Moisture-Dependent Some Engineering Properties of Soybean Grains

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ABSTRACT

This study was carried out to evaluate the effect of moisture content on some physical properties and mechanical behaviour under compression load of soybean grains (*Glycine max* L.). Four levels of moisture content ranging from 6.92 to 21.19 % d.b. were used. The average length, width, thickness, arithmetic and geometric mean diameter, surface area, thousand grains mass and angle of repose increased as the moisture content increased from 6.92 to 21.19 %. As the moisture content increased from 6.92 to 21.19 % d.b., the bulk density and true density were found to decrease from 650.95 to 625.36 kg/m^3 and from 1147.86 to 1126.43 kg/m^3 respectively, while the porosity was found to increase from 43.29 to 44.48 %. The static coefficient of friction of soybean increased linearly against various surfaces as the moisture content increased from 6.92 to 21.19 % d.b. The rupture energy of the grains increased in magnitude with an increase in moisture content, while rupture force decreased.

Keywords: Engineering Properties, Soybean, Grain Processing, Rupture Energy, Coefficient of Friction

1. INTRODUCTION

Soybean (*Glycine max* L.) is a species of legume native to Eastern Asia. Among the legumes, the soybean, is classified as an oilseed, is pre-eminent for its high protein content as well as its high oil content (Perkins, 1995). In Iran, soybean is widely cultivated as a legume crop for a long time and is cultivated on 54319 ha with an annual production of 135000 ton and its yield 2485 kg/ha (FAO, 2007).

In order to design equipment used in plantation, harvesting, transportation, storage, processing and oil extraction of soybean, there is need to know various physical and mechanical properties as function of moisture content. The size, shape and mechanical behaviour of soybean are important in designing of harvesting, separating, sizing, grinding and oil extraction machines. Bulk density, true density and porosity (the ratio of inter granular space to the total space occupied by the grain) are used in design of storage bins and silos, separation of desirable materials from impurities, cleaning and grading and quality evaluation of the products. The angle of repose is important in designing of storage and transporting structures. The static coefficient of friction of the grain against the various surfaces is also necessary in designing of conveying, transporting and storing structures.

In the recent years, physical properties have been studied for various crops such as groundnut kernel (Olajide and Igbeka, 2003); lentil seed (Amin et al., 2004); sweet corn seed (Coşkun et al., 2005); linseed (Selvi et al., 2006); faba bean grain (Altuntaş and Yildiz, 2007); rough rice grain (Ghasemi Varnamkhasti et al., 2008); jatropha seed (Garnayak et al., 2008) and karanja kernel (Pradhan et al., 2008).

Review of literatures showed that there is not much information relating to moisture-dependent physical properties and mechanical behaviour of soybean grain. Therefore the objective of this study was to investigate some moisture-dependent physical and mechanical properties of soybean grains, namely, linear dimensions, size, sphericity, surface area, thousand grain mass, bulk density, true density, porosity, angle of repose and static coefficient of friction on various surfaces in the moisture content range from 6.92 % to 21.19 % d.b. In addition, the effects of moisture content on rupture force and rupture energy of soybean grains were determined in this study.

2. MATERIALS AND METHODS

The soybean cultivar, Williams (Fig. 1), used for this study, was obtained from the seed and seedling research institute, Karaj, Iran. The cultivar Williams, used in the current study, is one of the prevalent varieties in Iran. The samples were manually cleaned to remove foreign matter, dust, dirt, broken and immature grains. The initial moisture content of the samples was determined by oven drying at 103 ± 1 °C for 72 h (ASAE, 2006b). The initial moisture content of the grains was 6.92 % d.b.

The samples of the desired moisture contents were prepared by adding the amount of distilled water as calculated from the following relationship (Coşkun et al., 2005):

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

Where Q is the mass of water added, kg, 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 the sample in d.b.%.

