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Moisture-dependent engineering properties of sunflower (var. Armaviriski)

Javad Tarighi*, Asghar Mahmoudi, Meysam Karami Rad

Department of Agricultural Machinery Engineering, Faculty of Agricultural Engineering and Technology, University of Tehran, Karaj, Iran

***Corresponding author: javad_tarighi63@yahoo.com**

Abstract

In this research some physical properties of sunflower seeds (Armaviriski variety) were investigated over moisture content range from 4.3-22 % dry basis (d.b.) using standard techniques. The average length, width, thickness, effective mean diameter, arithmetic diameter, sphericity, surface area and angle of repose ranged from 12.38 to 12.51 mm, 5.71 to 6 mm, 3.82 to 4.15 mm, 6.43 to 6.76, 7.21 to 7.55, 51.79% to 54.08%, 111.70 to 122.42 mm^2 and 46° to 60° as the moisture content increased from 4.3% to 22% d.b., respectively. The thousand grain weight (TGW) increased from 65.5 to 79 g whereas the bulk density decreased from 402 to 380 kgm^{-3} and the true density increased from 840 to 910 kg m^{-3} with an increase in the moisture content range of 4.3–22 % d.b.The data of sunflower seeds showed that the porosity ranged from 52.14% to 58.24%. The static coefficient of friction of sunflower seeds increased linearly against different surfaces of structural materials, namely, plastic (0.42–0.67), plywood (0.36–0.62), and galvanized iron (0.42–0.67) and the static angle of repose increased from 46º to 60º, respectively when the moisture content increased from 4.3 % to 22% d.b. Generally all physical properties of sunflower in this study were increased with increasing of moisture content.

Keywords: Sunflower, Physical properties, Moisture content, Armaviriski, angle of repose

Abbreviations:

L length, mm	μ coefficient of friction
W width, mm	θ_s static angle of repose, deg
T thickness, mm	ε porosity, %
S surface area, mm^2	D_g geometric mean diameter, mm
R^2 correlation determination	D_p equivalent diameter, mm
Q weight of required water, g	D_a arithmetic diameter, mm
M moisture content, %	V volume, mm^3
M_i initial moisture content, %	Φ sphericity, %
M_f final moisture content, %	ρ_b bulk density, kgm-3
W_t total weight of sample, g	ρ_t true density, kgm-3

Introduction

Among the most important crops which considered by Iran Agricultural Division are oilseeds, For instance sunflower oil seeds with cultivated area of about 10 thousands hectares in Golestan province, Iran as well as average yield of 1000 kgh^{-1} (Ghodsevali and Vafaei, 2008). In order to design equipment for handling, conveying, separation, drying, aeration, storing and processing of sunflower seeds, it is essential to determine their physical properties as a function of moisture content. The properties of different types of grains and seeds have been determined by other researchers such as Dutta et al. (1988) for gram seed; Amin et al. (2004) and carman (1996) for lentil seed; Ougt (1998) for white Lupin; Baryeh (2002) for millet; Cetin (2007) for barbunia bean; Ogunjimi et al. (2002) for locust bean seed and Coskun et al. (2006) for sweet corn seed. Bulk density, true density and porosity can be useful in sizing grain hoppers and storage facilities. They can affect the rate of heat and mass transfer of moisture during aeration and drying processes. Grain bed with low porosity will have greater resistance to water vapor escape during the drying process, which may lead to higher power to drive the aeration fans. The static coefficient of friction is used to determine the angle at which chutes must be positioned in order to achieve consistent flow of materials through the chute. Such information is useful in sizing motor requirements for grain transportation and handling (Ghasemi Varnamkhasti et al., 2007). In this study, some physical properties of sunflower seed were determined, namely, size and shape, bulk and true densities, porosity, static coefficient of friction against the different material surfaces and angle of repose at various moisture contents in the range of 4.3-22% d.b.

