

Engineering properties of sunflower seeds and materials other grain as moisture content for equipment of separator

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Abstract: This study was aimed to develop simple empirical equations to predict engineering properties of edible sunflower seed (cultivar of GALAMI) and material other grain (MOG) including of hollow seeds and chaff material for designing and setting equipment of cleaning and separation. The properties were evaluated at four levels of moisture content from 30% to 7% (w.b.) (moisture of harvesting to processing). The variation in moisture content showed a statistically significant effect on physical and aerodynamic properties. As the moisture content decreased from 30% to 7% (w.b), length, width, thickness, equivalent diameter, sphericity for seeds (GALAMI), and the projected area, coefficient of static friction, static angle of repose for all materials decreased, whereas the true density and porosity of Seeds (GALAMI) decreased from 561.02 to 457.29 kg/m³ and 63.35% to 52.41% respectively, however this value for Chaff materials increased from 822.57 to 897.56 kg/m³ and 89.19% to 90.64% respectively. The coefficient of static friction (μ) was determined for three different surfaces (plywood, rubber and mild steel). The highest difference of value between seeds (GALAMI) with Chaff material and Hollow seeds was in mild steel surface and moisture content of 30%. The value of terminal velocity of all material decreased with decreasing moisture content. The highest average terminal velocity was at moisture content of 30% that for Seeds (GALAMI), Hollow seeds and Chaff material obtained 7.08, 3.62 and 3.39 m/s respectively, and the lowest was at the moisture content of 7% for all material, and reported 5.46, 2.70 and 2.60 m/s respectively. With decrease in moisture content, drag coefficient tended to increase, so that its value for Seeds (GALAMI), Hollow seeds and chaff materials changed from 0.59 to 0.95, 0.80 to 1.42 and 0.98 to 1.53 respectively. According to this investigation complete theoretical separation of seeds from MOG using air and physical properties of product is possible at various moisture contents.

Keywords: Sunflower seed, material other grain, separation, aerodynamic and physical properties

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1 Introduction

Sunflower (*Helianthus annuus L.*) seed is one of the most important oilseed crops due to its highly nutritious oil, and large quantity in a unit volume. According to Iranian Bureau of Statistics, 2005, over 35 varieties of sunflower seeds are cultivated in Iran. The cultivation of sunflower seed in the country is aimed for oil production and fresh consumption with 90% and 10%, respectively. Undesirable materials such as light grains, weed seeds, chaff, plant leaves and stalks can be removed with air

flow and equipment of separation, when grains, fruits and vegetables are mechanically harvested (Khodabakhshian et al., 2009 and Kaleemullah et al., 2002). In order to harvest sunflower seeds with combine harvester, or perhaps a stationary thresher and cleaning unit, it is important to know the physical and aerodynamic properties (engineering properties) of grain and material other grain of sunflower. The aerodynamic properties such as terminal velocity, drag coefficient and Reynold's number are needed for determination of the proper air speed in air conveyor and pneumatic separator (Sahay and Singh, 1994). These parameters are affected by the density, shape, size and moisture content of samples (Kashaninejad et al., 2006). By defining the terminal velocity of different threshed materials, it is

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possible to determine and set the maximum possible air velocity in which material out of grain (MOG) can be removed without loss of grain (Zewdu, 2004; Freye, 1980) or the principle can be applied to classify grain into different size groups (Zewdu, 2007). The difference in terminal velocity between damaged and undamaged grains was utilized by Bueermann (1991) to separate them in a vertical wind tunnel. In addition, agricultural materials and food products are routinely conveyed using air. For such operations, the interaction between the solid particles and the moving fluids determine the forces applied to the particles (Zewdu, 2007). So, it is necessary to determine the aerodynamic properties as a function of numerous factors such as moisture content, size and variety. Moreover, dimensions are important to design the cleaning, sizing and grading machines. Bulk density, true density and porosity are major considerations in designing the drying, aeration and storage systems, as these

properties affect the resistance to air flow through the grain mass. Angle of repose and coefficient of friction are important in designing equipment for solid flow and storage structures. The coefficient of friction between seed and wall is an important parameter in the prediction of seed pressure on wall (Ayman, 2009; Gumble et al., 1990). There are various researches on the engineering properties of agricultural product and oil sunflower seeds, but there is lower information for about edible sunflower seeds and its material out of grain (MOG). In this study, aerodynamic and some physical properties of seed sunflower for Iranian cultivar of edible sunflower seeds (GALAMI) and its MOG (Chaff material and Hollow seeds) are measured with varying moisture content (% w.b.). With this information, these separation and cleaning of grains can be better understood for and the potential for developing separation machinery evaluated.