The samples were then transferred to separate polyethylene bags and the bags sealed tightly. The samples were kept at 5 °C in a refrigerator for a week to enable the moisture to be distributed uniformly throughout the sample. Before starting a test, the required quantities of the samples were taken out of the refrigerator and allowed to warm up to the room temperature for about 2 h. The rewetting technique to attain the desired moisture content in kernel and grain has frequently been used (Nimkar and Chattopadhyay, 2001; Sacilik et al., 2003; Coşkun et al., 2005; Garnayak et al., 2008; Pradhan et al., 2008). All the physical and mechanical properties of the grains were assessed at moisture levels of 6.92, 11.63, 16.42 and 21.19 % d.b. Five replications of each test were made at each moisture level. For each moisture content, the length, width, thickness and mass of soybean grains were measured on randomly selected 100 soybean grains. The length, width and thickness of materials were measured using a digital caliper with an accuracy of 0.01 mm.

Figure 1. Soybean grains.

The average diameter of the grains was calculated by using the arithmetic mean and geometric mean of the three axial dimensions. The arithmetic mean diameter D_a and geometric mean diameter D_g of the grains were calculated by using the following relationships (Mohsenin, 1970):

$$D_a = \frac{L + W + T}{3} \tag{2}$$

$$D_g = (LWT)^{1/3} \tag{3}$$

The sphericity Φ, of soybean grains was calculated by using the following relationship (Mohsenin, 1970):

$$\Phi = \left[\frac{(LWT)^{1/3}}{L} \right] \times 100 \tag{4}$$

Where *L* is the length, *W* is the width and *T* is the thickness, all in mm.

The thousand grains mass was determined using a digital electronic balance having an accuracy of 0.001 g. To evaluate the thousand grain mass, 100 grains were randomly selected from the bulk sample and averaged. The surface area of soybean grain was found by analogy with a sphere of the same geometric mean diameter, using the following relationship (Sacilik et al., 2003; Tunde-Akintunde and Akintunde, 2004; Altuntaş et al., 2005):

$$S = \pi D_g^{\ 2} \tag{5}$$

Where *S* is the surface area in mm^2.

The true density was defined as the ratio between the mass of soybean grains and the true volume of the grains, and determined using the toluene (C_7H_8) displacement method. Toluene was used instead of water because it is absorbed by grains to a lesser extent. The volume of toluene displaced was found by immersing a weighted quantity of soybean grains in the measured toluene (Sacilik et al., 2003; Garnayak et al., 2008; Pradhan et al., 2008). The bulk density was determined using the mass/volume relationship, by filling an empty plastic container of predetermined volume and tare weight with the grains by pouring from a constant height, striking off the top level and weighing (Ghasemi Varnamkhasti et al., 2008).

The porosity of the grains was calculated from bulk and true densities using the relationship given by Mohsenin (1970) as follows:

$$\varepsilon = (1 - \frac{\rho_b}{\rho_t}) \times 100 \quad (6)$$

Where ε is the porosity in %, ρ_b is the bulk density in kg/m^3 and ρ_t is the true density in kg/m^3.

The angle of repose is the angle compared to the horizontal at which the material will stand when piled. 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 grains to follow and assume a natural slope, this was measured as emptying angle of repose (Tabatabaeefar, 2003; Ghasemi Varnamkhasti et al., 2008).

The static coefficients of friction of soybean grains against three different surfaces, namely, plywood, glass and galvanized iron sheet were determined using a cylinder of diameter 75 mm diameter and 50 mm depth, filled with grains. With the cylinder resting on the surface, the surface was raised gradually until the filled cylinder just started to slide down (Razavi and Milani, 2006; Ghasemi Varnamkhasti et al., 2008). The coefficient of friction was calculated from the following relationship:

