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Moisture-Depend Physical Properties of Safflower (*Goldasht*)

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Abstract: Physical properties of safflower grains (*Goldasht variety*) were determined as a function of moisture content in the range of 3.9-22% wet basis (w.b.) using standard techniques. The average length, width, thickness, geometric mean diameter, arithmetic diameter, sphericity, surface area and angle of repose ranged from 7.50 to 8.09 mm, 4.58 to 4.97 mm, 3.58 to 4.06 mm, 4.97 to 5.46 mm, 5.22 to 5.70 mm, 66.29 to 67.90%, 65.63 to 79.15 mm^2 and 47º to 56º as the moisture content increased from 3.9 to 22% d.b., respectively. The greatest and smallest value of average length, width, thickness, geometric mean diameter, arithmetic diameter, sphericity, surface area occurred in 12 and 3.9% w.b., respectively. studies on rewetted safflower grains showed that the Thousand Kernel Weight (TKW) increased from 50.50 to 59.20 g, the surface area from 65.64 to 71.84 mm^2 and the bulk density from 520 to 547 kg/m^3. Whereas the porosity decreased from 51.4 to 45.84% and the true density from 1070 to 1010 kg/m^3 with an increase in the moisture content range of 3.9-22 % w.b. The static coefficient of friction of safflower grains increased linearly against surfaces of three structural materials, namely, plastic (0.36-0.45), plywood (0.31-0.55), and galvanized iron (0.31-0.49) and the static angle of repose increased from 47º to 56º, respectively as the moisture content increased from 3.9 to 22% w.b.

Key words: Iran, moisture content, physical properties, safflower

INTRODUCTION

Safflower is an annual herb whose botanical name is *Carthamus tinctorius*. It is a member of the Asteraceae family. It has long, spiny leaves and yellow or reddish flowers on a stiff, upright stem. The seeds produce edible oil. Safflower oil is used as condiment oil, along with sesame, red pepper and perillar oils in Iran (Kim *et al.*, 1998). Traditionally, these condiment oils are prepared by extracting the roasted seed with a mechanical press or expeller after the seeds have been roasted at the appropriate temperatures. In order to design equipment for the handling, conveying, separation, drying, aeration, storing and processing of safflower grains, it is necessary to determine their physical properties as a function of moisture content. The knowledge of some important physical properties such as shape, size, volume, surface area, grain weights, density, porosity, angle of repose, of different grains is necessary for the design of various separating, handling, storing and drying systems (Sahay and Singh, 1994). The size and shape are, for instance, important in their electrostatic separation from undesirable materials and in the development of sizing and grading machinery (Mohsenin, 1986). The shape of the material is important for an analytical prediction of its drying behavior. Bulk density, true density, and porosity (the ratio of intergranular space to the total space occupied by the grain) 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. Cereal grain kernel densities have been of interest in breakage susceptibility and hardness studies. 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). The design of storage and handling systems for buckwheat requires data on bulk and handling properties, friction coefficients on commonly used bin wall materials (galvanized steel, plywood, and concrete), and emptying and filling angles of repose (Parde *et al.*, 2003). Theories used to predict the pressures and loads on storage structures (Janssen, 1895) require bulk density, angle of repose and friction coefficients against bin wall materials. Also, the design of grain hoppers for processing machinery requires data on bulk

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density and angle of repose. An example of the use of various bulk and handling properties of grains in the design of storage structures is given by Singh and Moysey (1985). The angle of repose determines the maximum angle of a pile of grain with the horizontal plane. It is important in the filling of a flat storage facility when grain is not piled at a uniform bed depth but rather is peaked (Mohsenin, 1986).

Current study was conducted on investigate some moisture dependent physical and mechanical properties of safflower grain namely, dimensions, geometric mean, equivalent and arithmetic diameter, sphericity, kernel weight, surface area, bulk density, true density, porosity, static angle of repose, static coefficient of friction against different materials, rupture force and rupture energy.

