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Moisture dependent physico-mechanical properties of Iranian okra (*Ablemoschus esculentus* L.) seed

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Physical and mechanical properties of mature okra (*Hibiscus esculentus* L.) seeds from Ahvaz in Iran were evaluated. The physical and mechanical properties were evaluated at four moisture content levels of 7.1, 10, 15 and 20% dry basis (d.b). In this moisture range, seed length, width, thickness, geometric diameter, mass of 1000 seeds increased from 5.096 to 5.677 mm, 4.476 to 4.878 mm, 4.239 to 4.608 mm, 4.585 to 5.035 mm and 56.615 to 65.779 g, respectively. The angle of repose, volume, surface area and sphericity increased from 21.2 to 24.3°, 5.367 to 6.396 mm^3, 66.18 to 79.64 mm^2 and 90.07 to 0.92, respectively. The true density, bulk density and porosity decreased from 1096.34 to 1002.16 kg/m^3, 627.4 to 576.2 kg/m^3 and 41.1 to 38.01%, respectively. The rupture force and coefficient of static friction on aluminum, rubber, plywood, iron and galvanized iron sheets increased with increasing moisture content.

Key words: Okra seed, physical properties, moisture content.

INTRODUCTION

Okra (*Hibiscus esculentus* L.), a tropical to subtropical plant that is widely distributed from Africa to Asia, Southern European and America (Oyelade et al., 2003) belongs to the family *Malvaceae*. Okra is primarily a southern vegetable garden plant, grown for its immature pods, which are consumed when cooked either alone or in combination with other foods. There are some special varieties preferred by processing industries and others that are consumed as dried or fresh in Iran. The quality of the seed protein is high. The seeds of mature pods are sometimes used for chicken feed and have been used on a small scale for the production of oil (Martin and Ruberte, 1979; Oyelade et al., 2003).

Dimensions are very important in the design of sizing, cleaning and grading machines. Bulk density and porosity are major parameters in the design of drying and storage systems (Dursun and Dursun, 2005). Knowledge of the coefficient of friction is necessary in designing equipment for solid flow and storage structures. Recent scientific developments have made better the handling and processing of bio-materials through electrical, optical, thermal and other techniques, but little is known about the basic physical characteristics of biomaterials. Such basic knowledge is important not only to the engineers but also to food scientists, plant breeders, processors and other scientists who may find new uses (Mohsenin, 1978).

Several investigators determined the physical properties of seeds at various moisture contents such as Amin et al. (2004) for lentil seed, User et al. (2010) for red pepper seed, Konak et al. (2002) for chickpea seeds and Ogunjimi et al. (2002) for locust bean seed. However, no more published work seems to have been carried out on the physical and mechanical properties of okra seed and their relationship with moisture content. The aim of this

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study was to determine moisture-dependent physical and mechanical properties of okra seed cultivated in Iran to develop appropriate technologies for its processing. The development of the technologies will require knowledge of the properties of this seed.

MATERIALS AND METHODS

The okra seeds were collected from Ahvaz in Iran on May 2012, and kept in cooled bags during transportation to the laboratory. They were cleaned in an air screen cleaner to remove all foreign materials such as dust, dirt and chaff, as well as immature and damaged seeds. The initial moisture content (M_c) of the seeds, as brought from the market, was determined by drying samples in a hot air oven (Memmert-ULE500, Germany) set at 105°C (±1°C) for 72 h and was found to be 7.1% dry basis (d.b.) (AOAC, 2000).

Four levels of moisture contents of okra seeds were selected as 7.1 (initial M_C), 10, 15 and 20% d.b. The samples at the selected moisture contents were prepared by adding a calculated amount of water (Equation 1) and sealing them in separate polythene bags and storing in a refrigerator at 5°C for 7 days. Before each experiment, the required sample was taken out from the refrigerator and kept sealed in an ambient environment for 24 h to equilibrate the water and temperature throughout the sample. The sample is kept in the ambient environment in sealed conditions so there is no chance of change of moisture content (Yalcin, 2007; Kıilickan et al., 2010). Physical and mechanical properties were determined at the moisture contents of 7.1, 10, 15 and 20% d.b.

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

Where, Q is the mass of water to added; M_f is final moisture content of sample; M_i is initial moisture content of sample and W_i is initial mass of sample. The moisture content was checked at the end for all samples.

