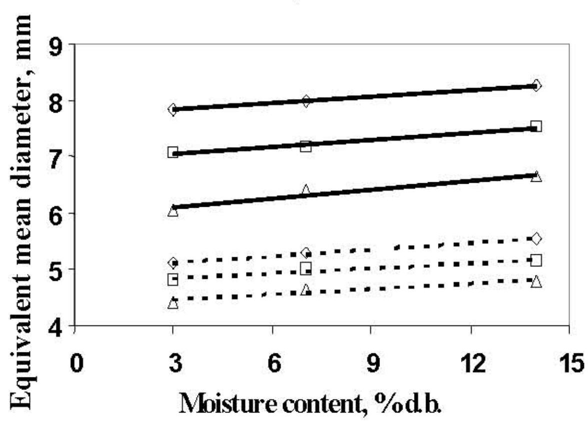

Fig. 11: Effect of moisture content and size on equivalent mean diameter of Azar gol variety of sunflower seed and kernel (◊, big; □, average; Δ, small; -, seed; - - -, kernel.)

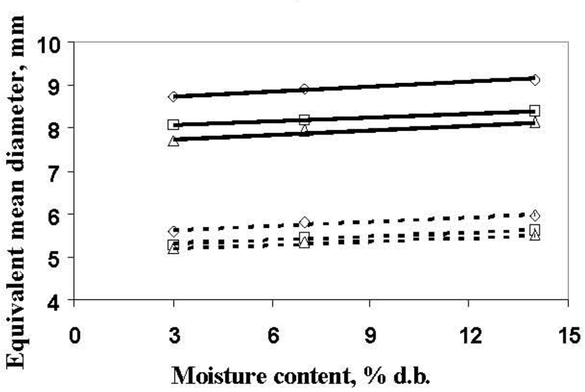

Fig. 12: Effect of moisture content and size on equivalent mean diameter of Shahroodi variety of sunflower seed and kernel (◊, big; □, average; Δ, small; -, seed; - - -, kernel.)

The results revealed that equivalent, geometric and arithmetic mean diameters of both seeds and kernels increased linearly with increase in moisture content. The average of geometric mean diameter in all treatments was higher than those reported for cumin seed [20] and millet [19]. The minimum and maximum of equivalent diameter for sunflower seed of all studied varieties and size categories were 5.44 and 9.14 mm respectively. The corresponding values for kernel were 4.29 and 5.96 mm respectively. It should be noted that the minimum and maximum values for both seed and kernel were belonged to Fandoghi and shahroodi varieties, respectively. The arithmetic mean diameter for Fandoghi, Azargol and Shahroodi sunflower seeds ranged from 6.6- 8.95, 7.15-9.29 and 8.34-9.83 mm, respectively. These values for sunflower kernels were 4.9-5.9, 5-6.33 and 5.95-6.71 mm, respectively. Also, the ranges of geometric mean diameter for Fandoghi, Azargol and Shahroodi sunflower seed were 5.38-8.51, 5.93-8.07 and 7.4 - 8.85 mm, respectively. Furthermore, this parameter for kernels ranged from 4.25 - 5.35, 4.34 - 5.41 and 4.96 - 5.73 mm, respectively. The equivalent diameter for Fandoghi, Azargol and Shahroodi sunflower seeds ranged from 5.44 - 8.62, 6.04 - 8.26 and - 9.14 mm, respectively. These values for their kernels were 4.29 - 5.46, 4.4 - 5.54 and 5.2 - 5.96 mm, respectively. Gupta and Das [4] reported 4.72 and 3.46 mm for equivalent diameter of sunflower seed and kernel respectively. Also, the variation of geometric mean diameter for sunflower seed was indicated as 6.15 - 7.93 mm when moisture content ranged from 10.06 - 27.06% [5].

Sphericity and Aspect Ratio: The average variation of sphericity and aspect ratio, as dependant variables, with moisture content, variety and size, as independent variables, are shown in Tables 5 and 6. Except a few cases, the sphericity for both seed and kernel of studied varieties increased with increase in size and moisture content. As it can be seen the sphericity of kernel was more dependent to the studied variables than seed. Furthermore, the aspect ratio of kernels increased with an increase in moisture content. This might be attributed to cellular organization or structure of the kernel. Deshpande *et al.* [7] found that the sphericity of soybeans increases linearly with moisture content up to 25%. Among all the studied varieties, Fandoghi had the maximum sphericity for both seed (0.68) and kernel (0.57). In addition, the minimum sphericity for seed (0.44) and kernel (0.42) belonged to Azargol variety. The average sphericity for sunflower seed and kernel was reported 0.57 and 0.53, respectively by Gupta and Das (1997).

