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Gravimetrical Properties of Sunflower Seeds and Kernels

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Abstract: Gravimetrical properties of sunflower seeds and their kernel, like those of other seeds, are essential for the design of equipment for handling, separating, sorting, dehulling and drying. In this study, gravimetrical properties of three common varieties of Iranian sunflower seeds and their kernel (namely; Shahroodi, Fandoghi and Azargol) were evaluated as a function of size category and variety with moisture content ranging from 3 to 14% (d.b.). In this moisture range, thousand grain mass, true volume, true density and porosity were increased linearly for both of seeds and kernels in all varieties and categories. The bulk density of seeds and kernels linearly was decreased as moisture content increased from 3 to 14 %. The true density of Fandoghi, Azargol and Shahroodi seeds for all sizes were found to vary from 700.80 - 791.22, 666.66 - 749.30, 718.59 - 800.70 kg m^{-3}, while this value for the corresponding kernels varied from 1046.60 - 1210.10, 1029.9 - 1199.9 and 1109.6 - 1249.9 kg m^{-3}, respectively when the moisture content increases from 3 to 14% d.b.

Key words: Gravimetrical properties · Sunflower seed and kernel · Moisture content · Variety · Size

INTRODUCTION

Sunflower seed (*Helianthus annuus* L.) is an important oilseed crop because it contains a large amount of highly nutritious oil [1]. According to Iranian government statistical data of 2005, about 35 varieties of sunflower are cultivated in several regions of Iran such as Khorasan Razavi, Golestan, Hamedan, Esfehan, Azarbayejan Gharbi, Azarbayejan Sharghi, Fars, Semnan and Markazi. In this country, sunflower seeds are cultivated and consumed in two different ways, directly as nut and as cooking oil. Information on gravimetrical properties of sunflower seed and kernel such as thousand grain mass, bulk density, true density, porosity and volume are essential for the design of various processing equipment including: conveying, separating, sorting, dehulling, drying, storing and mechanical oil expression. Like other particulate materials, their properties can be affected by some suspicious factors such as seed variety, size and moisture content. Bulk density, true density and porosity is useful in sizing grain hoppers and storage facilities as they can affect the rate of heat and mass transfer during aeration and drying operations [2]. Moreover, seed densities are of interest in breakage susceptibility and hardness studies. The porosity is the most important factor for packing as it affects the resistance to airflow through bulk seeds.

In spite of worldwide, extensive research on some physical properties of sunflower seed, no published literature was found on the detailed gravimetrical properties of this seed and its dependency on functional parameters which would be helpful for the design of various processing equipment. Though, many valuable studies have been carried out on the gravimetrical properties of agricultural particulate materials [3-15]. Gupta and Das [10] studied some physical properties of sunflower seed and its kernel as a function of moisture content. They reported an increase in true density, porosity and a decrease in bulk density for both seed and kernel of sunflower when moisture content increased from 4 to 20% (d.b). A similar trend has been observed between seed moisture content and bulk density of safflower [16]. Deshpande *et al.* [6] reported a direct correlation of true density and porosity with moisture content in soybeans. Isik and Izil [15] investigated some moisture-dependent properties of sunflower for only the Turkey sunflower seed cultivar. They showed that the "thousand grain mass", true density and porosity increased while the bulk density was decreased with increasing the moisture content in the range of 10.06 - 27.06 % (d.b.). Erica *et al.* [17] studied the effect of moisture content on some physical properties of safflower seeds typically cultivated in Argentina. They reported that volume and weight of seed, the expansion coefficient and porosity were

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increased linearly with increasing seed moisture content. Also, they revealed that an increase in moisture content yielded a linear decrease in bulk density whereas, true density decreased nonlinearly.

The objective of this study was to investigate some gravimetrical properties of three common varieties of Iranian sunflower seeds and their kernels (Shahroodi, Fandoghi and Azargol) including thousand grain mass, true volume, bulk density, true density, porosity as a function of size and variety and moisture content in the range of 3 to 14% (d.b.).