$$\mu = \tan\alpha \quad (7)$$

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

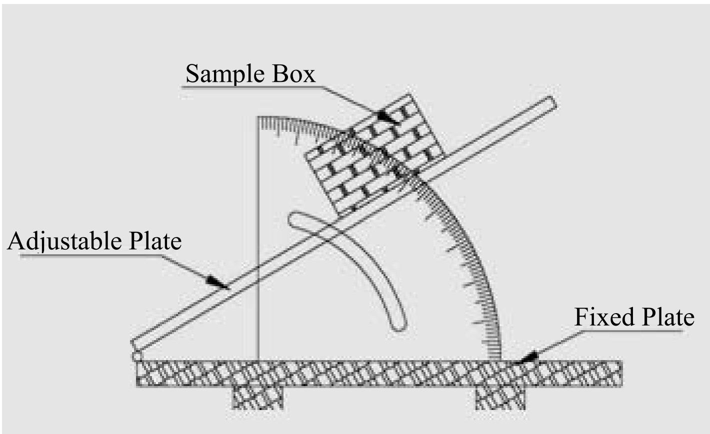

Figure 2. Apparatus for measuring empting angle of repose.

To determine the mechanical properties of soybean, a proprietary tension/compression testing machine (Instron Universal Testing Machine /SMT-5, SANTAM Company, Tehran, Iran) was used, equipped with a 500 kg compression load cell and integrator (Saiedirad et al., 2008). The measurement accuracy was ±0.001 N in force and 0.001 mm in deformation. The individual grain 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 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 5 mm/min for all moisture levels (ASAE, 2006a).

The mechanical behaviour of soybean grains were expressed in terms of rupture force and rupture energy required for initial rupture. Three replications were made for each test and 10 samples were used in each test. Energy absorbed by the sample at rupture was determined by calculating the area under the force–deformation curve from the following relationship:

$$E_a = \left[\frac{F_r D_r}{2}\right] \quad (8)$$

Where E_a is the rupture energy in mJ, F_r is the rupture force in N and D_r is the deformation at rupture point (Braga et al., 1999).

The results obtained were subjected to analysis of variance (ANOVA) and Duncan's test using SPSS 13 (SPSS Inc., USA) software and analysis of regression using Microsoft Excel 2003 (Microsoft Corp., USA).

3. RESULTS AND DISCUSSION

The effect of moisture content on all physical and mechanical properties of soybean grains was significant at 5 % probability level. Results obtained are discussed in detail below.

3.1. Grain dimensions

Average values of the three principal dimensions of soybean grain, namely, length, width and thickness determined in this study at different moisture contents are presented in Table 1. Each principal dimension appeared to be linearly dependent on the moisture content as shown in Fig. 3. Very high correlation was observed between the three principal dimensions and moisture content indicating that upon moisture absorption, the soybean grain expands in length, width and thickness within the moisture range of 6.92 to 21.19 % d.b. The average length, width and thickness of the 100 grains varied from 7.27 to 8.25 mm, 6.48 to 6.97 mm and 5.41 to 5.94 mm, respectively as the moisture content increased from 6.92 to 21.19 % d.b. Differences between values are statistically important at $P < 0.05$.

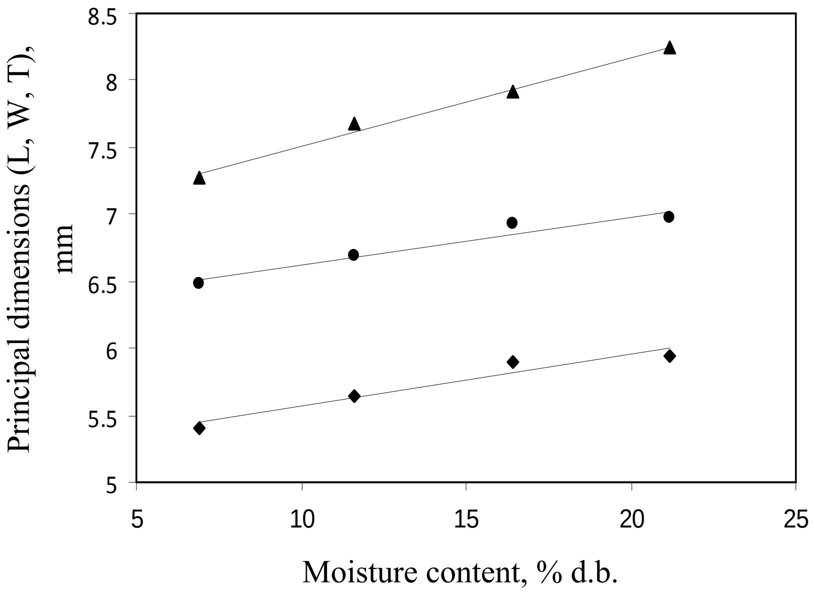

Figure 3. Variation of principal dimensions of soybean grains with moisture content. (▲) Length; (●) Width; (♦) Thickness.