A digital caliper (AND GF-600. JAPON) with an accuracy of 0.001 mm was used to measure dimensions of the samples. Seed mass was measured by a digital balance (Mitutoyo, JAPON) with an accuracy of 0.001 g. The geometric mean diameter (D_g), Sphericity (Φ), the volume (V) and surface area (S) of the seed were calculated by using the following equations (Mohsenin, 1978):

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

$$\phi = \frac{(abc)^{1/3}}{a} \times 100 \quad (3)$$

$$V = \frac{\pi B^2 a^2}{6(2a - B)} \quad (4)$$

$$S = \frac{\pi B a^2}{2a - B} \quad (5)$$

$$B = (bc)^{0.5} \quad (6)$$

Where, a is the major diameter (length); b is the intermediate diameter (width) and c is the minor diameter (thickness) (Figure 1). Surface area of seed is total area (mm^2) around seed surface.

The bulk density (P_b) was determined using the mass/volume relationship, by filling an empty plastic container of predetermined volume (75 cm^3) and tare weight with the grains by pouring from a constant height, striking off the top level and weighing (Ghasemi Varnamkhasti et al., 2008). Using Equation 2:

$$\rho_b = \frac{m}{V_s} \quad (7)$$

Where, m is the total mass of seed in cylindrical (g) and V_s is the volume of cylindrical (cm^3). True density (P_t) of seeds was determined by using the liquid displacement method. Toluene (C_7H_8) was used in place of water because it has lesser extent absorb by seed. Also, its surface tension is low, so that it fills even shallow dips in a seed and its dissolution power is low (Konak et al., 2002; Aydin and Ozcan, 2007). This way, 30 g seed were filled in thirty milliliters toluene and measurement displacement liquid in pipe. True density was obtained as the ratio of seeds weight to the volume of displaced liquid. The porosity is the fraction of the space in the bulk seeds which is not occupied by the seeds. The porosity of okra seed was calculated from the values of true density and bulk density by the following equation (Kabas et al., 2006):

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \quad (8)$$

The angle of repose (ψ) was determined by using a hollow cylindrical mould of 100 mm diameter and 150 mm height. The cylinder was placed on a wooden table, filled with okra seed and raised slowly until it forms a cone of seeds. The diameter (D) and height (H) of the cone were recorded. The angle of repose (ψ) was calculated by the fallowing equation (Mullah, 1992):

$$\psi = \tan^{-1}(2H / D) \quad (9)$$

Incline plane method was used to measure static coefficient of friction on different structural surfaces including (Figure 2): Aluminum, rubber, plywood, galvanized steel and iron sheet. A hollow metal cylinder (100 mm diameter and 100 mm high) opened at both ends was filled with samples at the specific moisture content. The cylinder was then placed on an adjustable tilting plate without allowing the metal cylinder to touch the inclined surface. The tilting surface was then raised slowly and gradually by a screw mechanism until the cylinder started to slide down. At this point, the angle of tilt was measured and the friction coefficient was calculated as the tangent of that specific tilt angle (Dutta et al., 1988; Suthar and Das, 1996; Gezer et al., 2002):

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

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

Rupture force (F) of okra seed was determined by the testing machine (H50 K-S, Hounsfield, England), equipped with a 5 kg compression load cell and integrator. The measurement accuracy was ±0.001 N in force and 0.001 mm in deformation. The individual seed was loaded between two parallel plates of the machine and compressed along with thickness until rupture occurred as is denoted by a rupture point in the force–deformation curve. The

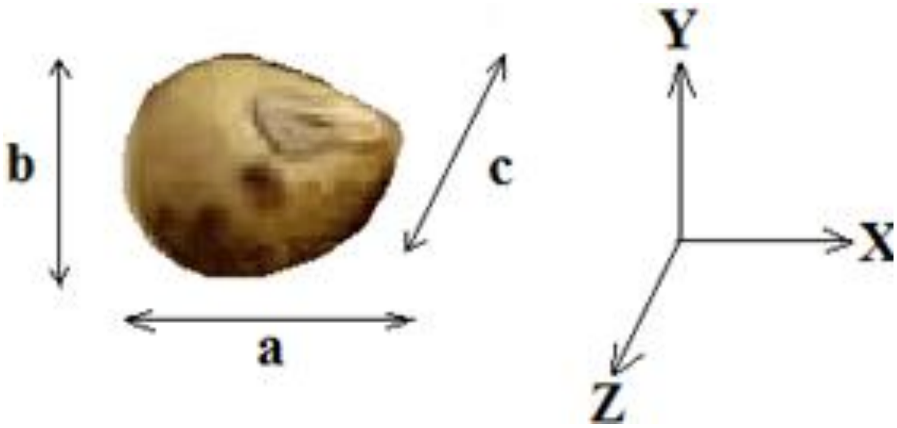

Figure 1. Dimensions of okra seed. a, Length; b, width; c, thicknes.