Materials and methods

The sunflower seeds, used in this research, are one of the prevalent varieties in Iran that were obtained from the Seed

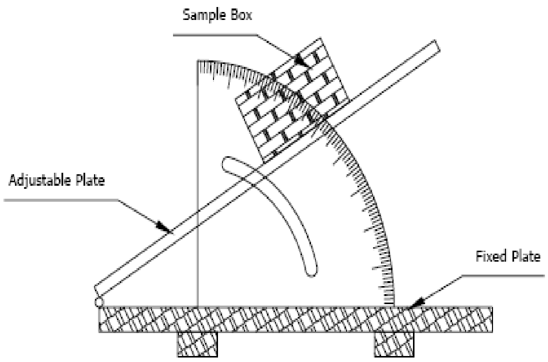

Fig 1. Schematic of apparatus for determining angle of repose

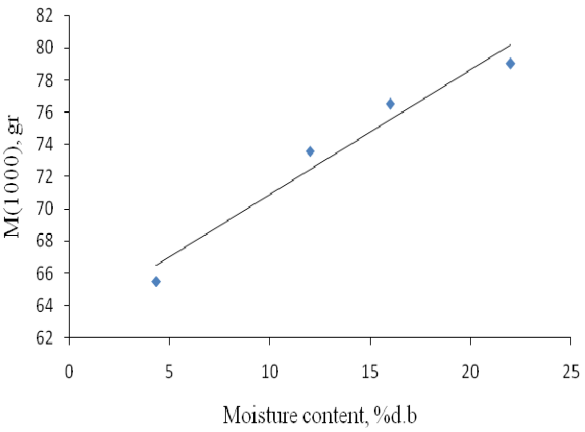

Fig 2. Variation of mass of 1000 seeds in 4 moisture contents (20 repeat for each moisture content)

and Seedling research institute, Karaj, Iran At first the seeds were cleaned manually to remove all foreign matters such as dust, dirt, stones and chaff as well as immature and broken seeds. Then the initial moisture contents of the seeds were determined by oven drying at 105±1 ^oC for 24 h (Ozarslan, 2002). The initial moisture content of the seeds was 4.3% d.b. The samples of the desired moisture contents were prepared by adding required the amount of distilled water as calculated from the following relation (Sacilik et al., 2003):

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

Where W_i, is the initial mass of the sample in kg; M_i, is the initial moisture content of the sample in % d.b.; and M_f, is the final moisture content of sample in % d.b.The samples were then poured into separate polyethylene bags and the bags sealed tightly. The samples were kept at 5 ^oC in a refrigerator for a week to enable the moisture to be distributed uniformly throughout the samples. Before starting a test, the required quantity of the seeds were taken out of the refrigerator and allowed to equilibrate to the room temperature for about 2 h (Singh and Goswami, 1996; Coskun et al., 2006). All the physical properties of the seeds were determined at four moisture contents in the range of 4.3 to 22% d.b. with four replications at each moisture contents. The following methods were used to determine some physical properties of Sunflower seeds.

Size and shape

Fifty seeds were randomly selected, in each moisture content according to the procedure described by Dutta et al. (1988). For each seed, three principal dimensions; length, width, and thickness were measured using a digital vernier caliper to an accuracy of 0.1 mm, Arithmetic diameters (Da), sphericity (ø), seed volume (V), and surface area (S) were calculated from the three principal dimensions according to the following relations (Jain & Bal, 1997):

$$D_e = (LWT)^{\frac{1}{3}} \quad (2)$$

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

$$Ø = \frac{(LWT)^{\frac{1}{3}}}{L} \quad (4)$$

$$V = \left(\frac{\pi B^2 L^2}{6(2L - B)}\right) \quad (5)$$

$$S = \frac{\pi B L^2}{2L - B} \quad (6)$$

$$B = (WL)^{1/2} \quad (7)$$

Thousand seed weight

Thousand seed weight was measured by counting 100 seeds and weighing them using an electronic balance having an accuracy of 0.001 g and then multiplied by 10 to give mass of 1000 seeds.

Bulk and true densities

The bulk density was determined by filling an empty 250 ml graduated cylinder with the seed and then it was weighed (Mohsenin, 1970). The weight of the seeds was obtained by subtracting the weight of the cylinder from the weight of both the cylinder and seed. The volume occupied was saved. The process was replicated four times and the bulk density for each replication was calculated from the following relation:

$$\rho_b = \frac{W_s}{V_s} \quad (8)$$

Where: the ρ_b is the bulk density in kg/m^3; Ws is the weight of the sample in kg; and V_s is the volume occupied by the sample in m^3. The true density was defined as the ratio between the mass of Sunflower seeds and the true volume of the seeds, and was determined using the toluene (C7H8) displacement method. Toluene was used instead of water because it is absorbed by seeds to a lesser extent. The volume of toluene displaced was found by immersing a weighted quantity of fennel seeds in the measured toluene (Tavakkoli et al., 2009).