Notation

| | | | |
|---------|--|------------|------------------------------------|
| a, b, c | Length, width, thickness, mm | V_t | Terminal velocity, m/s |
| D, H | Diameter and height of the cone, mm | M | Moisture content, % w.b. |
| V_f | Velocity of fluid or gas, m/s | V_T | True volume of particle, m^3 |
| g | Gravitational acceleration, m/s^2 | ϕ | Sphericity, dimensionless |
| w | Weight of the particle, kg | μ | Absolute viscosity of fluid, kg/ms |
| A_p | Projected area, cm^2 | ρ_T | True density, kg/m^3 |
| C_d | Drag coefficient, dimensionless | ρ_B | Bulk density, kg/m^3 |
| d_p | Equivalent spherical diameter of particle, m | θ | Angle of friction, degree |
| F_d | Drag force, N | ρ_f | Density of fluid, kg/m^3 |
| m_p | Mass of the particle, kg | ρ_p | Density of particle, kg/m^3 |
| N_R | Reynolds number, dimensionless | ϵ | Porosity, % |

2 Theoretical considerations for aerodynamic properties

A particle having a projected area (A_p) and immersed in flowing fluid with velocity (V_f) and density ρ_f is subjected to a drag force F_d given as Equation 1 (Menzies and Bilanski, 1968):

$$F_d = C_d A_p \frac{\rho_f V_f^2}{2} (1)$$

When a particle falls freely through air or during the separation of foreign material from grain the fundamental forces involved are the weight of the particle and the aerodynamic drag (Henderson, 1976; Sümer et al., 2008). In free fall, stable velocity of particle depends on its physical properties and density of air. A particle of mass (m_p) in a free fall attains a constant terminal or suspension or critical velocity (V_t) at which the net

gravitational force (F_g) equals the resisting upward aerodynamic drag force (F_d). When terminal velocity is attained under steady-state conditions, the particle motion will be upward or downward, depending on whether the particle density (ρ_p) is smaller or greater than of the fluid, respectively. Therefore, knowledge of the terminal velocities of particles defines the range of fluid velocities affecting the effective separation of the particles in the fluid stream. Consequently, terminal velocity is an important aerodynamic characteristic in pneumatic separation of particles (Mohsenin, 1986; Edwin et al., 2003).

When the fluid velocity (V_f) is equal to terminal velocity of the particle (V_t), drag coefficient can be obtained in terms of the terminal velocity, as Equation 2, Equation 3, Equation 4 and Equation 5:

$$F_g = F_d \quad (2)$$

$$m_p g \left[\frac{\rho_p - \rho_f}{\rho_p} \right] = \frac{C_d A_p \rho_f V_t^2}{2} \quad (3)$$

$$V_t = \left[\frac{2W(\rho_p - \rho_f)}{\rho_p \rho_f C_d A_p} \right]^{1/2} \quad (4)$$

$$C_d = \frac{2W(\rho_p - \rho_f)}{A_p \rho_p \rho_f V_t^2} \quad (5)$$

For the spherical bodies with an effective dimension d_p , the product projected area and weight can be given by Equation 6 and Equation 7 (Mohsenin, 1986)

$$A_p = \frac{\pi d_p^2}{4} \quad (6)$$

$$W = \frac{\pi g \rho_f d_p^3}{6} \quad (7)$$

Mohsenin (1986) stated both drag coefficient and Reynolds number equation include a velocity term, calculation of terminal velocity from Reynolds number and drag coefficient relationship require a trial-and-error solution (Equation 8).

$$N_R = \frac{V_t d_p \rho_f}{\mu} \quad (8)$$

Combining equations (4) and (8), the drag coefficient can be given by Equation 9

$$C_d N_R^2 = \frac{4g \rho_f d_p^3 (\rho_p - \rho_f)}{3\mu^2} \quad (9)$$

To eliminate a trial-and-error solution, the terms $C_d N_R^2$ (Equation 9) are first calculated and plotted against

N_R and for the theoretical calculation of the terminal velocity starting from a rearrangement of equation 8, according to the methodology proposed by Schiller (1932), and quoted by Mohsenin (1986).