Table 5: The sphericity and aspect ratio for each sunflower seed variety as a function of moisture content (3 - 14% d.b.) and size

			Moisture content (%d.b.)		
Variety	Topic	Size	3	7	14
Fandoghi	Sphericity	Big	0.66	0.67	0.68
		Average	0.6	0.58	0.59
		Small	0.52	0.53	0.54
	Aspect ratio	Big	0.66	0.68	0.68
		Average	0.57	0.55	0.54
		Small	0.45	0.46	0.46
Azargol	Sphericity	Big	0.53	0.52	0.5
		Average	0.5	0.49	0.49
		Small	0.44	0.45	0.46
	Aspect ratio	Big	0.5	0.49	0.47
		Average	0.46	0.44	0.43
		Small	0.37	0.38	0.39
Shahroodi	Sphericity	Big	0.6	0.59	0.59
		Average	0.55	0.54	0.55
		Small	0.56	0.58	0.58
	Aspect ratio	Big	0.63	0.63	0.61
		Average	0.57	0.56	0.56
		Small	0.59	0.6	0.61

Table 6: The sphericity and aspect ratio for each sunflower kernel variety as a function of moisture content (3 - 14% d.b.) and size

			Moisture content (%d.b.)		
Variety	Topic	Size	3	7	14
Fandoghi	Sphericity	Big	0.56	0.56	0.57
		Average	0.51	0.52	0.53
		Small	0.49	0.51	0.52
	Aspect ratio	Big	0.54	0.54	0.55
		Average	0.47	0.48	0.49
		Small	0.41	0.43	0.44
Azargol	Sphericity	Big	0.46	0.47	0.48
		Average	0.45	0.46	0.47
		Small	0.42	0.44	0.45
	Aspect ratio	Big	0.42	0.45	0.44
		Average	0.4	0.42	0.43
		Small	0.33	0.36	0.36
Shahroodi	Sphericity	Big	0.47	0.49	0.49
		Average	0.45	0.46	0.47
		Small	0.47	0.5	0.49
	Aspect ratio	Big	0.48	0.49	0.49
		Average	0.44	0.45	0.45
		Small	0.47	0.48	0.48

Isik and Izli [5] indicated an increase in sphericity of sunflower seed (0.79 to 0.84) with increase in moisture content. Also, Fandoghi had the maximum aspect ratio of sunflower seed and kernel that was 0.68 and 0.55 respectively. Moreover, Azargol had the minimum aspect ratio for seed and kernel with 0.37 and 0.33 respectively. The variation of aspect ratio for sunflower seed and kernel has not yet been reported. The mean equivalent diameter and sphericity of the sunflower seeds were reported 5.49 mm and 0.46, respectively by Santalla and Mascheroni [6], Also, they showed values of 4.01 mm and 0.44 for kernels, respectively.

Table 7: Regression models and coefficients of determination achieved for surface area of studied sunflower seed varieties as a function of moisture content (3 - 14% d.b.) and size.

Variety	Size	Surface area	R^2
Fandoghi	Big	$S=2.8532 M^c + 186.98$	0.99
	Average	$S=2.4621 M^c + 124.6$	0.99
	Small	$S=2.63.37 M^c + 85.944$	0.93
Azargol	Big	$S=1.9211 M^c + 177.83$	0.99
	Average	$S=1.9869 M^c + 143.79$	0.96
	Small	$S=2.09 Mc + 106.32$	0.94
Shahroodi	Big	$S=1.9569 M^c + 218.95$	0.99
	Average	$S=1.6608 M^c + 184.01$	0.99
	Small	$S=1.8818 M^c + 169.56$	0.85

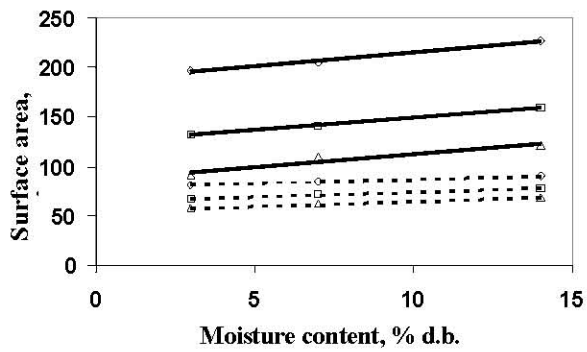

Fig. 13: Effect of moisture content and size on surface area of Fandoghi variety of sunflower seed and kernel (◊, big; □, average; Δ, small; -, seed; - - -, kernel.)

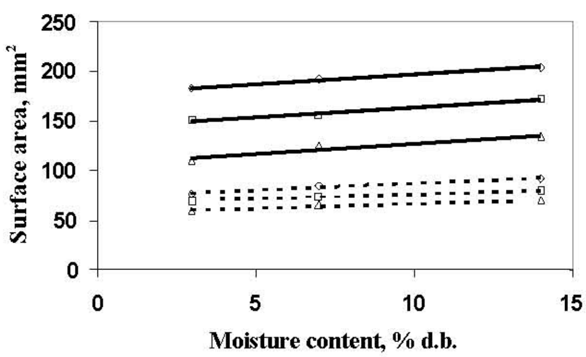

Fig. 14: Effect of moisture content and size on surface area of Azar gol variety of sunflower seed and kernel (◊, big; □, average; Δ, small; -, seed; - - -, kernel.)