The average diameter calculated by the arithmetic mean and geometric mean are also presented in Table 1. The average diameters increased with the increased in moisture content as axial dimensions. The arithmetic and geometric mean diameter ranged from 6.39 to 7.05 mm and 6.34 to 6.98 mm as the moisture content increased from 6.92 to 21.19 % d.b., respectively ($P < 0.05$).

3.2. Sphericity

The values of sphericity were calculated individually with Eq. (4) by using the data on geometric mean diameter and the major axis of the grain and the results obtained are presented in Table 1. The sphericity of the soybean grain decreased from 87.25 to 84.75 % as the moisture content increased from 6.92 to 21.19% d.b. The relationship between sphericity (Φ) and moisture content (M) appears linear and can be represented by the following equation:

$$\Phi = -0.172M + 88.68 \qquad (R^2=0.923) \qquad (9)$$

Similar trends of decrease have been reported by Nimkar and Chattopadhyay (2001) for green gram, Baryeh and Mangope (2002) for pigeon pea cv. ‘QP-38’, Çalişir et al. (2005) for rapeseed and Tekin et al. (2006) for bombay bean.

3.3. Thousand grain mass

The thousand grain mass of soybean increased linearly from 171.50 to 219.04 g (P<0.05) as the moisture content increased from 6.92 to 21.19 % d.b. (Table 1). This relationship between 1000 grain mass (m_{1000}) and the moisture content (M) can be represented by the following equation:

$$m_{1000} = 3.151M + 149.2 \qquad (R^2=0.961) \qquad (10)$$

Similar increasing trend has been reported by Kasap and Altuntaş (2006) for sugarbeet seeds, Altuntaş and Yildiz (2007) for faba bean grains, and Pradhan et al. (2008) for karanja kernel.

3.4. Surface area

The surface area of the grain was calculated by using Eq. (5). As seen from the Table 1, the surface area of soybean grain increases linearly from 126.95 to 153.95 mm^2 (statistically important at P <0.05) when the moisture content increased from 6.92 to 21.19 % d.b. The variation of moisture content (M) and surface area (S) can be expressed mathematically as follows:

$$S = 1.918M + 114.9 \qquad (R^2=0.977) \qquad (11)$$

Similar trend has been reported by Selvi et al. (2006) for linseed, Işik and Ünal (2007) for red kidney bean grains, and Garnayak et al. (2008) for jatropha seed.

Table 1. Physical properties of soybean grains at different moisture contents

Moisture content d.b.%	Axial dimensions, (mm)			Average diameters, (mm)		Sphericity, (%)	Surface area, (mm^2)	Bulk density, (kg/m^3)	True density, (kg/m^3)	Porosity, (%)	Angle of repose (°)	1000 grain Mass (g)
	Length, L	width, w	Thickness, T	Arithmetic mean, Da	Geometric mean, Dg							
6.92	7.27 a (0.58)*	6.48 a (0.49)	5.41 a (0.49)	6.39 a (0.48)	6.34 a (0.48)	87.25 a (3.03)	126.95 a (19.23)	650.95 a (2.14)	1147.86 a (3.32)	43.29 a (0.35)	24.56 a (1.29)	171.50 a (1.47)
11.63	7.67 b (0.55)	6.69 b (0.49)	5.64 b (0.60)	6.66 b (0.51)	6.61 b (0.52)	86.87 a (2.85)	138.18 b (21.66)	640.83 b (2.63)	1137.70 b (3.18)	43.67 a (0.07)	25.57 a (0.51)	188.01 b (1.99)
16.42	7.91 c (0.53)	6.93 c (0.42)	5.90 c (0.44)	6.91 c (0.42)	6.86 c (0.42)	86.18 a (3.32)	148.53 c (18.11)	630.97 c (2.94)	1131.07 bc (3.73)	44.21 b (0.08)	27.60 b (0.53)	195.41 c (3.02)
21.19	8.25 d (0.56)	6.97 c (0.48)	5.94 c (0.49)	7.05 c (0.45)	6.98 c (0.45)	84.75 b (3.20)	153.95 c (19.83)	625.36 c (2.19)	1126.43 c (1.69)	44.48 b (0.11)	29.93 c (1.01)	219.04 d (3.64)