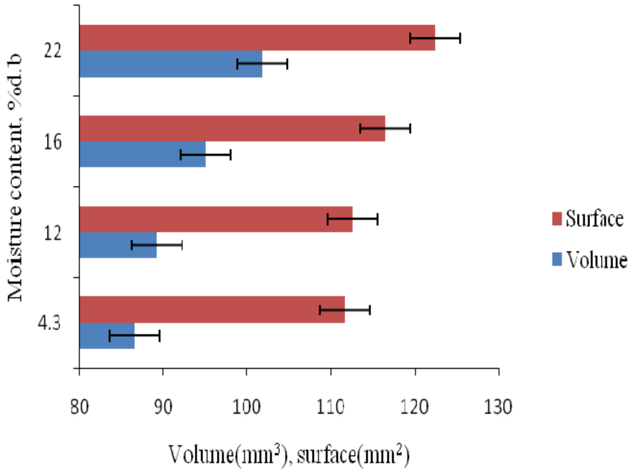

Fig 3. Effect of moisture content on volume and surface of sunflower seed

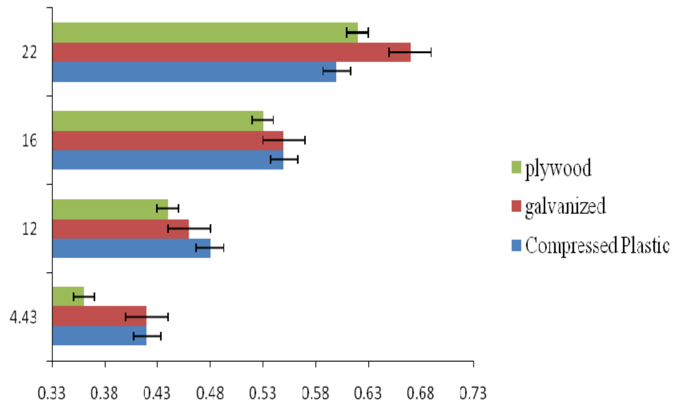

Fig 4. Effect of moisture content on the static coefficient of friction of sunflower against various surfaces

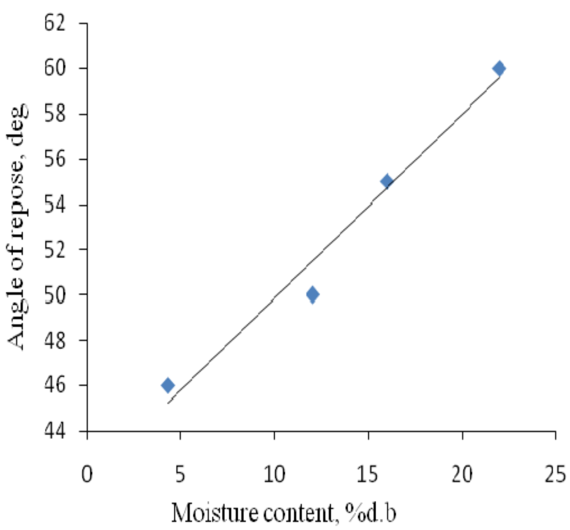

Fig 5. Effect of moisture content on angle of repose of sunflower seed (20 repeat for each moisture content)

Porosity

The porosity was calculated from the values of bulk and true densities using the following relationship (Mohsenin, 1970):

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

Where ρ_t is true density and ε is the porosity.

Angle of repose

The static angle of repose (θ_s) was determined using the apparatus shown in Figure 1 consisting of a plywood box of 140*160*35 cm^3 and two plates: fixed and adjustable. The box was filled with the sample and then the adjustable plate was inclined gradually allowing the seeds to follow, assuming a natural slope (Tabatabaeefar, 2003).