MATERIALS AND METHODS

Sample Preparation, Moisture Content Determination and Seed Size Grading: Three sunflower varieties namely Shahroodi, Fandoghi and Azargol were obtained from three regions of Khorasan razavi province (North East of Iran) during autumn in 2008. (Figure 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 [10,18,19]. 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 (Figure 2). All the geometrical properties of the seeds were measured for three levels of moisture content in the range of 3 to 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 quantity of water to the samples. The required amount of water for the samples was determined using the following equation [19]:

$$Q = \frac{W_i(M_f - M_i)}{100 - M_f} \quad (1)$$

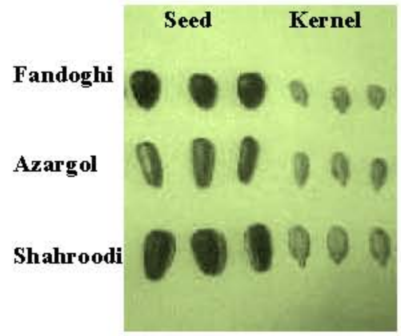

Fig. 1: The illustrated view of seed and kernel of three varieties of sunflower

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

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 [5,10].

Gravimetrical Characteristics: The "Thousand seed mass" was measured by counting and weighting 100 seeds (using a precision electronic balance with an accuracy of 0.001 g) and then multiplied by 10 to give the mass of 1000 seeds of each seed size category. The "thousand kernel mass" was also determined in the same way. The true volume (V, cm^3) of seeds and kernels as a function of variety, size and moisture content were determined using the toluene (C_7H_8) displacement method [9]. Toluene was used in place of water because it is absorbed by seed and kernel of sunflower to a lesser extent. Furthermore, its surface tension is low, so that it fills even shallow dips in a seed and its dissolution power is also low [11,20]. The true density of a seed or a kernel (ρt, kg m^{-3}) is defined as the ratio of its mass to its actual volume and hence was calculated by dividing the unit mass of each sample (seed or kernel) to its true volume [21]. The bulk density of particulate materials (ρb, kg m^{-3}) is the ratio of the sample mass to its total volume. This was determined by filling a cylindrical container of 500ml volume with seeds (kernels) to a height of 15cm at a constant rate and then weighting the contents. This method has also been employed by others [10,22,23]. Thompson and Isaac [24] described the porosity (ε) as the fractions of the space in the bulk grain that is not occupied by the grain. Accordingly, Mohsenin [25] calculated the porosity as follow:

$$\varepsilon = 1 - \frac{\rho_b}{\rho_t} \times 100 \quad (2)$$

The experiments for all moisture contents, varieties and categories were carried out with five replications and subsequently the average values were reported. Microsoft Excel software (2003) was employed to compute the statistical parameters including: average, minimum, maximum, standard deviations, correlation coefficients of dimensions and regression equations.

RESULTS AND DISCUSSION

Thousand Grain Mass: The variation of thousand grain mass of sunflower seeds and their kernel at different moisture contents for all varieties and categories are shown in Figures 3 to 5. The minimum and maximum of thousand grain mass for seeds were 70.998 and 181.16 g, respectively. Of course, the minimum and maximum seed were belonged to Fandoghi and shahroodi varieties, respectively; whereas these values for kernel were 18.4 and 128.8, belonged to Azargol and Shahrioodi, respectively. The ranges of thousand grain mass for Fandoghi, Azargol and Shahroodi sunflower seed were 70.998 - 161.44, 76.216 - 139.72 and 121.6 - 181.16 g, respectively. These values for sunflower kernels were 36.8 - 108.8, 18.4 - 105.2 and 54.8 - 128.8 g, respectively. The Figs indicate that the thousand grain mass was increased linearly with increasing moisture content in all varieties and size categories of samples (seeds and kernels). Deshpande *et al.* [6] Singh and Goswami, [9] Ogut, [11] Aviara *et al.* [12] have found similar trends for soybean, cumin seeds, white lupin and guna seeds, respectively. Isik and Izil [15] reported the thousand grain mass of sunflower seed in the range of 66 - 70 g when moisture content varied from 10.06% to 27.06%.

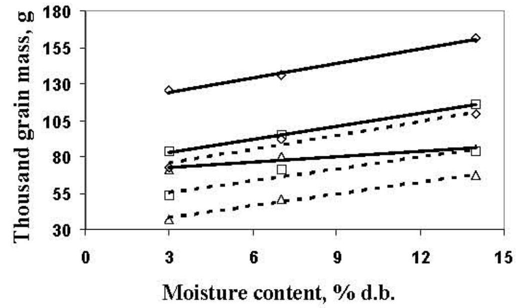

Fig. 3: Effect of moisture content and size on thousand grain mass of Fandoghi variety of sunflower seed and kernel (◇, big; □, average; Δ small; -, seed; - - -, kernel.)