*Values in parentheses represent standard deviation. Values in the same columns followed by different letters (a-d) are significantly different ($P<0.05$).

3.5. Bulk density

The grains bulk density at different moisture levels varied from 650.95 to 625.36 kg/m^3 (P < 0.05) (Fig. 4) and indicated a decrease in bulk density with an increase in moisture content from 6.92 to 21.19 % d.b. This was due to the fact that an increase in mass owing to moisture gain in the sample was lower than accompanying volumetric expansion of the bulk (Pradhan et al., 2008). The bulk density (ρ_b) of the grains was found to have the following linear relationship with the moisture content (M):

$$\rho_b = -1.819M + 662.5 \qquad (R^2=0.984) \qquad (12)$$

Similar decreasing trend in bulk density has been reported by Yalçin et al. (2007) for pea seed, Altuntaş and Demirtola (2007) for some legumes seeds, Garnayak et al. (2008) for jatropha seed and Pradhan et al. (2008) for karanja kernel.

3.6. True density

The true density of soybean grains at different moisture contents varied from 1147.86 to 1126.43 kg/m^3, (Fig. 4). The effect of moisture content on true density of the grains showed a decrease with increasing moisture content. The moisture (M) dependence of the true density (ρ_t) was described by a linear equation as follows:

$$\rho_t = -1.489M + 1156 \qquad (R^2=0.969) \qquad (13)$$

Although the results were similar to those reported by Sacilik et al. (2003) for hemp seed, Yalçin et al. (2007) for pea seed, Cetin (2007) for barbunia bean seed and Altuntaş and Demirtola (2007) for some legumes seeds, a different trend was reported by Altuntaş and Yildiz (2007) for faba bean grains, Garnayak et al. (2008) for jatropha seed and Pradhan et al. (2008) for karanja kernel.

3.7. Porosity

Porosity was calculated through Eq. (6) by using the data on bulk and true densities of the soybean grain. The variation of porosity depending upon moisture content is shown in Fig. 4. The porosity was found to increase linearly from 43.29 to 44.48 % (P<0.05) in the specified moisture levels. As seen in Fig. 4, both bulk and true densities of soybean grains decreased with increase in moisture content, whereas the porosity increased. This was due to the fact that a decrease in the true density was lower than decreasing of the bulk density. The relationship between porosity (ε) value and the moisture content (M) of the grains was obtained as:

$$\varepsilon = 0.086M + 42.70 \qquad (R^2=0.985) \qquad (14)$$

Yalçin and Özarslan (2004), Altuntaş and Yildiz (2007), Garnayak et al. (2008) and Pradhan et al. (2008) reported similar trends in case of vetch seeds, faba bean grains, jatropha seed and karanja kernel, respectively.