Surface Area: The surface area of sunflower seed and kernel were calculated using Equation 7. The variation of this parameter for seed and kernel with variety, size and moisture content are shown in Figs. 13 - 15. Among all the studied varieties, Shahroodi had the mximum surface area for both seed and kernel, that were 246.06 and 103.15, respectively. In addition, Fandoghi had the minimum

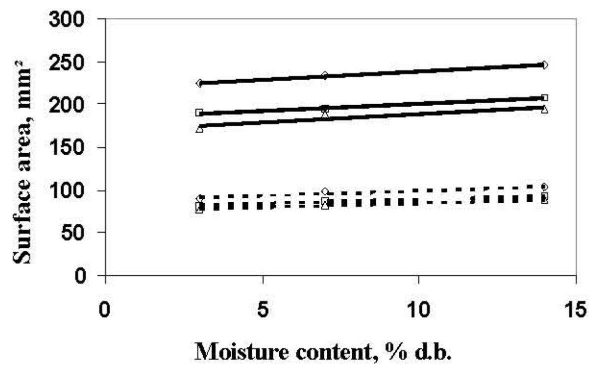

Fig. 15: Effect of moisture content and size on surface area of Shahroodi variety of sunflower seed and kernel (◊, big; □, average; Δ, small; -, seed; - - -, kernel.)

value for this parameter for both seed and kernel. Meanwhile, Fandoghi variety showed more variations with treatments. As it can be seen, the surface area of seed and kernel increased linearly with increasing moisture content in all varieties and categories. Deshpande *et al.* [7] attained a similar result for soybean. In contrary, Hsu *et al.* [27] found that the surface area of pistachio decreases with absorbing moisture.

The surface area of both seed and kernel increased with increasing size in all varieties. Similar variations for surface area of other grains with increasing moisture content have been revealed by Selvi *et al.* [28] for lineseed, Isik and Izli [5] for sunflower seed and Garnayak *et al.* [29] for jatropha seed. Santalla and Mascheroni [6] showed a surface area of approximately 102.41 mm² with an average length, width, thickness and unit mass of 11.53, 5.01 and 2.81 mm and 0.05 g, respectively for sunflower seed.

The regression relationships between surface area and moisture content for all varieties and size categories of sunflower seed and its kernel are presented in Table 7.

The positive linear relationship of surface area with moisture content was also observed by other researchers such as Selvi *et al.* [28] and Baryeh [19] for linseed and millet, respectively.

CONCLUSION

Geometrical properties of three varieties of sunflower seed and its kernel including Shahroodi, Fandoghi and Azargol, were investigated while moisture content ranged from 3% and 14% (d.b.). The seeds and their kernels were categorized on the basis of their size in three groups namely big, average and small. The results of this study are summarized as below:

- All the main dimensions (length, width and thickness) for all varieties and size of seeds and kernels increased linearly with the increase of moisture content. This implies that any delay in the processing of the seeds and their kernel leads to dimensions reduction due to moisture content decreasing.
- Due to moisture gain, for all three varieties while the maximum and minimum total average expansions were along the seed length and thickness, respectively, these values for the kernels were along the width and the length, respectively.
- Coefficients of determination between dimensions and moisture content showed a very high correlation in all cases.
- The results revealed that equivalent, geometric and arithmetic mean diameters for both seeds and kernels increased linearly with increase of moisture content.
- Except a few cases, the sphericity for both seeds and kernels of the studied varieties increased with increase of size and moisture content. This increase in sphericity was higher in kernels than seeds.
- Aspect ratio of kernels increased with an increase in moisture content.
- Fandoghi variety had the maximum sphericity and aspect ratio for both seed and kernel. In addition, the minimum sphericity and aspect ratio for both seed and kernel belonged to Azargol.
- The surface area of seed and kernel increased linearly with increasing moisture content in all varieties and size categories.
- Among all the studied varieties, Shahroodi had the maximum surface area for both seed and kernel. Additionally, Fandoghi had the minimum value of this parameter for both seed and kernel.

Complementary experimental studies including gravimetrical and frictional properties of sunflower seed and its kernel have been conducted through an integrated project and are available elsewhere.

Application of Investigated Properties: Values of the studied properties play a key role in minimizing losses during handling, processing and preservation of oil. Therefore, by adapting results of this study, the input cost in processing of sunflower seed is reduced and oil yield is increased. Totally, obtained values are applicable on the basis of investigated moisture content in each size category. Investigated values at 12% moisture content can be used in the threshing stage of sunflower processing. Because at this moisture content, thresher gives maximum outturn with a threshing efficiency of 98% [1]. On the other hand, common moisture content for cleaning and grading of sunflower seed is 7% d.b. So, values of geometrical properties at this moisture content are useful in the cleaning and grading steps. Pierce [30] has reported that decorticated sunflower seeds at 3.6% moisture content gave satisfactory results. Then, conducted studies at 3% d.b are valuable. Completely, main dimensions, sphericity, diameter and surface area showed information needed to estimate shape and size of sunflower seed for designing an electrostatic or the development of sizing and sorting machinery. The identification of seed shape could also be important for an analytical prediction of its drying behavior. Drying is one of the most important and energy intensive processes in agriculture and the food industry.

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