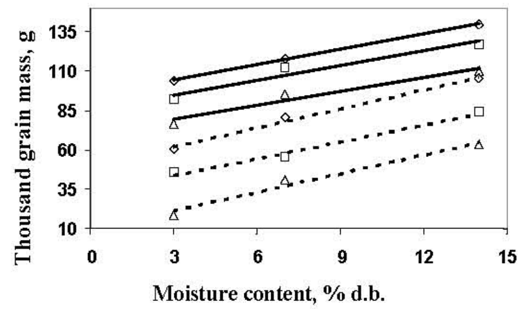

Fig. 4: Effect of moisture content and size on thousand grain mass of Azar gol variety of sunflower seed and kernel (◇, big; □, average; Δ, small; -, seed; - - -, kernel.)

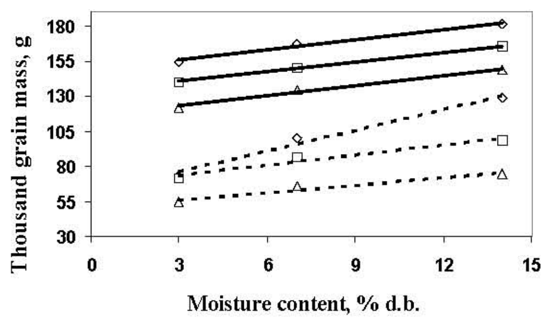

Fig. 5: Effect of moisture content and size on thousand grain mass of Azar gol variety of sunflower seed and kernel (◇, big;□, average; Δ, small; -, seed; - - -, kernel.)

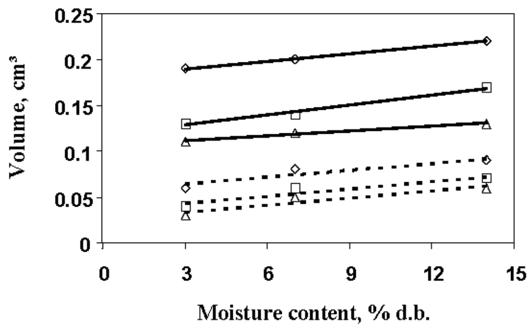

Fig. 6: Effect of moisture content and size on volume of Fandoghi variety of sunflower seed and kernel (◇, big;□, average; Δ, small; -, seed; - - -, kernel.)

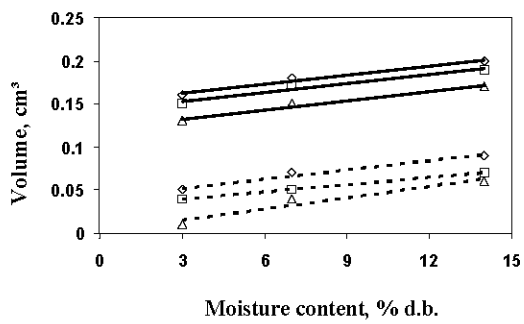

Fig. 7: Effect of moisture content and size on volume of Azar gol variety of sunflower seed and kernel (◇, big;□, average; Δ, small; -, seed; - - -, kernel.)

True Volume: The true volume of Fandoghi seeds for big, average and small size categories obtained in the ranged of 0.19 - 0.22, 0.13 - 0.17 and 0.11 - 0.13 cm^3, respectively. These values for Azargol were 0.16 - 0.2, 0.15 - 0.19 and 0.13 - 0.17 cm^3, respectively while for Shahroodi seeds were 0.23 - 0.25, 0.21 - 0.24, 0.18 - 0.21 cm^3, respectively. The true volume of Fandoghi kernels for big, average and small size categories were 0.06 - 0.09, 0.04 - 0.07, 0.03 - 0.06 cm^3, respectively. These values for Azargol kernels were

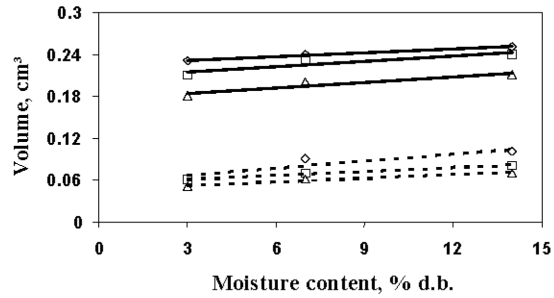

Fig. 8: Effect of moisture content and size on volume of Shahroodi variety of sunflower seed and kernel (◇, big;□, average; Δ, small; -, seed; - - -, kernel.)