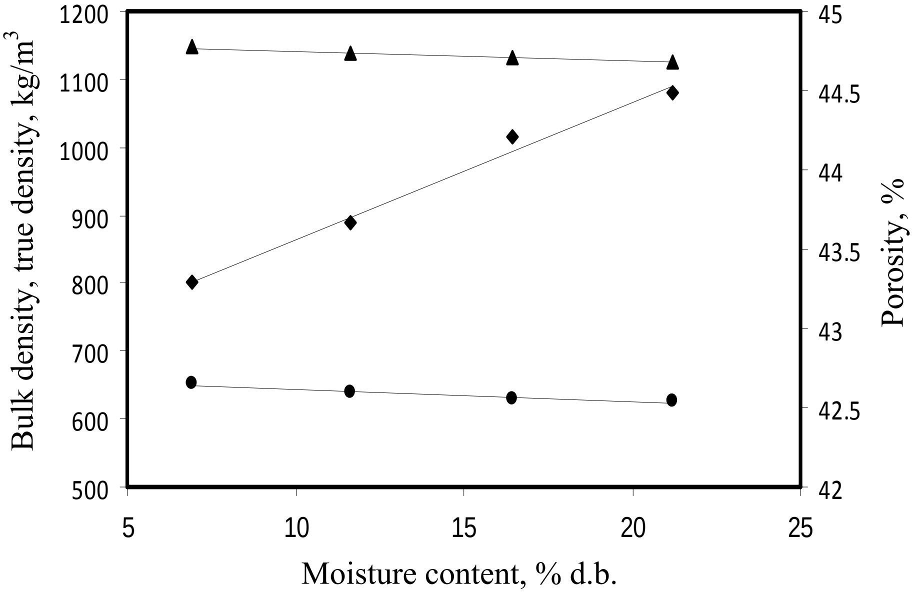

Figure 4. Variation of bulk density, true density and porosity of soybean grain with moisture content. (▲) True Density; (●) Bulk Density; (♦) Porosity.

3.8. Angle of Repose

The experimental results for the angle of repose with respect to moisture content are shown in Table 1. The values were found to increase from 24.56° to 29.93° ($P < 0.05$) in the moisture range of 6.92–21.19 % d.b. This increasing trend of angle of repose with moisture content occurs because surface layer of moisture surrounding the particle hold the aggregate of grain together by the surface tension (Pradhan et al., 2008). The values of the angle of repose (θ) for soybean grain bear the following relationship with its moisture content (M):

$$\theta = 0.381M + 21.56 \qquad (R^2=0.973) \qquad (15)$$

These results were similar to those reported by Kasap and Altuntaş (2006), Altuntaş and Yildiz (2007), Garnayak et al. (2008), and Pradhan et al. (2008), for sugarbeet seeds, faba bean grains, jatropha seed and karanja kernel, respectively.

3.9. Static coefficient of friction

The static coefficients of friction of soybean grain on three surfaces (plywood, glass and galvanized iron sheet) against moisture content in the range of 6.92-21.19 % d.b. are presented in Fig. 5. It was observed that the static coefficient of friction increased linearly with increase in moisture content for all contact surfaces. The reason for the increased friction coefficient at higher moisture content may be owing to the water present in the grain offering a cohesive force on the surface of contact (Garnayak et al., 2008). Increases of 25.83, 17.54 and 16.37 % were recorded in the case of plywood, glass and galvanized iron sheet, respectively, as the moisture content increased from 6.92 to 21.19 % d.b. At all moisture content, the maximum friction was offered by plywood, followed by galvanized iron sheet and glass surface. The least static coefficient of friction may be owing to smoother and more polished surface of the glass compared to the other materials used. Plywood also offered the maximum friction for pigeon pea, gram, rape seed, neem nut, Jatropha seed and karanja kernel and the coefficient of friction increased with the moisture content (Shepherd and Bhardwaj

1986; Dutta et al., 1988; Kulkelko et al., 1988; Visvanathan et al., 1996; Garnayak et al., 2008; Pradhan et al., 2008). The relationships between static coefficient of friction (μ) and the moisture content (*M*) on plywood (*wd*), glass (*gl*) and galvanized iron sheet (*gi*) can be represented by the following equations:

$$\mu_{wd} = 0.005M + 0.242 \qquad (R^2=0.926) \tag{16}$$

$$\mu_{gl} = 0.003M + 0.233 \qquad (R^2=0.852) \tag{17}$$

$$\mu_{gi} = 0.003M + 0.253 \qquad (R^2=0.961) \tag{18}$$

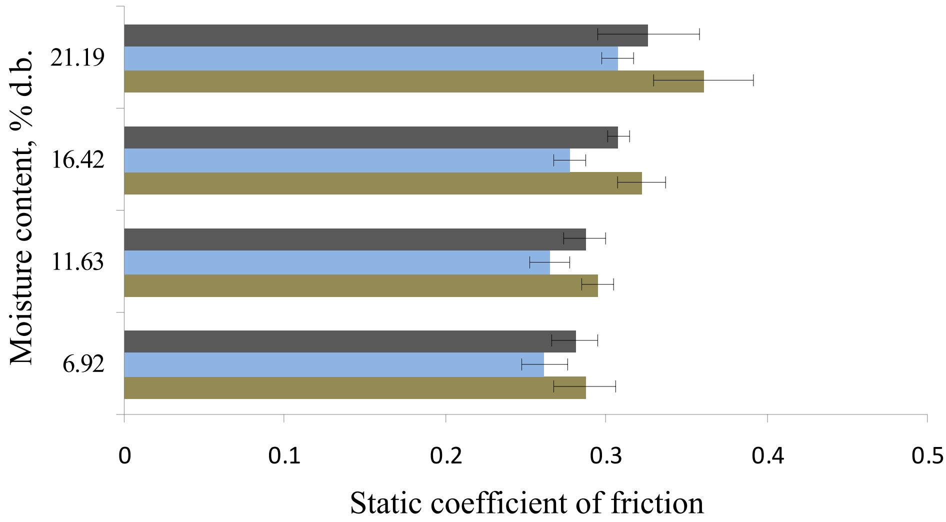

Figure 5. Effect of moisture content on static coefficient of friction of soybean grain against various surfaces. (■) Wood, (■) Glass, (■) Galvanized Iron Sheet.

3.10. Rupture force

The forces required to initiate grain rupture for loading along the thickness at different moisture contents are presented in Fig. 6. It can be observed from the Fig. 6 that the rupture force decreased as the moisture content increased from 6.92 to 21.19 % d.b. The rupture force values ranged from 270.66 to 191.09 N ($P<0.05$). As seen in Fig. 6, the lower rupturing forces were obtained at higher moisture contents. This might have resulted from the fact that the soybean grain might have soft texture at high moisture content (Altuntaş and Yildiz, 2007). The relationship between moisture content (*M*) and rupture force (*F*) of soybean grain can be expressed mathematically as follows:

$$F = -0.277M^2 + 2.321M + 267.2 \qquad (R^2=0.997) \tag{19}$$

The results are similar to those reported by Olaniyan and Oje (2002) for shea nut, Vursavuş and Özgüven (2004) for apricot pit and Altuntaş and Yildiz (2007) for faba bean grains.

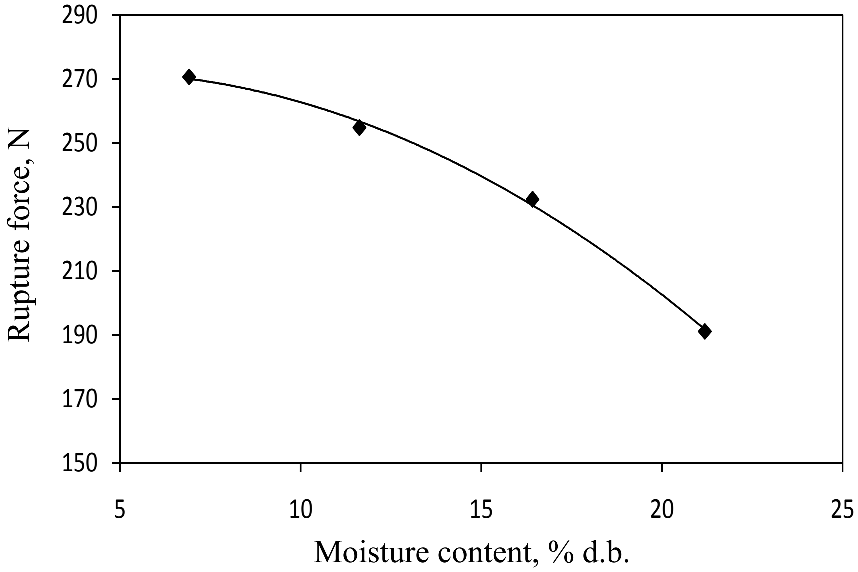

Figure 6. Effect of moisture content on rupture force of soybean grain.