Coefficient of friction

The Coefficients of static friction of seeds on the three different surfaces including wood, galvanized iron sheet, and compressed plastic were determined. The seeds were put on the surface with adjustable slips. Then, the surface was raised gradually until the seeds just start to slide down. Finally, the coefficient of friction was calculated from the following equation:

$$\mu = \tan \alpha \qquad (10)$$

Where μ is the coefficient of friction and α is the angle of tilt in degree.

Results and discussion

Mass of 1000 kernels was found to be increased from 62.5 to 79 gr as moisture content increased (Fig. 2) relationship between mass of 1000 seeds (M1000) and moisture content (Mc) can be represented by the following equation:

$$M_{1000} = 0.771\,(Mc) + 63.17 \qquad (R^2 = 0.955)$$

The results showed that the mass of 1000 seeds was close to Turkey okra (C¸alısır et al., 2005), lentils (Makanjuola, 1972), but larger than millet (Baryeh, 2002), and karingda seeds (Suthar & Das, 1996).

Axial dimensions

A summary of the dimensions of Sunflower seed is shown in Table 1. The mean dimensions of 50 samples at a moisture content of 4.3% d.b. were: length 7.6 mm, width 3.95 mm, and thickness 3.37 mm. All dimensions were increased with an increase in moisture content from 4.3% to 22% d.b. A nonlinear and four linear relationships were observed between moisture content and axial dimensions as follows:

$$L = 0.004\,(Mc)^2 - 0.101\,(Mc) + 12.73 \qquad (R^2 = 0.998)$$
$$W = 0.013\,(Mc) + 5.662 \qquad (R^2 = 0.544)$$
$$T = 0.003\,(Mc)^2 - 0.043(MC) + 3.977 \qquad (R^2 = 0.956)$$
$$D_a = 0.002\,(Mc)^2 - 0.049(MC) + 7.453 \qquad (R^2 = 0.821)$$
$$D_e = 0.001\,(Mc)^2 - 0.008(MC) + 6.452 \qquad (R^2 = 0.964)$$

As moisture content increased from 4.3% to 22% (d.b.); the seed length increased from 12.38 to 12.51 mm, seed width increased from 5.71 to 6 mm, seed thickness increased from 3.82 to 4.15 mm, effective mean diameter increased from

Table1. Means and standard deviations of the seed dimensions at different moisture content

Characteristics	Moisture content		(%d.b.)	
Property (mm)	4.3%	12%	16%	22%
Length	12.38±0.70[a]	12.11±0.58	12.18±0.47	12.51±0.63
With	5.71±0.54	5.19±0.44	5.75±0.44	6±0.67
Thickness	3.82±0.13	3.82±0.10	3.83±0.26	4.15±0.58
Arithmetic diameters	6.43±0.11	6.48±2.15	6.60±0.24	6.76±0.49
Effective diameters	7.27±0.59	7.28±0.50	7.19±0.77	7.55±1.93

6.43 to 6.76 mm and arithmetic diameters from 7.27 to 7.55 mm. The increase in width and thickness was about twice as much as increase in length. Axial dimensions are important in determining aperture size of grain handling machines.

Seed volume and surface area

The moisture dependence of seed volume and surface area for the moisture content ranging from 4.3% to 22% d.b. are shown in Fig. 3. These relationships were best fitted using nonlinear equation as follows:

$S = 0.042\,(Mc)^2 - 0.494(Mc) + 112.9 \qquad (R^2 = 0.989)$

$V = 0.040(Mc)^2 - 0.170(Mc) + 86.43 \qquad (R^2 = 0.984)$

Seed volume and surface area increased by 17.57% and 9.59% respectively as moisture content increased from 4.3% to 22%. The nonlinear relationships might be due to the wide range of moisture content used (4.3–22%) which was selected to simulate the moisture content range for the sunflower seed from harvest to storage stages. Similar studies, however, with smaller moisture content ranges showed that such nonlinear relationships may be needed to adequately predict the relation of volume and surface area and moisture content. Some of those studies were reported for millet (Baryeh, 2002), gram (Dutta et al., 1988), soybean (Deshpande et al., 1993), and popcorn (Karababa, 2006), Soybean (Tavakkoli et al., 2009).

The ratio between volume and surface area is usually called the characteristic length. Characteristic length has important role in irregularly shaped objects. Some of its applications include determination of projected area of particles moving in turbulent air streams, which can be useful in designing of grain cleaners, separators, and pneumatic conveyors. As the ratio between surface area and volume increases, the rate of heat and mass transfer from seed increases, which affects several operations such as drying, cooling, and heating.