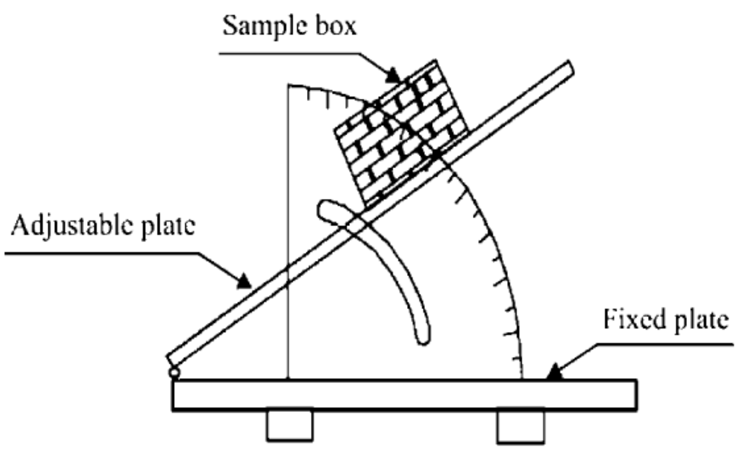

Figure 2. Apparatus for measuring static coefficient of friction.

rupture point is a point on the force–deformation curve at which the loaded specimen shows a visible or invisible failure in the form of breaks or cracks. This point is detected by a continuous decrease of the load in the force-deformation diagram. While the rupture point was detected, the loading was stopped. These tests were carried out at the loading rate of 3 mm/min for all moisture levels (Aydin and Ozcan, 2007).

Statistical analysis

For each of the moisture level, 100 okra seeds were randomly selected for measurement of properties. All the data were analyzed using the SPSS statistical software. Data means were compared using one way analysis of variance (ANOVA). Means that differed significantly were separated using Duncan's multiple range test. Significant differences were accepted at P<0.05.

RESULTS AND DISCUSSION

Seed dimensions and size distribution

The average of dimensional and technological properties of 100 okra seeds at different moisture content is presented in Table 1. Linear relationship was observed between moisture content and axial dimensions as follows:

$$a = 0.197M_C + 4.901 (R^2 = 0.996) \quad 11$$

$$b = 0.135M_C + 4.35 (R^2 = 0.992) \quad 12$$

$$c = 0.125M_C + 4.11 (R^2 = 0.996) \quad 13$$

$$D_g = 0.15M_C + 4.444 (R^2 = 0.995) \quad 14$$

According to the results from Figure 3, major diameter, intermediate diameter and minor diameter of okra seeds increased linearly with increase in moisture content. For the increase in moisture contents from 7.1 to 20% d.b., the increase of the major diameter, intermediate diameter, minor diameter and geometric mean diameter were 11.41% (5.096 to 5.677 mm), 8.99% (4.476 to 4.878 mm), 8.71%(4.239 to 4.608 mm) and 9.7% (4.589 to 5.035 mm), respectively. The increase of the major diameter

Table 1. Effect of moisture content on physical and mechanical properties of okra seed.

Property	Moisture content (%, d.b.)			
	7.1	10	15	20
Length (mm)	5.096±0.41	5.289±0.43	5.516±0.44	5.677±0.43
Width (mm)	4.476±0.32	4.629±0.25	4.775±0.28	4.878±0.36
Thickness (mm)	4.239±0.34	4.359±0.4	4.505±0.38	4.608±0.33
Geometric mean (mm)	4.585±0.29	4.743±0.31	4.914±0.34	5.035±0.35
Volume (mm^3)	5.367±0.33	5.703±0.38	6.108±0.35	6.396±0.41
1000 seed mass (g)	56.615±1.72	60.233±1.84	63±1.87	65.779±1.91
Porosity (%)	41.1±1.14	40.01±1.12	39.1±1.08	38.01±1.03
True density (kg/m^3)	1096.34±11.28	1067.14±10.64	1035.27±10.38	1002.16±9.25
Bulk density (kg/m^3)	627.4±32.12	610.1±31.35	590.7±30.18	576.2±28.87
Sphericity (%)	90.07±7.19	90.9±7.65	91.5±8.14	92.01±9.06
Surface area (mm^2)	66.18±4.62	70.69±4.98	75.86±5.39	79.64±6.47
Angle of repose (degree)	21.2±1.85	22.1±1.96	23.2±2..05	24.3±2.17
Static coefficient of friction				
Steel sheet	0.389±0.11	0.431±0.12	0.463±0.13	0.493±0.16
Galvanized steel sheet	0.372±0.15	0.395±0.18	0.408±0.16	0.419±0.19
Aluminum	0.347±0.07	0.361±0.11	0.381±0.13	0.399±0.17
Plywood	0.493±0.18	0.534±0.16	0.564±0.17	0.582±0.21
Rubber	0.524±0.15	0.562±0.16	0.591±0.19	0.625±0.22
Rupture force (N)	13.75±1.11	12.77±1.03	11.54±0.97	9.44±0.92