MATERIALS AND METHODS

The study was carried out in laboratory of department of Agricultural Machinery Engineering of university of Tehran, Iran in January-March 2010. One of popular varieties of cleaned safflower (*Goldasht*) was obtained from Plant and Seed Institute in Karaj. The initial moisture content of seeds was determined by oven method (Tabatabeefar, 2003) and in order to achieve the desired moisture level as 12, 16, and 22% w.b., the rewetting formula was used Eq. (1), and to allow the moisture be absorbed by samples were placed in refrigerator:

$$\Delta W_w = W_t \frac{(M_f - M_i)}{(100 - M_f)} \tag{1}$$

A digital caliper was used to determine length, width, and thickness of about 40 randomly selected grains of each sample. The geometric mean, D_g, equivalent, D_p and arithmetic diameter, D_a, in mm was calculated by considering prolate spheroid shape for a safflower grain and hence Eq. (2), (3) and (4), respectively (Mohsenin, 1986):

$$D_g = (LDT)^{\frac{1}{3}} \tag{2}$$

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

$$D_a = \frac{(L + W + T)}{3} \tag{4}$$

The sphericity (S_p) defined as the ratio of the surface area of the sphere having the same volume as that of grain to the surface area of grain, was determined using following formula (Mohsenin, 1986):

$$S_p = \frac{(LDT)^{\frac{1}{3}}}{L} \tag{5}$$

Kernel weight (g per 1000 kernels) was measured by counting 100 seeds and weighing them in an electronic balance to an accuracy of 0.001 g and then multiplied by 10 to give mass of 1000 kernels. Jain and Bal (1997) have considered grain volume, V and surface area, S may be given by:

$$V = 0.25\left[\left(\frac{\pi}{6}\right) L (W + T)^2\right] \tag{6}$$

$$S = \frac{\pi B L^2}{(2L - B)} \tag{7}$$

Where, B is:

$$B = \sqrt{WT} \tag{8}$$

The aspect ratio (R_a) was calculated by:

$$R_a = \frac{W}{L} \tag{9}$$

The true density is a ratio of mass sample of grains to its pure volume. It was determined by the toluene displacement method (Mohsenin, 1986). Bulk density is the ratio of the mass sample of grains to its total volume. It was determined by filling a predefined container with from a constant high, striking the top level and then weighing the constants. The porosity is the ratio of free space between grains to total of bulk grains. That was computed as:

$$\varepsilon = \frac{\rho\tau - \rho b}{\rho b} \times 100 \tag{10}$$

The coefficient of static friction was determined with respect to different surfaces: plywood, plastic and galvanized iron. A hollow metal cylinder (Fig. 1) with 75 mm diameter and 50 mm depth and open at the both ends, was filled with the seeds with desired moisture content and placed on adjustable titling surface. Then the surface was raised gradually until the filled cylinder just started to slide down (Razavi and Milani, 2006).

The static angle of repose is the angle with the horizontal at which the material will stand when piled.

Fig. 1: Apparatus to determine coefficient of static friction

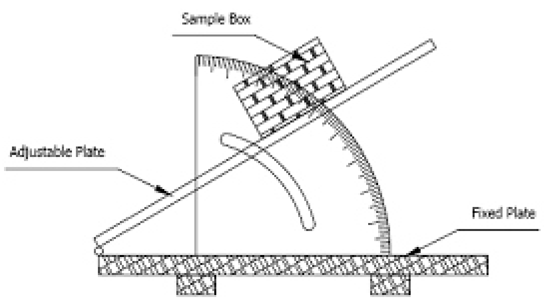

Fig. 2: Apparatus to determine empting angle of repose

This was determined by using the apparatus (Fig. 2) consisting of a plywood box of 140-160-35 mm 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 and assume a natural slope (Tabatabeefar, 2003). Finally, the data were analyzed statistically and figures were plotted using Excel software 2003.