Mohsenin (1986) reported that drag coefficient for spherical particles in the air, when Reynolds number is variable from 1.0×10^3 to 2.5×10^5 , can be assumed constant and it is about 0.44 for the spherical particles that are immersed into fluid. Because most of agricultural products have irregular shapes, various definitions for consideration as spherical equivalent diameter are expressed. Mohsenin (1986) and Jain and Bal (1997) stated the following relations for equivalent diameter and spherical that are defined as Equation 10 and Equation 11

$$\varphi = \frac{(abc)^{1/3}}{a} \quad (10)$$

$$d_p = \left(a \frac{(b+c)^2}{4} \right)^{1/3} \quad (11)$$

3 Materials and methods

3.1 Sample preparation

Samples were procured from Experimental Orchard of university of Tabriz at season of harvesting and were obtained from thresher of sunflower at season of harvesting. Samples were separated and divided to the three portions of good seeds (GALAMI), Hollow seeds, Chaff material that shown in Figure 1. They were transported into polyethylene bags to the laboratory of agricultural products of university of Tabriz and were kept in a refrigerator at 5°C . The initial moisture content was determined by oven drying at $105 \pm 2^\circ\text{C}$ for 24 h (ASAE, 1998). To obtain the different moisture contents of the products used in this study, an air conditioning unit equipped with devices for controlling the temperature and relative humidity of the drying air were used to accomplish the drying process (Afonso Junior et al., 2007). In this research samples were prepared at four moisture levels of 30%, 20%, 15% and 7% (w.b.), that it is moisture content of harvesting to processing.

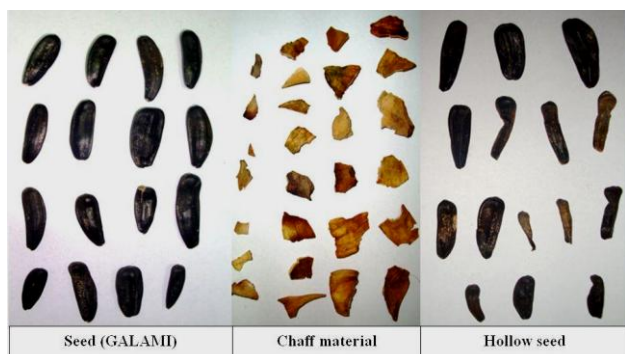


Figure 1 Materials for measuring physical and aerodynamic properties

3.2 Geometric characteristics

The average diameter of seeds was calculated by using the arithmetic mean and geometric mean of the three axial dimensions. The average diameter was also determined similarly to the one calculated by considering it as an equivalent diameter by Equations 11 (Mohsenin, 1986; Jain and Bal 1997). Degree of sphericity in decimal were determined using the Equation 10. The physical dimensions of seeds were determined by taking 400 seeds randomly and measuring the seed length, width and thickness at different moisture contents using a digital caliper to an accuracy of 0.01 mm.

3.3 Measuring projected area

For measuring the projected area of samples method of image processing and software of ImagePro was used. So that each sample image was prepared using a digital camera the image sensor 12 on the Samsung model. The pictures were provided with the background of a light on a particular container to reduce influences of the environmental and the shadowy images.

3.4 Gravimetric properties

The bulk density ρ_B was determined by filling a 500 mL beaker with seeds by dropping them from a height of 150 mm and weighing the seeds as performed by Mohsenin (1980) and calculated as the ratio of the mass of the sample to its container volume. The mass of single sample was determined by digital scale with accuracy of 0.01g. The solid density or true density, ρ_T is defined as the ratio of mass of the sample to its true volume (Mohsenin, 1986) as obtained by Equation 12:

$$\rho_T = \frac{m_P}{V_T} \quad (12)$$

Porosity, ε (%) indicates the amount of pores in the bulk material and was calculated as Equation 13 (Mohsenin, 1980):

$$\varepsilon = \left[1 - \frac{\rho_B}{\rho_T} \right] 100 \quad (13)$$

3.5 Solid flow properties

The filling angle of repose is the angle with the horizontal at which the material will stand when piled. This was determined by using a topless and bottomless hollow cylindrical mould of 15 cm diameter and 50 cm height. The cylinder was placed at the center of a raised circular plate having a diameter of 35 cm, filled with seeds and raised slowly until it formed a cone of seeds. The diameter (D) and height (H) of the cone were recorded. Average value of five replications for each variety was reported. The filling angle of repose (θ_f) was calculated by the Equation 14 as given by Zewdu et al. (2009) and Mohsenin (1986):

$$\theta_f = \text{Arc tan} \left(\frac{2H}{D} \right) \quad (14)$$

The coefficient of static friction (μ) was determined for three different surfaces (plywood, rubber, and mild steel). A plastic cylinder of 150mm diameter and 105mm height filled with seeds was placed on a tilting table covered with the different surfaces and having a scale to read the tilting angle directly. The seeds filled cylinder was raised slightly so that it will not have contact with the surface. The table was raised gradually using a screw device until the cylinder just starts to slide down and the corresponding tilting angle, \emptyset was recorded (Zewdu et al., 2009). The value of μ was calculated using the following Equation 15:

$$\mu = \text{tang} (\emptyset) \quad (15)$$

3.6 Aerodynamic properties

Along with most agriculture products, sunflower seeds are not spherical so it is better to measure terminal velocities experimentally rather than predicting them from mathematical relationships. For measuring the terminal velocity experimentally (V_t), vertical wind

tunnel according to recommendation of Mehta (1977) and Afonso Junior and et al. (2007) was built and evaluated. In this device the fan was powered by a three-phase 3 hp electrical motor and rate of air flow was controlled by diaphragm adapted to the entrance inlet of air or alteration of rotational speed of motor with inverter of TECO model as shown Figure 2. With changing the air flow inlet the velocity of air that kept the samples suspended in air as terminal velocity of samples was recorded. The air speed were calculated using a calibrated hot-wire anemometer with accuracy of 0.1 m/s. The value

of drag coefficient was calculated from Equation 5. The experiments with selection of 25 sample for any material (Seed (GALAMI), Hollow seed, Chaff material) from mass of samples and 4 replicates were performed, So that for each of sample 100 data were available for study. The data were subjected to regression analysis for fitting the experimental data to models that predict the terminal velocity or drag coefficient as a function of the moisture content. For adjusting the models to experimental data, the MICROSOFT OFFICE 2007 and SPSS version 17 computational program was used.



Figure 2 Vertical wind tunnel used to determine the terminal velocity of seeds

4 Result and discussions

4.1 Seed dimension

The frequency distribution curves (Figure 3) for the mean values of the dimensions show a trend towards a normal distribution. Information about the distribution of values of dimension and shape of the grains is very important for designing of equipment (sieve) for separations and cleaning. Mean values for seeds measured and calculated variables are presented in Table 1 at different levels of moisture content. Analysis of variance showed that moisture content had a significant effect on seed width and equivalent diameter at ($P \leq 0.05$), no significant effect was found for length and thickness seed. Very high

positive correlation was observed between these dimensions and the seed moisture content. This indicates that, on moisture absorption, the seeds constrict in length, width and thickness within the moisture range of 30% to 7% (w.b.). The mean value for length, width, thickness, equivalent diameter and percent sphericity was 25.84%, 9.30%, 4.99%, 10.93% and 41.20% respectively. Jafari (2007) reported average value of length, width, thickness and percent sphericity for sunflower seeds were 20.10, 7.51, 3.95 mm and 41.20 % respectively at moisture content 5.90 (%d.b.). Relationships between principal dimensions (L, W, T, ϕ, d_p) and seed moisture content represented as follows:

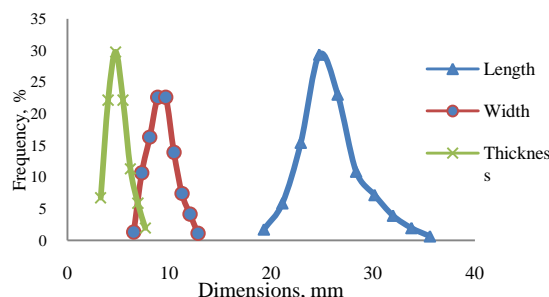


Figure 3 Frequency dimensions for sunflower seeds (GALAMI)

Table1 Means and standard errors of Length, Width, Thickness, Equivalent diameter and Sphericity of seed

| property | Mean moisture content. | | | |
|--------------------------------------|----------------------------|----------------------------|----------------------------|---------------------------|
| | 30% | 20% | 15% | 7% |
| Length(L) | 26.77 ± 0.014 ^A | 26.42± 0.014 ^A | 26.32± 0.014 ^A | 26.26± 0.014 ^A |
| Width(W) | 10.24± 0.06 ^A | 9.85± 0.06 ^{AB} | 9.73± 0.06 ^{AB} | 9.55± 0.06 ^B |
| Thickness(T) | 5.67± 0.047 ^A | 5.25± 0.047 ^A | 5.10± 0.047 ^A | 5.09± 0.047 ^A |
| Equivalent diameter(d _p) | 11.90± 0.055 ^A | 11.43± 0.055 ^{AB} | 11.29± 0.055 ^{AB} | 11.17± 0.055 ^B |
| Sphericity(φ) | 43.54± 0.23 ^A | 42.12± 0.23 ^B | 41.67± 0.23 ^B | 41.42± 0.23 ^B |

Note: means within the same row carry different small superscripts are significant at level P≤0.05

$$L=0.023Mc+26.036 \quad (R^2=0.91)$$

$$W=0.03Mc+9.304 \quad (R^2=0.98)$$

$$T=0.026Mc+4.82 \quad (R^2=0.86)$$

$$d_p=0.032Mc+10.86 \quad (R^2=0.93)$$

$$\phi=0.094Mc+40.49 \quad (R^2=0.90)$$

4.2 Projected area

Table 2 shows the results of statistical analysis carried out to examine the effect of moisture content and material (seeds (GALAMI), Hollow seeds, Chaff materials) on projected area. There was significant difference among

the material in terms of projected area 1% level of significance. The interaction of moisture content and material was found to have insignificant.