3.11. Rupture energy

The results for the rupture energy are presented in Fig. 7. The rupture energy values increased from 318.34 to 376.68 mJ (P<0.05) as the moisture content increased from 6.92 to 21.19 % d.b. At the lower moisture levels, the rupture energy was low and vice versa. The relationship between moisture content (M) and rupture energy (E) of soybean grain can be represented by the following equation:

$$E = -0.336M^2 + 13.38M + 242.9 \qquad (R^2=0.988) \qquad (20)$$

The results are similar to those reported by Oloso and Clarke (1993) for cashew nuts, Güner et al. (2003) for hazelnut and Altuntaş and Yildiz (2007) for faba bean grains.

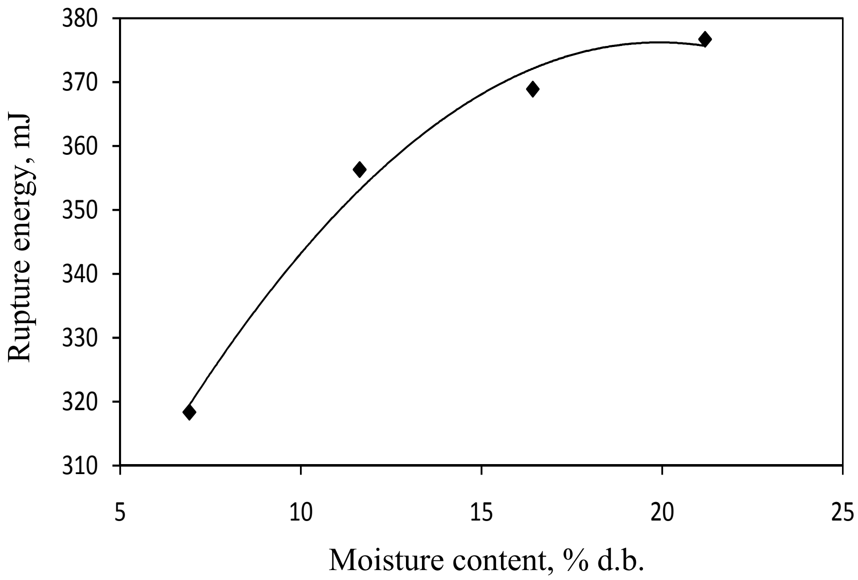

Figure 7. Effect of moisture content on rupture energy of soybean grain.

4. CONCLUSIONS

The following conclusions are drawn from the investigation on physical and mechanical properties of soybean grains for moisture content range of 6.92 to 21.19 % d.b.

The average length, width, thickness, geometric mean diameter, thousand grain mass, angle of repose and surface area of soybean grains ranged from 7.27 to 8.25 mm, 6.48 to 6.97 mm, 5.41 to 5.94 mm, 6.34 to 6.98 mm, 171.50 to 219.04 g, 24.56° to 29.93° and 126.95 to 153.95 mm^2, respectively. The sphericity was found to decrease from 87.25 to 84.75 % in the moisture range of 6.92 to 21.19 % d.b. As the moisture content increased from 6.92 to 21.19 % d.b., the bulk density and true density decreased from 650.95 to 625.36 kg/m^3, 1147.86 to 1126.43 kg/m^3, respectively, while the porosity increased from 43.29 to 44.48 %. The static coefficient of friction increased for all three surfaces, namely, plywood (0.287-0.361, 25.83 %), glass (0.262-0.307, 17.54 %) and galvanized iron sheet (0.280-0.326, 16.37 %) as the moisture content increased from 6.92 to 21.19 % d.b. The rupture force decreased from 270.66 to 191.09 N, while the rupture energy increased from 318.34 to 376.68 mJ, as the moisture content increased from 6.92 to 21.19 % d.b. Differences between all values were statistically important at $P<0.05$.

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