RESULTS AND DISCUSSION

A summary of the dimensions of *Goldasht* safflower cultivar is shown in Table 1. The mean dimensions of about 10 samples at moisture content of 3.9% w.b. where: length 12.24 mm, width 6.05 mm, and thickness 4.04 mm. All dimensions have similar trend and first decreased with the increase in moisture content from 4 to 12% then L started to increase in the range of 12-22% but W and T didn't have this behavior and again decreased with an increase in moisture content from 16 to 22% w.b. The increasing trend in axial dimensions, with gain in moisture content, was due to filling of capillaries and voids upon absorption of moisture and subsequent swelling (Table 1).

kernel weight (g/1000 kernel) was increased significantly at 5% level of probability from 20.13 to 24

Table 1: Some physical properties of *Goldasht* variety considering moisture content

Item	MC (%)			
	3.9	12	16	22
L (mm)	7.50±0.74	8.09±0.76	7.71±1.02	7.67±0.50
W (mm)	4.58±0.71	4.97±0.68	4.73±0.82	4.79±0.61
T (mm)	3.58±0.59	4.06±0.52	3.75±0.65	3.85±0.43
D_g (mm)	4.97±0.38	5.46±0.66	5.14±0.66	5.21±0.49
D_p (mm)	5.00±0.54	5.48±0.66	5.17±0.66	5.23±0.62
D_a (mm)	5.22±0.72	5.70±0.66	5.70±0.66	5.44±0.36
S_p (%)	66.29±4.73	67.53±2.36	66.76±6.49	67.90±3.37
V (mm^3)	66.18±17.14	87.02±12.03	73.27±29.74	75.09±15.41
S (mm^2)	65.64±11.81	79.16±19.23	70.34±18.76	71.84±10.49
R_a (%)	0.611±0.062	0.614±0.069	0.614±0.107	0.625±0.082

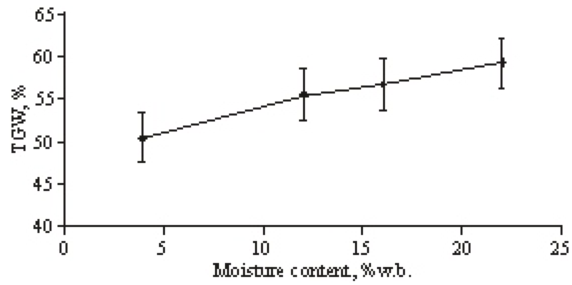

Fig. 3: Effect of moisture content on aspect ratio

g as the moisture content increased from 3.9-22% w.b. (Fig. 3). Linear Relationship for one Thousand Kernel Weight (TKW) based on moisture content, M, was determined as follows:

$$TKW = 0.39M + 16.90 \qquad R^2 = 0.99 \qquad (11)$$

A linear increase in the one thousand kernel weight as increased seed moisture content has been noted by Tabatabeefar (2003) for safflower represented that the TKW increased linearly from 23.2 to 39.7 g when the moisture content increased from 0 to 22 % d.b.

$$TGW = 0.4768M + 49.05 \qquad R^2 = 0.980 \qquad (12)$$

The surface area, sphericity and volume of safflower grains increased from 65.63 to 71.84 mm^2, 66.29 to 67.90% and 66.18 to 75.09 mm^3 when the moisture content of grains increased from 3.9 to 22% w.b. The aspect ratio generally increased with an increase in moisture content from 3.9 to 22% w.b.

$$R_a = 7E - 0.5M^2 + 0.614 \qquad R^2 = 0.93 \qquad (13)$$

The values of the bulk density for different moisture levels increased linearly from 520 to 547 kg/m^3 (Fig. 4a, b). The bulk density of seed was found to bear the following relationship with moisture content:

$$\rho b = 1.553M + 515.5 \qquad R^2 = 0.946 \qquad (14)$$

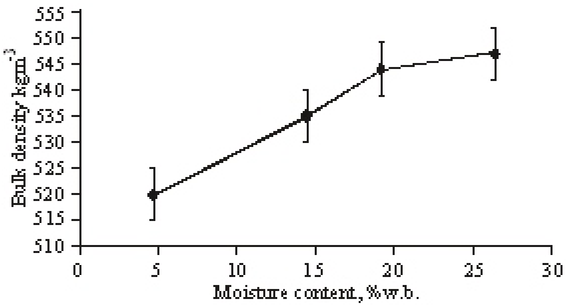

Fig. 4a: Effect of moisture content on bulk density

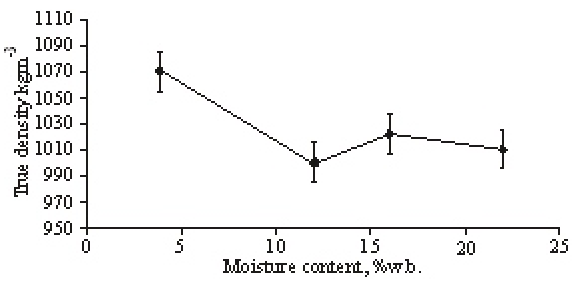

Fig. 4b: Effect of moisture content on true density

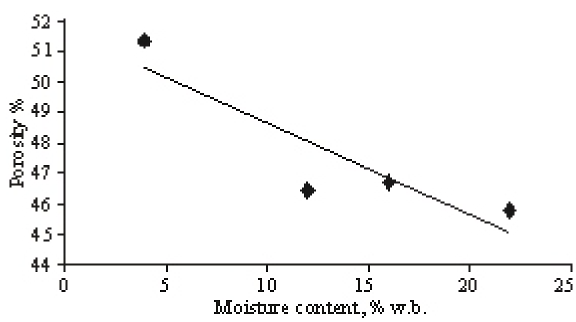

Fig. 5: Effect of moisture content on porosity

A similar increasing trend in bulk density has been reported by Parde *et al.* (2003) for Koto buckwheat from 603.90 to 612.90 kg/m^3 with an increase in moisture content from 14.8 to 15.8% Whereas Gupta and Das (1997) reported that the standard bulk density of safflower seed decreased significantly with an increase in moisture content.

The true density varied from 1070 to 1010 kg/m^3 when the moisture level increased from 3.9-22% w.b. (Fig. 4). The true density and the moisture content of grain can be correlated as follows:

$$\rho_t = 0.359M2 - 12.23M + 1109 \quad R^2 = 0.83 \qquad (15)$$

The porosity of safflower grains decreased linearly from 51.40 to 45.84% with the increase in moisture content from 3.9-22% w.b. (Fig. 5). The relationship between porosity and moisture content can be represented by the following equation:

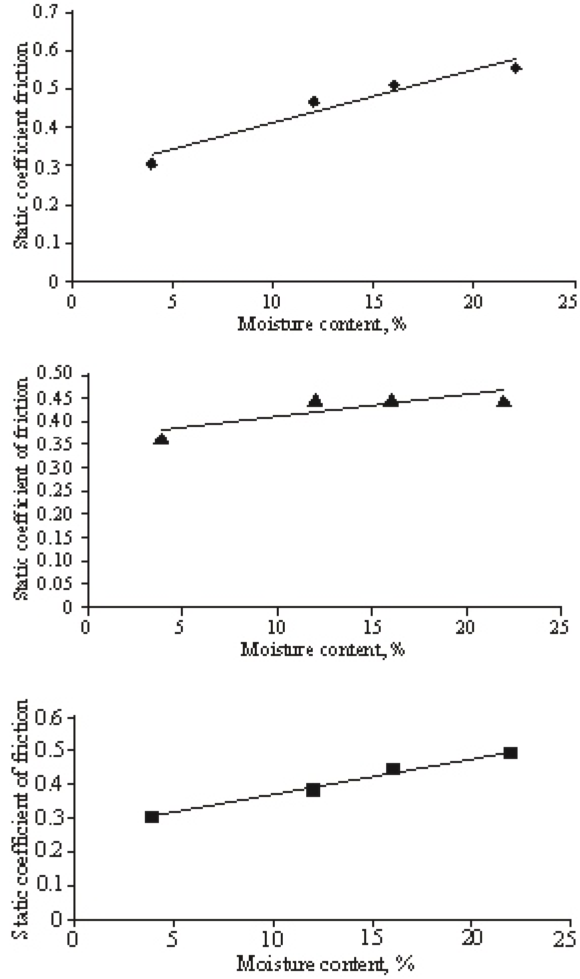

Fig. 6: Effect of moisture content on static coefficient of friction: plastic (Δ); galvanized iron (□) and plywood (◊)