0.05 - 0.09, 0.04 - 0.07, 0.01 - 0.06 cm^3 and for Shahroodi kernels 0.06 - 0.1, 0.06 - 0.08, 0.05 - 0.07 cm^3, respectively. Among all varieties under study, Shahroodi had the highest true volume for both seed and kernel. Furthermore, Fandoghi seed and Azargol kernel had the lowest volume among all varieties for the whole range of moisture content in this study. Figures 6 to 8 show the variation of the true volume of sunflower seed and kernel with moisture content for all studied varieties and different size categories.

The equations representing the relationship between the true volume and moisture content of sunflower seeds and their kernels for all studied varieties are presented in Table 1. As it can be observed, there was a linear relationship with a very high correlation (R^2) between the true volume and moisture content for all varieties and size categories.

There is a likeness between the results of this paper for sunflower and the findings of Shepherd and Bhardwaj [3] for pigeon pea, Deshpande *et al.* [6] for soybean, Dutta *et al.* [26] for gram and Ogut [11] for lupin. In all of these works, the true volume of seed increased linearly with moisture content.

Table 1: Regression models and coefficients of determination achieved for true volume of studied sunflower varieties (seed and its kernel) as a function of moisture content (3 - 14% d.b.) and size

Variety	Size	Seed	R^2	Kernel	R^2
Fandoghi	Big	M = 0.0037Mc+0.1259	0.99	M = 0.0032Mc+5.06	0.97
	Average	M = 0.0033Mc+0.0817	0.99	M = 0.0032Mc+0.0434	0.95
	Small	M = 0.0014Mc+0.0756	0.91	M = 0.0027Mc+3.17	0.99
Azar gol	Big	M 0.0035Mc+0.1047	0.99	M = 0.0041Mc+0.0488	0.97
	Average	M = 0.0033Mc+0.0954	0.94	M = 0.0037Mc+0.0319	0.99
	Small	M = 0.0032Mc+0.0774	0.95	M = 0.0043Mc+0.005	0.99
Shahroodi	Big	M = 0.0027Mc+0.1632	0.99	M = 0.0051Mc+0.0622	0.94
	Average	M = 0.0025Mc+0.1472	0.99	M = 0.0028Mc+0.0622	0.95
	Small	M = 0.0027Mc+0.1272	0.99	M = 0.002Mc+0.0489	0.99

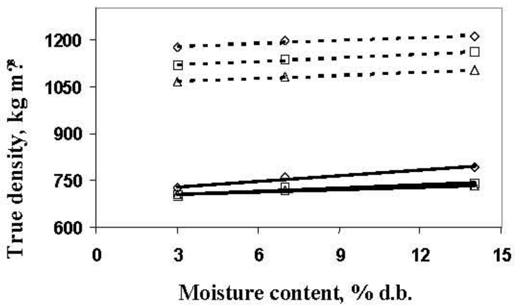

Fig. 9: Effect of moisture content and size on true density of Fandoghi variety of sunflower seed and kernel (◇, big; □, average; Δ, small; -, seed; - - -, kernel.)

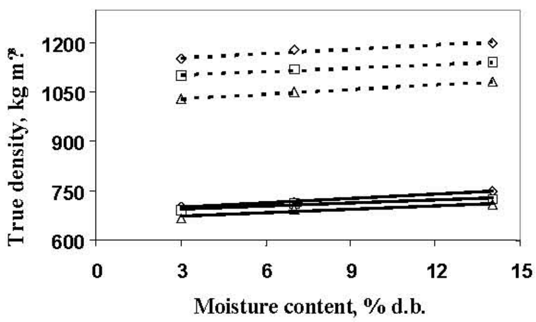

Fig. 10: Effect of moisture content and size on true density of Azar gol variety of sunflower seed and kernel (◇, big; □, average; Δ, small; -, seed; - - -, kernel.)

True Density: The experimental results of the true density of sunflower seeds and their kernel for the studied varieties and size categories at various moisture contents are shown in Figurs 9 to 11. The true density of Fandoghi, Azargol and Shahroodi seeds for all sizes varied from 700.80 - 791.22, 666.66 - 749.30 and 718.59 - 800.70 kg m^{-3}, respectively, while the true density of their kernel varied from 1046.60 - 1210.10, 1029.9 - 1199.9 and 1109.6 - 1249.9 kg m^{-3}, respectively when the moisture content increased from 3 to 14% d.b. Among all varieties under study,

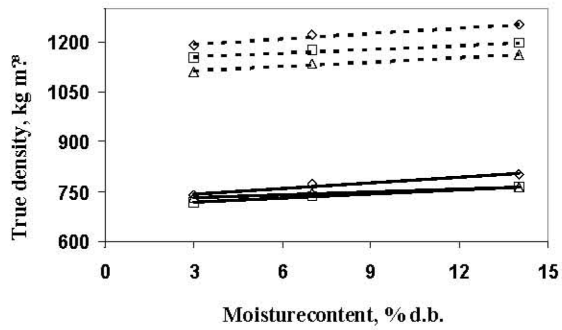

Fig. 11: Effect of moisture content and size on true density of Shahroodi variety of sunflower seed and kernel (◇, big; □, average; Δ, small; -, seed; - - -, kernel.)