Variation of the material projected area with seed moisture content is shown in Table 3. The projected area decreased with decreasing of moisture content from 30% to 7% (w.b). Linear increase in surface area with increase in seed moisture content has been observed by Ayman and Amer (2009) for flaxseed and Sacilik K, et al. (2003) for hemp seed.

Table2 The analysis of variance test to examine the effect of moisture content of material and its variety on projected area

| Source | Degree of freedom | Mean square | F _{calculated} |
|---------------------|-------------------|-------------|-------------------------|
| material | 2 | 1.118 | 16.48** |
| moisture | 3 | 0.25 | 3.69* |
| Material × moisture | 6 | 0.014 | 0.2 ns |
| Error | 24 | 0.068 | |

Note:**, * significant at 1% and 5% level respectively

Table3 Means and standard errors at different moisture content

| Projected area of material (cm ²) | Mean moisture content ± S.E. | | | |
|---|------------------------------|-------------|-------------|-------------|
| | 30% | 20% | 15% | 7% |
| Seeds (GALAMI) | 2.05± 0.040 | 2.05± 1.79 | 2.05± 1.79 | 2.05± 1.69 |
| Hollow seeds | 1.70± 0.042 | 1.58± 0.042 | 1.51± 0.042 | 1.45± 0.042 |
| Chaff material | 2.50± 0.056 | 2.19± 0.056 | 2.03± 0.056 | 1.96± 0.056 |

The following equations represent the relationships between projected area of materials and its moisture content represented as follows:

Seeds (GALAMI), $A_p = 0.015M_c + 1.544$ ($R^2 = 0.96$)

Hollow seeds, $A_p = 0.011M_c + 1.385$ ($R^2 = 0.98$)

Chaff material, $A_p = 0.016M_c + 1.827$ ($R^2 = 0.98$)

4.3 Gravimetric properties

The results of statistical analysis carried out to examine the effect of moisture content and material (seeds (GALAMI), Hollow seeds, Chaff material) bulk density, true density and porosity shown in Table 4. It is indicated that there was significant difference among the material in terms of bulk density, true density and porosity 1% level of significance. Non-uniform size and mass variations with changing moisture is major cause of significant material differences in the properties of gravity. The experimental results of the true and bulk densities and porosity for materials at different moisture levels are presented in Figure 4, Figure 5 and Figure

6. With reducing moisture content from 30% to 7% (w.b.) the true density and porosity of Seeds (GALAMI) and Hollow seeds decreased from 561.02 to 457.29, 319.75 to 249.20 kg/m³ and 63.35% to 52.41%, 79.80% to 74.40% respectively. The bulk density had non-linear behavior approximately. These results are in accordance with results of Figueiredo et al. (2011) and Seifi (2010) for sunflower seeds. While, true density and porosity of Chaff material increased from 822.57 to 897.56 kg/m³ and 89.19 to 90.64 with decreasing moisture contents. The lowest value of bulk density was for Chaff material due to characteristics of shape of Chaff material and it is a reason that Chaff materials have highest value of porosity. Porosity is one of the major factors in the loss of air pressure in handling and cleaning with air flow. Materials with lower porosity have more resistance against air flow. These results are according to results of Koocheki et al. (2007) for watermelon seeds.

Table4 The analysis of variance test to examine the effect of moisture content of material and its variety on bulk density, true density and porosity.

| Source | Degrees of | Bulk density, (kg/m ³) | | True density, (kg/m ³) | | Porosity, % | |
|---------------------|------------|------------------------------------|-------------------------|------------------------------------|-------------------------|-------------|-------------------------|
| | | Mean | F _{calculated} | Mean square | F _{calculated} | Mean square | F _{calculated} |
| material | 2 | 123142.56 | 7514.62** | 4939307.19 | 9808.42** | 7221.77 | 7602.7** |
| Moisture | 3 | 409.189 | 24.97** | 4346.67 | 17.48** | 96.05 | 101.116** |
| Moisture × material | 6 | 183.139 | 11.176** | 11361.88 | 45.68** | 47.714 | 50.23** |
| Error | 72 | 54.5 | | 248.7 | | 0.95 | |