was more than the minor and intermediate diameter. Bagherpour et al. (2010) and Kiani Deh Kiani et al. (2008) found similar results for lentil seed and red bean grain, respectively.

Mass, volume and densities

As shown in Figure 4 mass of 1000 seeds was found to increase from 56.615 to 65.779 g as moisture content increased from 7.1 to 20% d.b. This parameter is useful in determining the equivalent diameter that can be used in the theoretical estimation of seed volume and in cleaning using aerodynamic forces. The increase of 1000 seeds mass is in conformity with the findings of Amin et al. (2004), Kiani Deh Kiani et al. (2008), Gharibzhedi et al. (2010) and Tabatabaeefar (2003) for lentil, red bean grains, sesame seed and wheat, respectively. For the increase in moisture contents, the increase of the volume was 19.17% as shown in Figure 4 as follows:

$$m_{1000} = 3.025 M_C + 53.84 \; (R^2 = 0.995) \tag{15}$$

$$V = 0.349 M_C + 5.02 \; (R^2 = 0.996) \tag{16}$$

The effect of the increase in moisture contents was increased in the volume (19.17%) to increase the mass (18.39%). Therefore, the decrease in the true density was higher than the decrease in bulk density. The bulk and true densities of seeds decreased with increase in moisture content. The bulk and true density was found to decrease from 627.4 to 576.2 kg/m^3 (8.88%), 1096.34 to 1002.2 kg/m^3 (9.39%), as moisture content increased from 7.1 to 20% d.b. as shown in Figure 5. The following linear relationships were developed for bulk density and true density.

$$\rho_b = -17.3 M_C + 6443 \; (R^2 = 0.997) \tag{17}$$

$$\rho_t = -31.44 M_C + 1128 (R^2 = 0.998) \tag{18}$$

Similar decreasing moisture content has been observed for other products (Gharibzahedi et al., 2010; Cagaty et al., 2006).

Porosity

Porosity was found to decrease from 41.1 to 38% with the moisture content increase from 7.1 to 20% d.b. as shown in Figure 6. A linear relationship was obtained as follows:

$$\varepsilon = -1.02 M_C + 42.1 \; (R^2 = 0.998) \tag{19}$$

This could be attributed to the expansion and swelling of seeds that might have resulted in more voids between the seeds and increased bulk volume. This is also exhibited in the reduction of bulk density with increase in

