Determination of physical properties of soybean at different moisture levels

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Abstract: The physical properties of soybean are important in designing and fabricating equipment and structures for handling, transporting, processing and storage, and also for assessing the quality of soybean. The study was conducted to investigate some physical properties of soybean at various moisture levels. The average length, width, thickness and thousand mass were 6.55 mm, 5.56 mm, 4.53 mm and 103.57 g, respectively, at moisture content of 7.37% (dry basis). The geometric mean diameter increased from 5.44 to 5.57 mm and the sphericity varied between 0.83 and 0.84 as moisture content increased from 7.37% to 15.80% (db), respectively. In the same moisture range, the bulk and true densities decreased from 749.1 to 644.4 kg m^{-3} and 1250 to 1111.11 kg m^{-3}, respectively, whereas the corresponding porosity increased from 40.07% to 41.9%. As the moisture content increased from 7.37% to 15.80% (db) angle of repose as found to increase from 26.35° to 30.96°. The static coefficient of friction of soybean increased linearly against the surfaces of two structural materials, namely glass and wood as the moisture content increased from 7.37% to 15.80% (db).

Keywords: moisture content, physical properties, soybean, India

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1 Introduction

Soybean is known as the "Golden Bean" of the 20th century. Though soybean is a legume crop, yet it is widely used as oilseed. It is now the second largest oilseed in India after groundnut. Soybean is coming first with 56% seed production among oily seed production in the world. Soybean is the most important leguminous plant in both production area and international trade (Hymowitz, 1990; Denis, 1994). For the past several decades soybean production had steady increase in India. The major soybean growing states in India are Madhya Pradesh, Maharashtra, Rajasthan and Uttar Pradesh. Soybean has a very high nutritional value; it contains 17 g protein, 1 g oil, 44 g total carbohydrates, 88 mg calcium, 4 mg iron, 1 mg sodium, 6% calories from fat per 250 mL (dry) (Anonymous, 2006).

The physical properties of soybean are important to design the equipments and machines for sorting, separation, transportation, processing and storage. Designing of such equipments and machines without taking these into considerations may yield poor results. For this reason the determination and considerations of these properties become an important role. The major moisture-dependent physical properties of biological materials are shape, size, mass, bulk density, true density, porosity and static coefficient of friction against various surfaces (Mohsenin, 1980). In recent years, many researchers have investigated these properties for various

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agricultural crops such as lentil grains (Carman, 1996), locust bean seed (Olajide and Ade-Omowage, 1999; Ogunjimi, Aviara and Aregbesola, 2002), pumpkin seeds (Joshi, Das and Mukharjee, 1993), sunflower seeds (Gupta and Das, 1997), legume seeds (Altuntaş and Demirtola, 2007) and Faba bean (Altuntaş and Yıldız, 2007).

In addition, engineering and aerodynamic properties of soybean have been determined by Polat, Atay and Saglam (2006) and Isik (2007). But there is limited information on properties of soybean which is inadequate to design equipment and machines in scientific literatures for soybean to be cultivated in India.

In considering this, the study was undertaken to investigate some physical properties of soybean at different moisture content. The properties studied includes size distribution, sphericity, bulk density, true density, porosity, thousand grain mass, angle of repose and static coefficient of friction.

2 Materials and Methods

2.1 Sample preparation

This research work was conducted in Maharashtra, India. Soybean used for all the experiments were obtained from local farmers. The samples were cleaned manually to remove foreign materials, broken and immature soybeans.

The moisture content of sample was determined by oven drying (103±2℃) method until constant weight was reached (Kashaninejad , Tabil, Mortazavi and Safe kordi, 2003). The average moisture content of the soybeans was found to be 7.37% (db). Soybeans were conditioned by adding a calculated quantity of water, mixed thoroughly and then sealed in separate polyethylene bags (Karababa, 2005). The samples were kept for 15 days for the moisture to distribute uniformly throughout the sample. Before each test, the required quantity of sample was taken out and allowed to warm up to room temperature. All the physical properties were determined at the moisture content of 7.37%, 10.92% and 15.80% (db).