Note: **, * significant at 1% and 5% level respectively

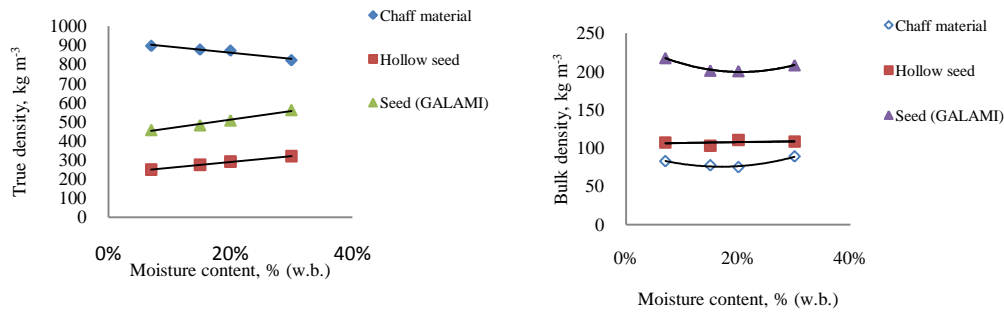


Figure 4 Effect moisture content on true density Figure 5 Effect moisture content on bulk density

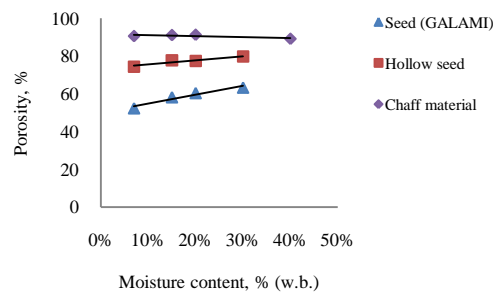


Figure6 Effect moisture content on porosity

5.4 Solid flow properties

The experimental results for the static angle of repose with respect to moisture content are shown in Figure 7. The values of the static angle of repose were found to decrease significantly at the 5% level of probability from 48.80 to 33.56 in the moisture range of 30% to 7% (w.b.). The static angle of repose for seeds has the following relationships with its moisture content:

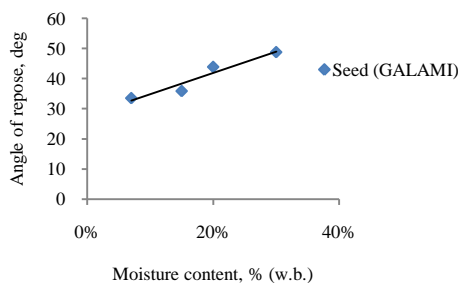


Figure 7 Effect moisture content on angle of repose

$$\theta_f = 70.96 Mc + 27.81$$

The variation coefficient of static friction for material with moisture content is shown in Table 5. Analysis of

variance showed that moisture content had a significant effect ($p \leq 0.05$) on coefficient of static friction. The coefficient of static friction on the three surfaces (mild steel, wooden and rubber) decreased significantly ($p \leq 0.05$) and progressively with decrease in moisture content from 30% to 7% (w.b.). Accordingly, the coefficient of static friction of seeds (GALAMI) decreased from 0.498 to 0.241, 0.503 to 0.248 and 0.668 to 0.516 for mild steel, wooden and rubber surfaces, respectively. The maximum value of seeds (GALAMI) was found to be 0.668 at 30% for rubber surface. The highest difference of value between seeds (GALAMI) with Chaff materials and Hollow seeds was in mild steel surface and moisture content of 30%. The design and the dimension of sieve surfaces, hoppers, bunker silos and other bulk solid storage and handling structures should ensure non-arching (avoid stoppage of flow of bulk solids) phenomena. The trend observed in this study was in agreement with the studies made for safflower seeds (Seifi et al. 2010).