Shahroodi had the highest true density for both seed and kernel. While, the lowest true density for both seed and kernel was observed for Azargol variety. Gupta and Das [10] found the true density of use sunflower seed and kernel variety in the range of 706 - 765 and 1050 - 1250 kg m^{-3}, respectively. Isik and Izil [15] reported the true density of sunflower seed in the range of 885 - 902 kg m^{-3} when moisture varied from 10.06 to 27.06%. The variation of results for the true density of different studies indicates that this parameter is highly dependant of seed variety. The results also show a linearly increasing trend of true density with moisture content for all varieties and categories of both seed and kernel. This implies a denser seedbed structure of such particulate materials with high moisture content. This agrees with the results of Singh and Goswami [9] for cumin seed, Gupta and Das [10] for sunflower seed, Ogut [11] for white lupin, Aviara *et al.* [12] for guna seeds and Baryeh [13] for millet. However, it is in contradiction of the results of Deshpande *et al.* [6], Joshi *et al.* [5], Suthar and Das [8] who found that the true density decreases with moisture content for soybeans, pumpkin seeds and karigda seeds, respectively.

Table 2: Regression models and coefficients of determination achieved for true density of studied sunflower varieties (seed and its kernel) as a function of moisture content (3 - 14% d.b.) and size

Variety	Size	Seed	R^2	Kernel	R^2
Fandoghi	Big	$\rho_t = 5.8499Mc+712.27$	0.95	$\rho_t = 3.0845Mc+1168.6$	0.95
	Average	$\rho_t = 3.2869Mc+695.14$	0.91	$\rho_t = 3.6458Mc+1108.9$	0.99
	Small	$\rho_t = 2.3708Mc+698.57$	0.96	$\rho_t = 3.2Mc+1056$	0.99
Azar gol	Big	$\rho_t = 4.47Mc+685.83$	0.99	$\rho_t = 4.3194Mc+1142.2$	0.93
	Average	$\rho_t = 3.1975Mc+682.99$	0.96	$\rho_t = 3.4903Mc+1091.8$	0.97
	Small	$\rho_t = 3.5Mc+660.69$	0.91	$\rho_t = 4.606Mc+1016.8$	0.99
Shahroodi	Big	$\rho_t = 5.4826Mc+726.57$	0.96	$\rho_t = 5.3097Mc+1177.5$	0.98
	Average	$\rho_t = 2.7325Mc+723.58$	0.99	$\rho_t = 4.0532Mc+1140.8$	0.96
	Small	$\rho_t = 4.041Mc+706.69$	0.99	$\rho_t = 4.4726Mc+1098.9$	0.98

Therefore, it can be concluded that while, some particulate materials may dilate with increasing moisture content the others exhibit a denser bed structure. Regression equations and their coefficients of determination (R^2) obtained for the true density of sunflower seeds and their kernel are presented as a function of variety, size category and moisture content in Table 2. These equations and coefficients confirm a linear behavior for all treatments.