2.2 Physical properties

In order to determine dimensions, one hundred soybeans were randomly selected. For each soybean, the three principle dimensions, namely length, width and thickness were measured using a vernier caliper having the least count of 0.001 mm at each moisture level. The length (*L*) was defined as the distance from the tip cap to kernel crown. Width (*W*) was defined as the widest point to point measurement taken parallel to the face of the kernel. Thickness (*T*) was defined as the measured distance between the two kernels faces as described by Pordesimo et al. (1990).

The geometric mean diameter D_g of the soybean was calculated by using the following relationship (Mohsenin, 1980):

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

where, L is the length; W is the width and T is the thickness in mm.

The sphericity Φ is calculated using the formula (Mohsenin, 1980):

$$\Phi = \frac{(LWT)^{\frac{1}{3}}}{L} \tag{2}$$

The thousand grain mass was determined using an electronic balance having an accuracy of 0.001 g.

2.3 Bulk density, true density and porosity measurements

The bulk density is the ratio of the mass sample of soybeans to its total volume. It was determined by filling a 1000 mL container with kernels from a height of about 150 mm, striking the top level and then weighing the content (Deshpande, Bal and Ojha, 1993; Gupta and Das, 1997; Konak Carman and Aydin, 2002). True density of the soybean was determined by the toluene displacement method. Grain sample (about 5 g) was submerged in toluene in a measuring cylinder having an accuracy of 0.1 mL, the increase in volume due to sample was noted as true volume of sample which was then used to determine the true density of the sample.

Porosity $\acute{\varepsilon}$ is the ratio of volume of internal pores in the particle to its bulk volume. It was calculated as the ratio of the difference in the true density and bulk density to the true density and expressed by Mohsenin (1980):

$$\acute{\varepsilon} = \frac{\rho t - \rho b}{\rho t} \tag{3}$$

where, ρt is the true density and ρb is the bulk density.

2.4 Angle of repose

The angle of repose is the characteristics of the bulk material which indicates the cohesion among the individual grains. The higher the cohesion, the higher the angle of repose. The angle of repose is the angle from the horizontal at which the material will rest in a pile. This was determined by using an open-ended cylinder of 15 cm diameter and 30 cm height. The cylinder was placed at the centre of circular plate having a diameter of 70 cm and was filled with soybean grains. The cylinder was raised slowly until it formed a cone on the circular plate. The height of the cone was recorded. The angle of repose, θ was calculated by using the following formula:

$$\theta = \tan^{-1} (2h/d) \tag{4}$$

where, θ is the angle of repose; h is the height of pile and d is the diameter of cone.

2.5 Static coefficient of friction

The coefficient of static friction of soybeans at different moisture content was measured. The static coefficients of friction of soybean grains were determined on two different materials, namely, glass and wood. The tilting platform of 350 mm × 120 mm was fabricated and used for experimentation. A topless and bottomless plastic box of dimensions 45 mm × 45 mm × 100 mm was filled with grain and placed on the adjusted tilting surface. The box was raised slightly so as not to touch the surface. The structural surface with the box resting on it was inclined gradually with a screw device until box just started to slide down and the angle of tilt was read from a graduated scale (Nimkar, Dipali and Renu, 2005). The coefficient of friction was calculated from following relationship:

$$\mu = \tan\alpha \tag{5}$$

where, μ is the static coefficient of friction and α is the angle of tilt in degrees.

3 Results and Discussion

3.1 Dimensions and thousand grain mass of soybean

The result of soybean size and mass at different moisture content are shown in Table 1. All the dimensions increased with moisture content in the moisture range of 7.37%–15.80% (db). The relationship between the axial dimensions (L, W, T and D_g) and moisture content (M_c) can be expressed using the regression equations as:

$$L = 6.409 + 0.021M_c \quad R^2 = 0.953 \tag{6}$$

$$W = 5.493 + 0.009M_c \quad R^2 = 0.992 \tag{7}$$

$$T = 4.426 + 0.013M_c \quad R^2 = 0.973 \tag{8}$$

$$D_g = 5.343 + 0.015M_c \quad R^2 = 0.907 \tag{9}$$

Table 1 Principle dimensions, geometric mean diameter, sphericity and thousand grain mass of soybean