Table 5 Standard errors of coefficient of static friction on various surfaces

| Type of surface | material | Mean moisture content \pm S.E. | | | |
|-----------------|----------------|----------------------------------|---------------------------------|---------------------------------|--------------------------------|
| | | 30% | 20% | 15% | 7% |
| Mild steel | Seed (GALAMI) | 0.498 \pm 0.027 ^c | 0.429 \pm 0.027 ^{bc} | 0.377 \pm 0.027 ^b | 0.241 \pm 0.027 ^a |
| | Hollow seed | 0.528 \pm 0.021 ^d | 0.426 \pm 0.021 ^c | 0.326 \pm 0.021 ^b | 0.269 \pm 0.021 ^a |
| | Chaff material | 0.603 \pm 0.037 ^d | 0.476 \pm 0.037 ^c | 0.356 \pm 0.037 ^{ab} | 0.293 \pm 0.037 ^a |
| wooden | Seed (GALAMI) | 0.503 \pm 0.017 ^d | 0.356 \pm 0.017 ^{cb} | 0.320 \pm 0.017 ^b | 0.248 \pm 0.017 ^a |
| | Hollow seed | 0.405 \pm 0.026 ^d | 0.372 \pm 0.026 ^c | 0.277 \pm 0.026 ^{ab} | 0.220 \pm 0.026 ^a |
| | Chaff material | 0.580 \pm 0.029 ^d | 0.408 \pm 0.029 ^c | 0.357 \pm 0.029 ^{ab} | 0.279 \pm 0.029 ^a |
| rubber | Seed (GALAMI) | 0.668 \pm 0.037 ^c | 0.670 \pm 0.037 ^c | 0.574 \pm 0.037 ^{ab} | 0.516 \pm 0.037 ^a |
| | Hollow seed | 0.680 \pm 0.045 ^c | 0.643 \pm 0.045 ^{bc} | 0.601 \pm 0.045 ^b | 0.493 \pm 0.045 ^a |
| | Chaff material | 0.820 \pm 0.046 ^d | 0.656 \pm 0.046 ^c | 0.531 \pm 0.046 ^{ab} | 0.522 \pm 0.046 ^a |

Note: Means within the same row carry different small superscripts are significant at level $P \leq 0.05$

5.5 Aerodynamic properties

Table 6 shows the results of statistical analysis of materials on terminal velocity and drag coefficient. There was significant difference among the material in term of terminal velocity at 1% level of significant. The

interaction of moisture content and material was also found to have significant effect on terminal velocity. Similarly, effect moisture content on drag coefficient was found significant at 1% level of significance. A similar result was found by Gupta, et al. (2007) and Khodabakhshian, et al. (2009) for sunflower seeds.

Table 6 The analysis of variance test to examine the effect of moisture content of material and its variety terminal velocity and drag coefficient

| Source | Degrees of freedom | Terminal velocity, ms^{-1} | | | Drag coefficient | |
|----------------------------|--------------------|-------------------------------------|-------------------------|------------|-------------------------|--|
| | | Meansquare | $F_{\text{calculated}}$ | Meansquare | $F_{\text{calculated}}$ | |
| material | 2 | 84.83 | 934.23** | 1.5 | 64.34** | |
| Moisture | 3 | 4.68 | 51.57** | 0.972 | 41.71** | |
| Moisture \times material | 6 | 0.55 | 6.08** | 0.041 | 1.74ns | |
| Error | 72 | 0.091 | | 0.023 | | |

Note: **, ns significant at 1% level and non-significant

The mean and standard error value of terminal velocity and drag coefficient of Seeds (GALAMI), Hollow seeds and Chaff materials for different moisture content are shown in Table 7. Analysis of variance showed that moisture content had a significant effect on aerodynamic properties of material at ($P \leq 0.05$). Results show that with a decrease in moisture content from 30% to 7%, there is a reduction and increasing in value of terminal velocity and

drag coefficient respectively for all materials. A similar behavior was observed in the results of Song and Litchfield (1991), who studied the aerodynamic properties of several types of agricultural products using the same methodology. It has been shown when the moisture content decreased, terminal velocity for Seeds (GALAMI), Hollow seeds and Chaff materials changed from 7.074 to 5.46, 3.62 to 2.70 and 3.39 to 2.60 m/s and

value of drag coefficient changed from 0.59 to 0.95, 0.80 to 1.42 and 0.98 to 1.98 respectively. Similar results were found by Gupta (2007), Khodabakhshian (2009) for sunflower seeds and Afonso Junior and et al (2007) for coffee cherry and beans, who used the same methodology. Their correlations are presented in Table 8 and their respective relationships are presented in Figure 8 and Figure 9. A decrease in terminal velocity value and increase in drag coefficient with decrease in moisture content was observed as shown in Figure 8 and Figure 9 respectively. Also, this relationship confirms the view

that with decrease in moisture content decreased terminal velocity and increased drag coefficient. Difference between the value of aerodynamic properties sunflower seeds (GALAMI) and other material grain, MOG (Hollow seeds, Chaff materials) is important in designing and setting of equipment in separation and cleaning. From the above discussion, it is possible to observe in terminal velocities between Seeds and MOG. As a result, complete pneumatic separation is possible at any moisture content.