Bulk Density: Figures 12 to 14 depict the bulk density variations of seed and kernel of all varieties (Fandighi, Azargol and Shahroodi) at studied moisture contents (3 to 14% d.b.). The range of bulk density at different moisture levels for seed of Fandighi, Azargol and Shahroodi were obtained between 390.80 - 500.48, 420.10 - 500.48 and 375.10 - 469.50 kg m^{-3}, respectively. Theses values for the corresponding kernels were 550.30 - 629.70, 553.90 - 644.50 and 539.84 - 609.94 kg m^{-3}, respectively. The results showed that Azargol and Shahroodi varieties had the highest and the lowest bulk density for both seed and kernel, respectively. Furthermore, the bulk density of seeds was lower than that of kernels for all varieties and size categories in the whole range of moisture content under study. This might be attributed to the hull or the seed coat which is bulkier than the kernel such that it causes a considerable reduction in the total mass per unit volume occupied by the seed. The same results also for modern variety of sunflower by Gupta and Das [10]. They reported the bulk density of seeds and kernels in the range of 438 - 465 and 570 - 625 kg m^{-3}, respectively. As it can be seen from the figures, the bulk density for both seeds and kernels decreased linearly when the moisture content increased from 3 to 14% d.b. In other words, the increase in mass because of moisture gain in the sample (seed or kernel) was smaller than the accompanying volumetric expansion of the bulk. Also, for all treatments the small seeds exhibited a higher bulk density than the bigger seeds. This can be related to the ratio of kernel mass to the hull mass of seeds. In other words for small seeds the specific surface area of hull (with lower true density) is lower than the bigger seeds. Gupta and Das [10] revealed a decrease in bulk density of both seeds and kernels of sunflower with increase in moisture content. Isik and Izil [15] also reported that the bulk density of sunflower seed decrease from 415.40 to 406.56 kg m^{-3} with an increase in the moisture content in the range of 10.06 - 27.06% d.b.

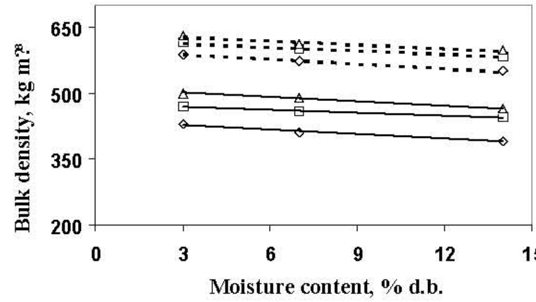

Fig. 12: Effect of moisture content and size on bulk density of Fandoghi variety of sunflower seed and kernel (◇, big;□, average; Δ, small; -, seed; - - -, kernel.)

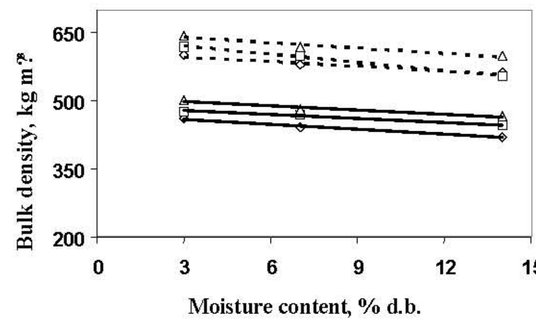

Fig. 13: Effect of moisture content and size on bulk density of Azar gol variety of sunflower seed and kernel (◇, big;□, average; Δ, small; -, seed; - - -, kernel.)

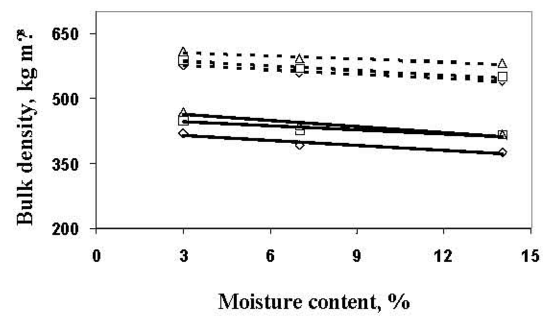

Fig. 14: Effect of moisture content and size on bulk density of Shahroodi variety of sunflower seed and kernel (◇, big;□, average; Δ, small; -, seed; - - -, kernel.)

The correlations of sunflower bulk density (seeds and kernels) with moisture content are shown in Table 3. As the coefficients of determination (R^2) for all varieties were adequately high, it seems that the moisture content had a remarkable influence on the bulk density of sunflower seeds and kernels.

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

Variety	Size	Seed	R^2	Kernel	R^2
Fandoghi	Big	$?_b = -3.6425Mc+470.25$	0.99	$\rho_b = -3.3903Mc+607.66$	0.96
	Average	$\rho_b = -2.8093Mc+485.67$	0.98	$\rho_b = -5.9871Mc+638.33$	0.99
	Small	$\rho_b = -3.1255Mc+507.06$	0.95	$\rho_b = -4.0861Mc+653.51$	0.96
Azar gol	Big	$\rho_b = -3.4729Mc+438.22$	0.98	$\rho_b = -3.5758Mc+600.14$	0.99
	Average	$\rho_b = -2.2958Mc+476.74$	0.99	$\rho_b = -2.6606Mc+621.31$	0.98
	Small	$\rho_b = -3.2484Mc+510.58$	0.99	$\rho_b = -2.8226Mc+636.41$	0.98
Shahroodi	Big	$\rho_b = -3.8832Mc+426.68$	0.91	$\rho_b = -3.4065Mc+586.53$	0.98
	Average	$\rho_b = -2.9987Mc+454.49$	0.91	$\rho_b = -3.5597Mc+598.11$	0.98
	Small	$\rho_b = -4.6729Mc+477.60$	0.91	$\rho_b = -2.5387Mc+614.49$	0.92