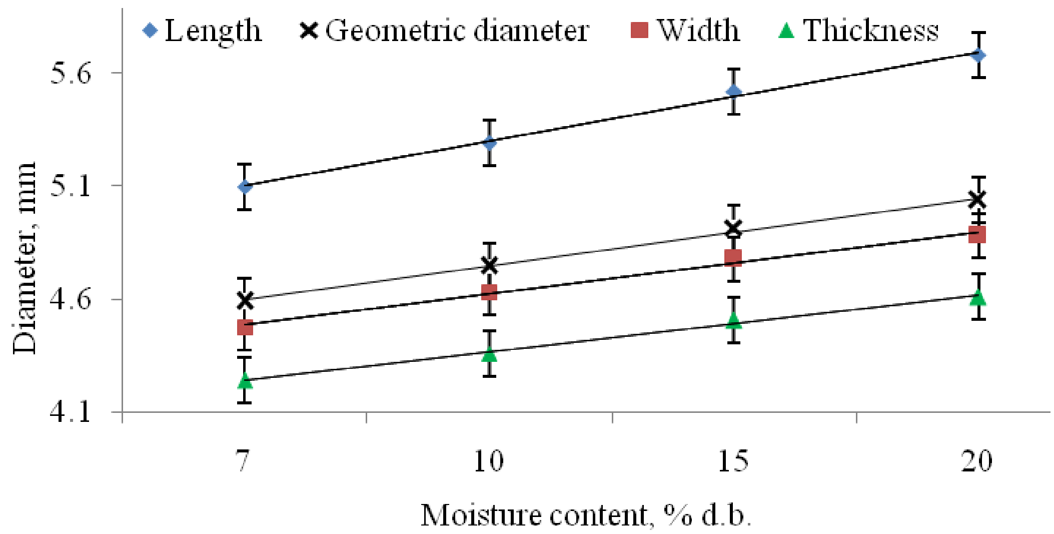

Figure 3. Effect of moisture content on dimensions of okra seed.

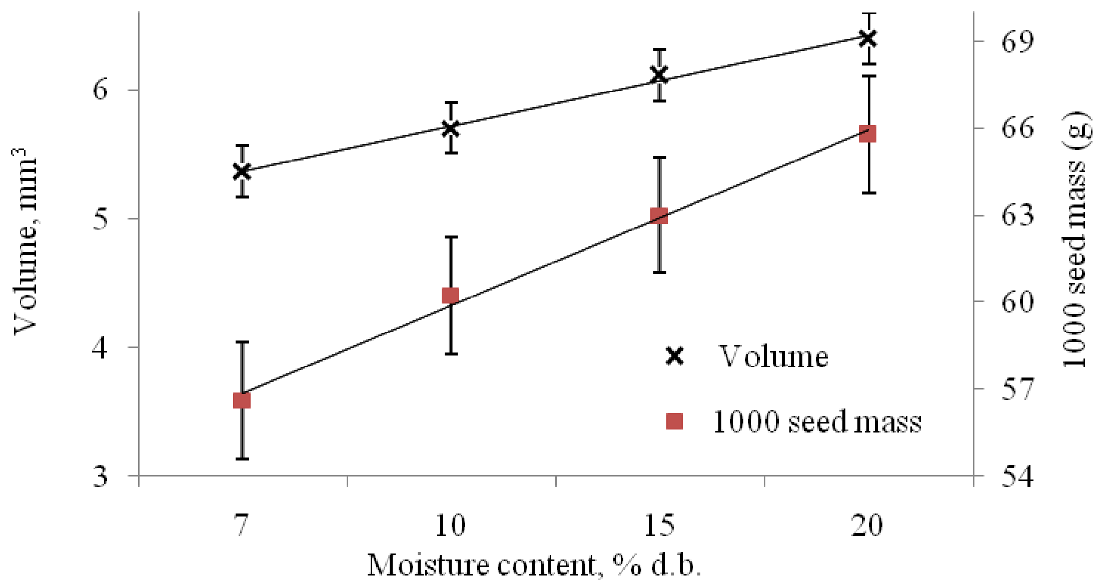

Figure 4. Mass of 1000 seeds and volume of okra seed as a function of moisture content.

moisture content. Similarly, for lentil, Bagherpour et al. (2010) stated that as the moisture content increased so did the porosity value.

Sphericity

The sphericity of okra seed was found to increase from 90.07 to 92.01% with the increase in moisture content (Figure 6). The following a linear relationship was developed for Sphericity.

$$\phi = 0.006M_C + 0.895 (R^2 = 0.986) \qquad 20$$

Similar trends have been reported by Gharibzhedi et al. (2009) for sesame seed Sacilik et al. (2003) for hemp seed.

Surface area

According to the results, surface area of okra seeds increased linearly with increase in moisture content as shown in Figure 7. For the increase in moisture contents from 7.1 to 20% d.b., the increase of the surface area was 20.34% (66.18 to 79.64 mm^2). Similar increases have been reported by Gharibzahedi et al. (2010) and Sacilik et al. (2003) for black cumin and hemp seed,