Table 7 The mean and standard error value of terminal velocity and drag coefficient of material for different moisture content (% w.b.)

| property | material | Mean moisture content ± S.E. | | | |
|-------------------|----------------|------------------------------|-------------------------|-------------------------|------------------------|
| | | 30% | 20% | 15% | 7% |
| Terminal velocity | Seed (GALAMI) | 7.08±0.60 ^A | 6.62±0.60 ^B | 5.63±0.60 ^C | 5.46±0.60 ^C |
| | Hollow seed | 3.62±0.54 ^A | 3.49±0.54 ^{AB} | 3.40±0.54 ^B | 2.70±0.54 ^C |
| | Chaff material | 3.39±0.61 ^A | 3.00±0.61 ^B | 2.75±0.61 ^{BC} | 2.60±0.61 ^C |
| Drag coefficient | Seed (GALAMI) | 0.59±0.04 ^A | 0.74±0.04 ^B | 0.75±0.04 ^B | 0.95±0.04 ^C |
| | Hollow seed | 0.80±0.07 ^A | 0.95±0.07 ^B | 1.17±0.07 ^{BC} | 1.42±0.07 ^C |
| | Chaff material | 0.98±0.09 ^A | 1.13±0.09 ^B | 1.17±0.09 ^B | 1.53±0.09 ^C |

Note: Means within the same row for any surface carry different small superscripts are significant at level $P \leq 0.05$

Table 8 Adjusted regression equation for predicting terminal velocity, V_t and the drag coefficient C_d of material as a function of the moisture content (% w.b.), M_c with the respective determination coefficients R^2

| Material of sunflower | Regression equation |
|-----------------------|---|
| Seed (GALAMI) | $V_t = 18.14x^2 + 0.594x + 5.290 R^2 = 97\%$ |
| | $C_d = 2.918x^2 - 2.583x + 1.108 R^2 = 96\%$ |
| Chaff material | $V_t = 6.907x^2 + 0.923x + 2.492 R^2 = 99\%$ |
| | $C_d = 10.10x^2 - 6.089x + 1.90 R^2 = 97\%$ |
| Hollow seed | $V_t = -25.14x^2 + 13.22x + 1.896 R^2 = 99\%$ |
| | $C_d = 11.12x^2 - 6.746x + 1.831 R^2 = 99\%$ |

Note: x indicates the moisture content (w.b.)

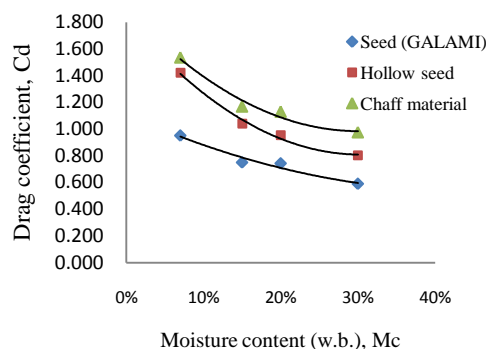
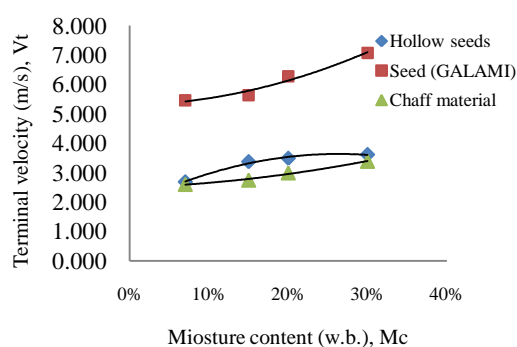


Figure 8 Effect moisture content on terminal velocity Figure 9 Effect moisture content on drag coefficient

6 Conclusion

1. Analysis of variance performed for all materials (Seeds (GALAMI), Hollow seeds and Chaff materials) that moisture content had a significant effect on all the engineering properties considered.
2. Generally, length, width, thickness, equivalent diameter, sphericity, projected area, true density, bulk density, porosity, angle of repose, coefficient of static decreased with the decrease of moisture content from 30% to 7% (w.b.) for all materials, except an inverse linear relationship of moisture content with true density and porosity of Chaff material was found.
3. The physical and aerodynamic properties of material were expressed by the linear and non-linear regression equations as a function of moisture content with the respective determination R square.
4. The highest value of true density was for Chaff material at moisture content 7% and in this moisture content, Chaff material had maximum difference value of true density with Seeds (GALAMI).
5. With decreasing in moisture content from 30% to 7%, terminal velocity for (GALAMI), Hollow seeds and Chaff material changed from 7.08 to 5.46, 3.62 to 2.70 m/s and 3.39 to 2.60 m/s respectively, and drag coefficient changed from 0.59 to 0.95, 0.80 to 1.42 and 0.98 to 1.53 respectively.
6. In conclusion, this report studied the moisture dependence of the engineering properties of sunflower

seeds and MOG (Hollow seeds and Chaff material) to improve the performance of equipment of harvesting, processing and conveyer or for designing new machinery. According to this investigation complete theoretical separation of seeds from MOG using air and physical properties of product is possible in moisture contents of various.

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