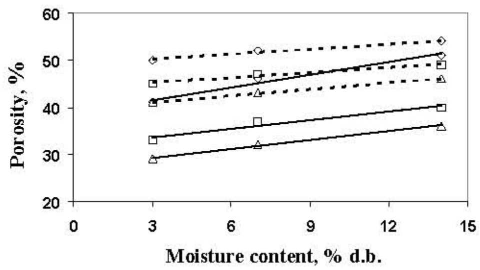

Fig. 15: Effect of moisture content and size on porosity of Fandoghi variety of sunflower seed and kernel (◊, big;□, average; Δ, small; -, seed; - - -, kernel.)

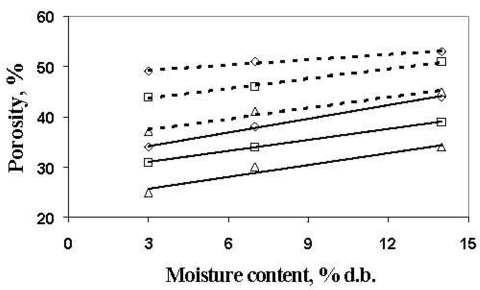

Fig. 16: Effect of moisture content and size on porosity of Azar gol variety of sunflower seed and kernel (◊, big;□, average; Δ, small; -, seed; - - -, kernel.)

A similar decreasing trend of bulk density with moisture content has been reported by Deshpande *et al.* [6], Carman [7], Visvanathan *et al.* [27], Ogut [11] and Garnayak *et al.* [23] for soybean, lentil seeds, neem, white lupin and jatropha seed, respectively. It can be implied that such materials become more turgid in the presence of moisture, consequently occurring the dilation phenomenon of bed structure which is very important for silo structural analysis. However, a direct correlation between bulk density and moisture content was found for some other agricultural particulate materials by Hsu *et al.* [4], Suther and Das [8] and Chandrasekar and Viswanathan [27] for pistachios, karingda seeds and coffee, respectively.

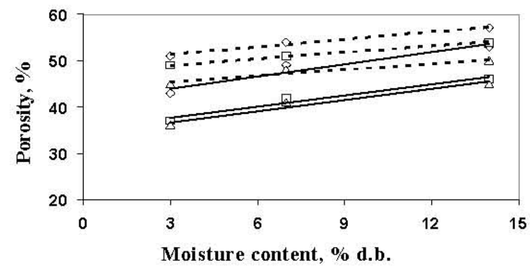

Fig. 17: Effect of moisture content and size on porosity of Shahroodi variety of sunflower seed and kernel (◊, big;□, average; Δ, small; -, seed; - - -, kernel.)

Porosity: As it can be found from Eq. (1), the porosity of particulate materials depends on their both bulk and true densities; therefore the variation of porosity is directly affected by these factors. Figures 15 - 17 show these variations with moisture content for all varieties and size categories of seed and kernel. As it can be seen, the porosity linearly increased with increasing moisture content. Also, the porosity of kernels was higher than that of seed in all size categories and moisture levels. The porosity of seeds for Fandoghi, Azargol and Shahroodi ranged from 29 - 51, 25 -44 and 36 - 53 %, respectively. These values for kernels were 41 - 54, 37 - 53 and 45 - 57 %, respectively. Among all studied varieties, the least porosity for both seeds and kernels belonged to Azargol, with 25 and 37 %, respectively. On the other hand, Shahroodi had the highest porosity for both seeds and kernels, with 53 and 57 %, respectively. In agreement with these results Gupta and Das [10] reported that the porosity of sunflower seeds and kernels increased from 34.3 to 43.3 % and 45.5 to 50.2 %, respectively when the moisture content changed from 4 to 20% d.b. Furthermore, Isik and Izil [15] also reported that the porosity of sunflower seed varied from 53.06 to 54.93 % by. The linearly increasing trend of porosity with increasing moisture content was also observed for some other seeds, such as Carman [7], Singh and Goswami [9], Ogut [11],