$$\varepsilon = -0.3M + 51.67 \quad R^2 = 0.80 \qquad (16)$$

Baumler *et al.* (2006) reported an increase in porosity against moisture content variations and have then evaluated the relationship between porosity and moisture content for sunflower seed as:

$$e = 39.53 + 0.34M \quad R^2 = 0.930 \qquad (17)$$

The static coefficient of friction of safflower grain on three surfaces (plastic, plywood and galvanized iron) against moisture content in the range 3.9 - 22% w.b. are presented in Fig. 6. It was observed that the static coefficient of friction increased (probability < 0.05) linearly with increase in moisture content for plywood and galvanized iron but for plastic it is not linear. This is due to the increased adhesion between the grains and the material surfaces at higher moisture values. Increases of 20.00, 70.59 and 52.94% were recorded in the case of

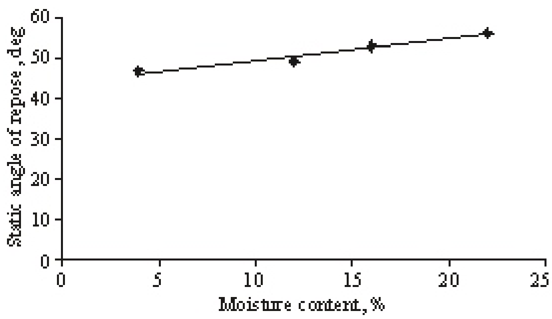

Fig. 7: Effect of moisture content on static angle of repose

plastic, plywood and galvanized iron, respectively, as the moisture content increased from 3.9-22% w.b. at all moisture contents, the least static coefficient of friction was on plastic. This may be owing to smoother and more polished surface of the plastic than the other materials used. The relationships between static coefficient of friction and moisture content on plastic, plywood and galvanized iron can be represented by the following equations:

$$\varphi\ plyw = 0.013M + 0.272 \qquad R^2 = 0.944 \qquad (18)$$
$$\varphi\ galv = 0.010M + 0.266 \qquad R^2 = 0.986 \qquad (19)$$
$$\varphi\ plas = 0.004M + 0.364 \qquad R^2 = 0.707 \qquad (20)$$

Similar results were found by Sahoo and Srivastava (2002) for okra. Parde *et al.* (2003) reported that the friction coefficient against plywood, galvanized steel and concrete surfaces for the Koto buckwheat cultivar increased significantly 0.26 to 0.31, 0.25 to 0.29 and 0.38 to 0.43, respectively, with increase in moisture content from 14.8 to 17.9%. The authors continued for significantly increasing the moisture content variation required more than 1%. The experimental results for the static angle of repose with respect to moisture content are shown in Fig. 7. The values of the static angle of repose were found to increase significantly at the 5% level of probability from 47 to 56 in the moisture range of 3.9 to 22% w.b. The static angle of repose for safflower has the following relationships with its moisture content:

$$\theta\ st = 0.514M + 44.32 \qquad R^2 = 0.938 \qquad (21)$$

Tabatabeefar (2003) found that the values of dynamic angle of repose for safflower increased from 34.7 to 45° in the moisture range of 0 to 22% d.b. Parde *et al.* (2003) reported that the emptying angle of repose for Koto buckwheat cultivar remained constant at about 23.5° from 14.8 to 15.8% mc and then increased significantly and the filling angle of repose did not differ significantly at 14.8 to 16.6% but increased significantly to 28.4° at 17.9%.

CONCLUSION

The various properties measured will serve as a useful tool in process and equipment design and this will go a long way in assisting to improve yield and quality of safflower grains. The following conclusions are drawn from this investigation into the properties of safflower grains, All the studied physical properties of safflower grains depend on their moisture contents. In the moisture content of 3.9% (w.b.), the average length, width and thickness of 10 safflower grains were 7.50, 4.58 and 3.58 mm, respectively. The bulk density, static angle of repose, aspect ratio and static coefficient of friction of safflower grains against different materials (plastic, galvanized iron and plywood) were increased and volume, surface area, sphericity, average geometric mean, equivalent and arithmetic diameter were generally increased with increase in moisture content whereas the porosity and true density were decreased with an increase in moisture content in safflower grains.

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