Sphericity

The sphericity of sunflower seed increased from 51.79% to 54.08 % as the moisture content increased. The relationship between sphericity and moisture content can be represented by the following equation:

$\Phi = 0.001(Mc) + 0.515 \qquad (R^2 = 0.860)$

However, Gupta and Prakash (1992) did not find any specific trend between the sphericity and seed moisture content.

True density (ρ_t) and bulk density (ρ_b) were found to decrease with the increase in moisture content, as follows:

$\rho_t = 0.116(Mc) + 0.942(Mc) + 833.5 \qquad (R^2 = 0.997)$

$\rho_b = -1.293(Mc) + 400.8 \qquad (R^2 = 0.568)$

Bulk density was found to decrease from 402 to 380 kg/m^3 and true density was found to increase from 840 to 910 kg/m^3, as moisture content increased from 4.3% to 22%. The decrease in bulk density with respect to the moisture content increase was greater than the increase in true density.

Porosity

The porosity decreases with increasing seed moisture content. The relationship existed between porosity and seed moisture content was found to be linear and can be expressed using the following equation with a coefficient of determination R^2=0.985:

$\varepsilon = 0.351(Mc) + 51.24 \qquad (R^2 = 0.918)$

Higher porosity provides better aeration and water vapor diffusion during deep bed drying. Similar trend was reported for hazel nuts (Aydin, 2002), gram (Dutta et al., 1988), sunflower (Gupta & Das, 1997).

Static coefficient of friction

The static coefficients of friction for sunflower seeds were determined on three different surfaces, compressed plastic, galvanized iron sheet and ply wood. It was observed that the static coefficient of friction of seed increased with the increase in the moisture content on all surfaces. At all moisture contents, the static coefficient of friction was greatest against galvanized iron (0.42–0.67) followed by compressed plastic (0.42–0.60), and plywood (0.36–0.62). (Fig .4). It was observed that moisture content had more effect than the surface material on the static coefficient of friction due to the increase of adhesion at higher moisture values. The linear relationship existing between the coefficient of friction and moisture content can be expressed for different surfaces using the following equations:

$f_{pl} = 0.010Mc + 0.368 \qquad (R^2 = 0.978)$

$f_g = 0.014Mc + 0.329 \qquad (R^2 = 0.914)$

$f_w = 0.015Mc + 0.282 \qquad (R^2 = 0.980)$

Similar findings were reported for millet (Baryeh, 2002), pumpkin seeds (Joshi et al., 1993), and karingda seeds (Suthar and Das, 1996), corn seed (Seifi and Alimardani, 2010)

Angle of repose

The variation of the angle of repose, with seed moisture content is plotted in Figure 5. The angle of repose increases linearly with seed moisture content from 46 degree at 4.3 % seed moisture content to 60 degree at 22 %d.b. The relationship can be expressed in equation form as follows:

$\theta = 0.807(Mc) + 41.79 \qquad (R^2 = 0.972)$

A linear increasing angle of repose as the seed moisture content increases has also been noted by Chandrasekar and Viswanathan (1999), Oje and Ugbor (1991) for oilbean seeds, Joshi et al. (1993) for pumpkin seeds.

Conclusions

1. Due to change in moisture content from 4.3% to 22% d.b. the average length, width , thickness , effective mean diameter and arithmetic diameters of sunflower seed increased from , 12.36 to 12.51 mm, 5.71 to 6.00 mm, 3.82 to 4.15 mm, and 6.43 to 6.76 mm,7.27 to 7.55 mm, respectively.
2. The values of thousand seed mass, surface area and volume increased from 65.5 to 79 gr, 111.70 to 122.43 mm^2, 86.62 to 101.81 mm^3, respectively, as the moisture content increased from 4.3 to 22% d.b.
3. The bulk density, decreased from 402 to 380 kg/m^3 in the specified moisture content.
4. The true density and porosity increased from 840 to 910 kg/m^3 and 52.14% to 58.24% in the specified moisture content
5. The angle of repose increased from 46º to 60º whereas, the static coefficient of friction varied between 0.36 to 0.67 over different material surfaces in the specified moisture level.

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