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

Variety	Size	Seed	R^2	Kernel	R^2
Fandoghi	Big	ε = 0.98Mc+38.9	0.98	ε = 0.35Mc+49.16	0.98
	Average	ε = 0.61Mc+31.76	0.94	ε = 0.35Mc+44.16	0.98
	Small	ε = 0.63Mc+27.3	0.99	ε = 0.45Mc+39.72	0.99
Azar gol	Big	ε = 0.9Mc+31.44	0.99	ε = 0.35Mc+48.16	0.98
	Average	ε = 0.73Mc+28.86	0.99	ε = 0.65Mc+41.84	0.99
	Small	ε = 0.79Mc+23.34	0.95	ε = 0.65Mc+41.84	0.99
Shahroodi	Big	ε = 0.87Mc+41.37	0.93	ε = 0.53Mc+49.74	0.98
	Average	ε = 0.79Mc+35.34	0.95	ε = 0.45Mc+47.72	0.99
	Small	ε = 0. 79Mc+34.34	0.95	ε = 0.44Mc+44.18	0.93

Baryeh and Mangope [28] for lentil seeds, cumin seed, white lupin and pigeon pea, respectively. However, Baryeh, [28] reported a nonlinearly increasing trend of porosity with increase of moisture content for millet. In contrast, Deshpande *et al.* [6], Joshi *et al.* [5], Suther and Das [8], Chandrasekar and Visvanathan [29] reported a linearly decreasing trend of porosity with increasing moisture content for soybean, pumpkin seed, karingda seed and coffee, respectively. Kashaninejad *et al.* [30] reported a nonlinearly decreasing trend of porosity with moisture content for pistachio. These discrepancies can be related to the cell structure and the variation of densities in different seeds and grains when moisture content is altered.

Regression equations and their coefficients of determination (R^2) obtained for porosity of sunflower seeds and their kernels as a function of variety, size category and moisture content are presented in Table 4. As it can be seen, for all varieties and size categories, a linear relationship with a very high correlation is observed between porosity and moisture content.

CONCLUSION

The moisture dependant gravimetrical properties of sunflower seeds and their kernel as a function of variety and size category were studied with the following results:

- The unit mass of all varieties and size categories of seeds and their kernel linearly increased with increasing moisture content. Among the studied varieties, Shahroodi had the highest unit mass of both seed and kernel. While the least unit mass of seed and the least unit mass of kernel observed for Fandoghi and Azargol, respectively.
- The "thousand grain mass" of all varieties and size categories of both seeds and kernels linearly were increased with increasing moisture content. The highest and lowest "thousand grain mass" of seeds were 70.998 g and 181.16 g, respectively. These values for kernels were 18.4 g and 128.8 g, respectively.
- For all varieties the true volume linearly was increased with increasing moisture content from 3 to 14% d.b. Among the studied varieties, the true volume of Shahroodi was higher than the other varieties for both seed and kernel.
- For all varieties and size categories a linearly increasing trend between the true density and moisture content was observed for both seeds and kernels. Among the studied varieties, Shahroodi and Azargol had the highest and the lowest true density for both seeds and kernels, respectively.
- Azargol and Shahroodi varieties had the highest and the lowest bulk density for both seeds and kernels, respectively. Also, the bulk density of seeds was lower than the corresponding kernels for all varieties, size categories and moisture levels. Totally, the bulk density for both seeds and kernels were linearly decreased with increasing moisture content from 3 to 14% d.b. Moreover, the bulk density of small seeds was higher than big seeds in all samples.
- The porosity of both seeds and kernels linearly were increased with increasing moisture content. Furthermore, the porosity of kernels was higher than the corresponding seeds for all size categories and moisture levels. The lowest porosity of both seeds and kernels was observed for Azargol, with 25 and 0.37% and the highest for Shahroodi with 53 and 57 %, respectively.

Application of Investigated Properties: The obtained results of gravimetrical properties in this study could be applied to help predict the behavior of material during handling, processing and storage. Values of studied parameters in each size category and moisture content are useful for determining the possibility of developing a similar or alternative mechanical dehuller that may reduce the risk of kernel breakage. On the other hand, Bulk density and true density values are practical in sizing grain hoppers and storage facilities as they can affect the rate of heat and mass transfer during aeration and drying operations. Moreover, Seed densities are of interest in breakage susceptibility and hardness studies. This application is realistic for designing a dryer that minimize energy and equipment costs while maintaining high product quality. Also, Values of volume and densities are valuable during separating particles by segregating on gravity Tables. The results of porosity could be used in packaging process of sunflower seed or kernel.

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