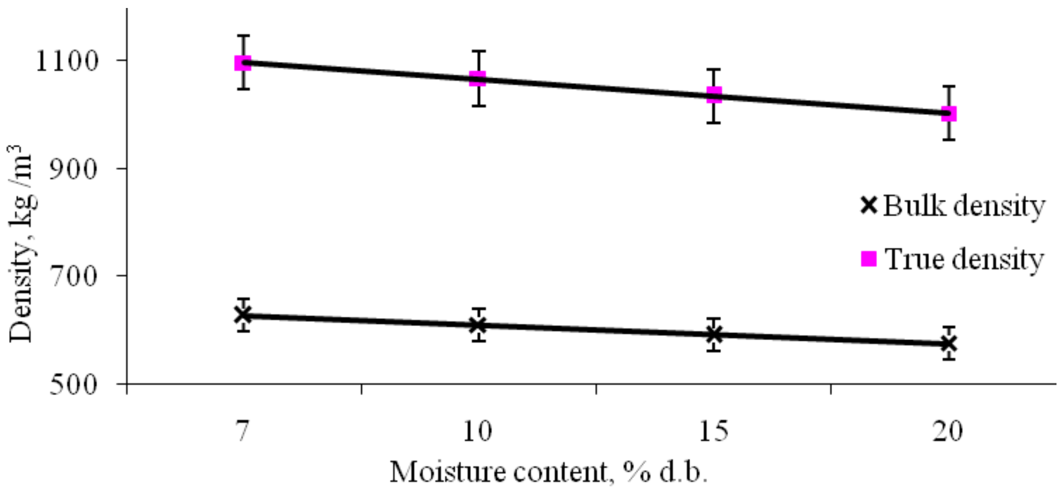

Figure 5. Effect of moisture content on true and bulk density of okra seed.

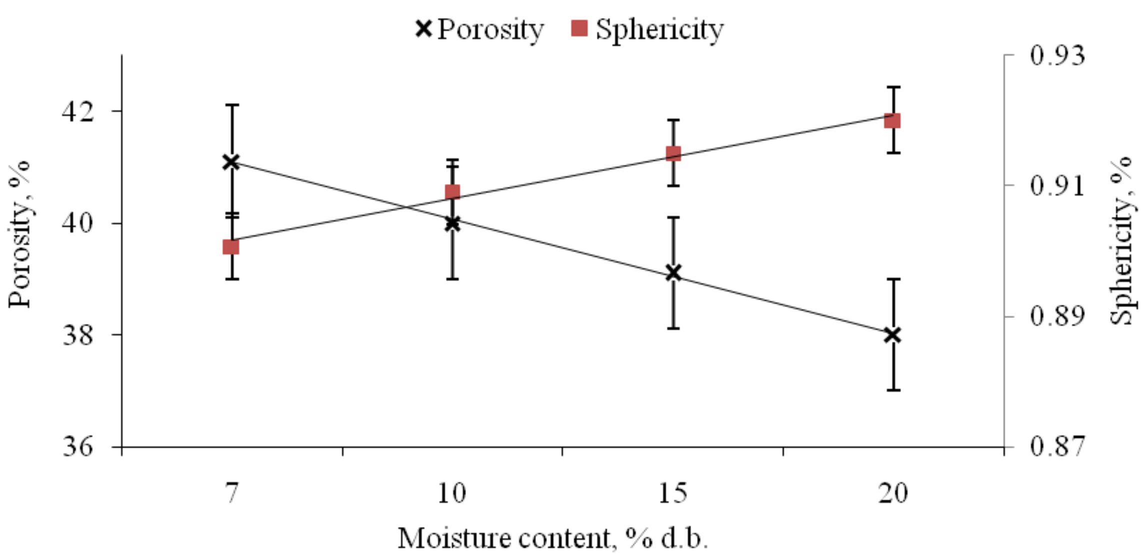

Figure 6. Porosity and sphericity of okra seed as a function of moisture content.

respectively. The relationship between surface area and moisture content of okra seeds was found to be as follows:

$$S = 4.55M_C + 61.70\ (R^2 = 0.996) \quad 21$$

Angle of repose

The angle of repose of okra seeds increased with increase in moisture content as shown in Figure 7. It increased from 21.2 to 24.3° in the moisture range of 7.1 to 20 % d.b. The increase in the angle of repose with increase in moisture content of the seed could be the cause of the higher surface area which may increase the internal friction of the seeds. The obtained results are similar to those reported by Amin et al. (2004) and Sacilik et al. (2003) for lentil seed and hemp seeds, respectively. The angle of repose is importance in designing hopper openings, sidewall slopes of storage bins, chutes for bulk transporting of seeds and it is particularly useful for calculating the quantity of granular materials which can be placed implies or flat storages (Gharibzahedi et al., 2009). Therefore, seed moisture content should be taken into account while designing transport and storage equipment. The relationship existing between moisture content and angle of repose appears a linear relationship was obtained as follows:

$$\psi = 1.04M_C + 20.1\ (R^2 = 0.997) \quad 22$$

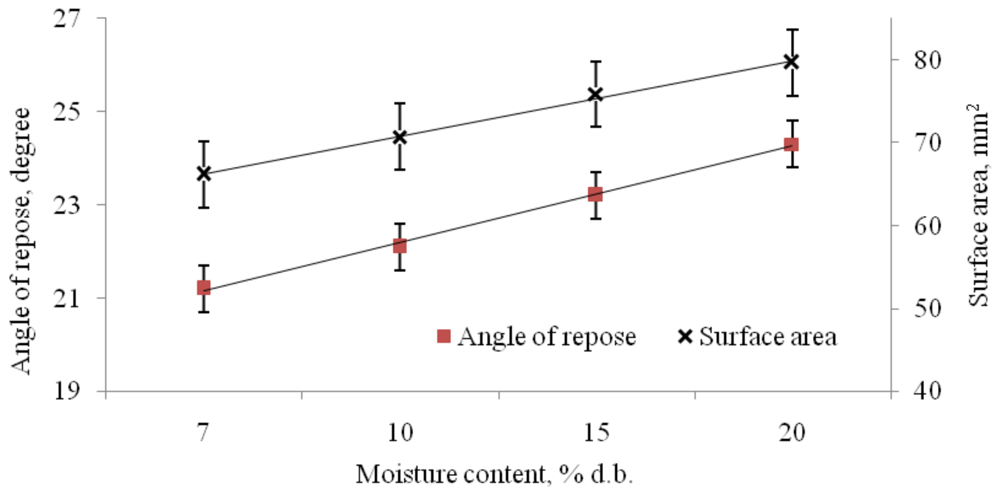

Figure 7. Effect of moisture content on surface area and angle of repose of okra seed.

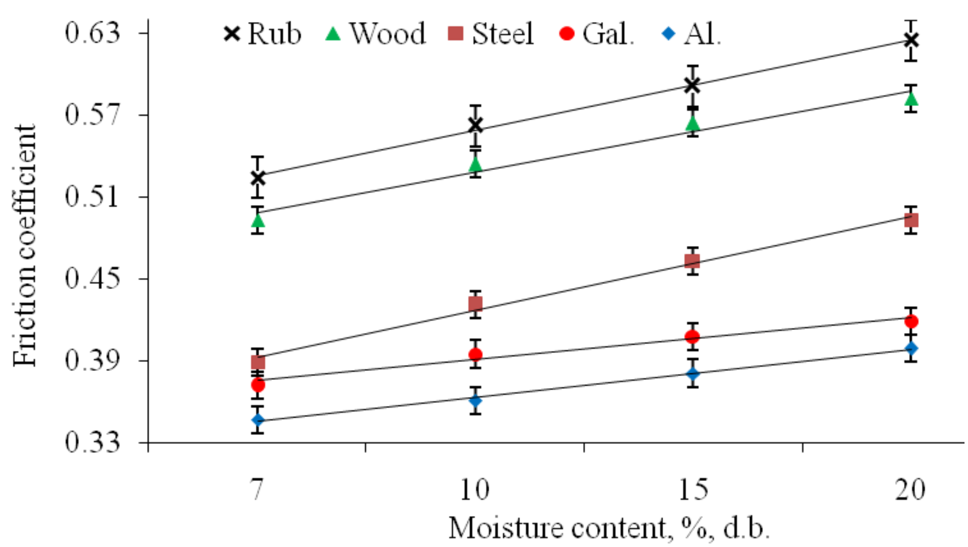

Figure 8. Effect of moisture content on static coefficient of friction of okra seed.

Static coefficient of friction

The static coefficient of friction of okra seed on five surfaces (plywood sheet, rubber sheet, galvanized steel sheet, aluminum sheet and steel sheet) against moisture content in the range 7.1 to 20% d.b. are presented in Figure 8. According to the results, the static coefficient of friction increased with increase in moisture content for all the surfaces. This is due to the increased adhesion between the seed and the material surfaces at higher moisture values. At all moisture contents, the least static coefficient of friction were on aluminum sheet. This may be owing to smoother and more polished surface of the aluminum sheet than the other materials used. A higher variation in the relationship of coefficient of static friction with moisture content was detected on steel sheet (26.73%) than on rubber (19.21%), plywood (18.01%), aluminum (14.98%) and galvanized steel (12.63%). The relationship between static friction coefficient and moisture content of okra seed was found to be as follows:

$$\mu_{steel} = 0.034 M_C + 0.358 (R^2 = 0.993) \quad 23$$

$$\mu_{gal} = 0.015 M_C + 0.36 (R^2 = 0.968) \quad 24$$

$$\mu_{wood} = 0.029 M_C + 0.469 (R^2 = 0.971) \quad 25$$

$$\mu_{rub} = 0.033 M_C + 0.492 (R^2 = 0.997) \quad 26$$

$$\mu_{Al} = 00.17 M_C + 0.328 (R^2 = 0.995) \quad 27$$

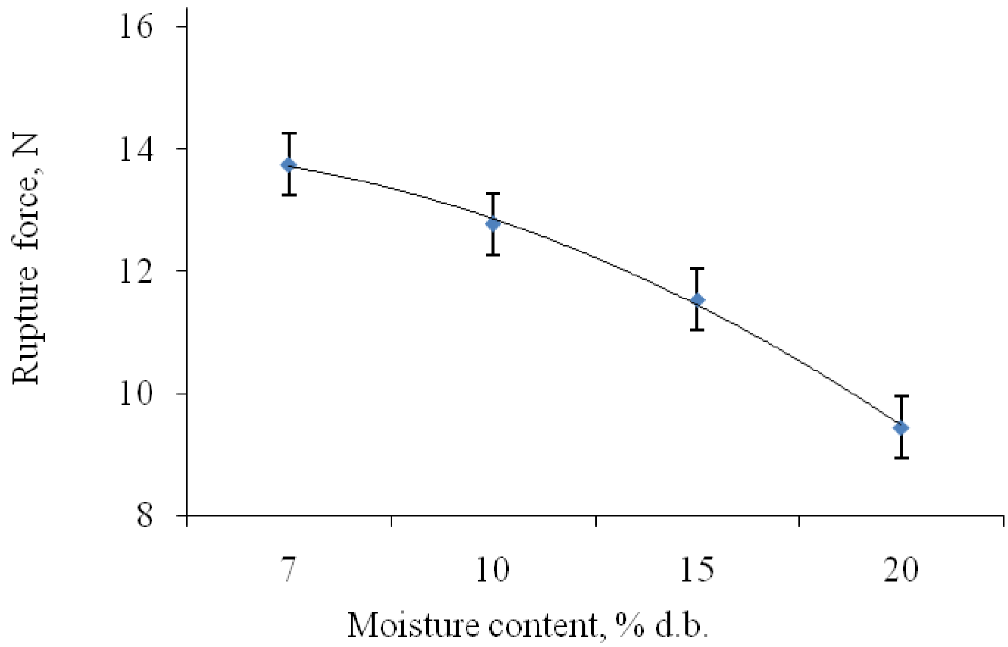

Figure 9. Rupture force of okra seed as a function of moisture content.

Similar trend has been observed by Coskun et al. (2006), Tabatabaeefar (2003), Tekin et al. (2006) and Kingsly et al. (2006) for sweet corn, wheat, bombay bean and anardana seeds respectively.

Rupture forces

The rupture force was found to decrease from 13.75 to 9.44 N (31.31%, decreases), as moisture content increased from 7.1 to 20% d.b. as shown in Figure 9. The small rupture forces at higher moisture content might have resulted from the fact that the seed became more sensitive to rupture at high moisture. These findings are similar to those reported for lentil seed (Bagherpour et al., 2010) and pine nut (Vursavus and Ozguven, 2005). The following a second-order polynomial relationships were developed for rupture forces:

$$F = -0.279 M_C{}^2 - 0.018 M_c + 14.01 \; (R^2 = 0.998) \quad 28$$

Conclusions

Some physical and mechanical properties of okra seed were measured. The following conclusions may be made based on statistical analysis of the data: The average dimensions for each of the three principal diameters (major, intermediate and minor), geometric mean diameter, mass of 1000 seeds, volume, sphericity, porosity, surface area, and angle of repose increased significantly in the moisture range from 7.1 to 20% d.b. True density decreased from 1096.34 to 1002.16 kg/m^3 and the bulk density decreased from 627.4 to 576.28 kg/m^3. Also, the coefficient of static friction on all surfaces (plywood sheet, rubber sheet, galvanized steel sheet, aluminum sheet and steel sheet) of okra seeds increased in the moisture range from 7.1 to 20% d.b. Finally, the average rupture force of okra seeds decrease from 13.75 to 9.44 N.

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