MC/%(db)	Length/mm	Width/mm	Thick./mm	Geometric mean diameter/mm	Sphericity	Thousand grain mass/g
7.37	6.55±0.27 (6.9)^{max} (6.0)^{min}	5.56±0.26 (6.0)^{max} (5.0)^{min}	4.53±0.24 (5.1)^{max} (4.0)^{min}	5.44±0.22 (6.08)^{max} (5.0)^{min}	0.8324±0.020 (0.8902)^{max} (0.7789)^{min}	103.57±0.42 (103.88)^{max} (103.08)^{min}
10.92	6.66±0.26 (7.1)^{max} (6.1)^{min}	5.60±0.21 (6.0)^{max} (5.0)^{min}	4.56±0.20 (5.1)^{max} (4.2)^{min}	5.53±0.17 (6.21)^{max} (5.14)^{min}	0.8339±0.019 (0.9031)^{max} (0.7822)^{min}	104.87±0.59 (105.44)^{max} (104.25)^{min}
15.80	6.73±0.24 (7.4)^{max} (6.2)^{min}	5.64±0.24 (6.6)^{max} (5.1)^{min}	4.64±0.19 (5.3)^{max} (4.2)^{min}	5.57±0.17 (6.24)^{max} (5.23)^{min}	0.8415±0.015 (0.9084)^{max} (0.8092)^{min}	109.67±0.40 (110.14)^{max} (109.42)^{min}

All the dimensional properties were significantly correlated to different moisture content. The result indicates that the soybeans increased in length, width, thickness and geometric mean diameter within the moisture range 7.37 to 15.80%. Thousand grain mass and sphericity was also found to increase with the increase in moisture content in the same moisture range. The relationship of thousand grain mass and sphericity with moisture content can be expressed using regression equation as:

$$M_{1000} = 97.636 + 0.739M_c \quad R^2 = 0.948 \tag{10}$$

$$\Phi = 0.823 + 0.001M_c \quad R^2 = 0.924 \tag{11}$$

where, M_{1000} is the thousand grain mass and Φ is the sphericity of grains.

Similar investigations have been made to evaluate the mass and dimensional properties and similar results were found by Deshpande, Bal and Ojha (1993) for soybeans.

3.2 Bulk density, true density and porosity

The bulk density of soybean decreased from 749.1 to 644.4 kg m^{-3}, respectively, as moisture content increased from 7.37% to 15.80% (db). The true density of soybean was found to decrease from 1,250 to 1,111.11 kg m^{-3} with the increase in moisture content from 7.37% to 15.80% respectively (Table 2). Deshpande, Bal and Ojha (1993), Polat, Atay and Saglam (2006) and Isik (2007) also reported the same results for soybean. The bulk and true density of soybean can be represented by the following equations:

$$\rho b = 838.261 - 12.358M_c \qquad R^2 = 0.997 \qquad (12)$$

$$\rho t = 1364.297 - 16.290M_c \qquad R^2 = 0.985 \qquad (13)$$

where, ρb is the bulk density and ρt is the true density.

Table 2 Bulk density, true density, porosity and angle of repose of soybean

Moisture content/% (db)	Bulk density/kg • m^{-3}	True density/kg • m^{-3}	Porosity/%	Angle of repose/(º)
7.37	749.1±3.76 $(752.87)^{max}$ $(745.34)^{min}$	1250±4.67 $(1255.21)^{max}$ $(1246.16)^{min}$	40.07±0.59 $(40.75)^{max}$ $(39.65)^{min}$	26.35±0.69 $(27.14)^{max}$ $(25.83)^{min}$
10.92	700±4.63 $(705.18)^{max}$ $(696.24)^{min}$	1176.47±3.12 $(1180.19)^{max}$ $(1173.99)^{min}$	40.49±0.66 $(41.25)^{max}$ $(40.05)^{min}$	27.89±0.39 $(28.35)^{max}$ $(27.65)^{min}$
15.80	644.4±8.74 $(652.9)^{max}$ $635.43)^{min}$	1111.11±5.13 $(1114.54)^{max}$ $(1105.21)^{min}$	41.90±0.52 $(42.38)^{max}$ $(41.34)^{min}$	30.96±0.70 $(31.77)^{max}$ $(30.55)^{min}$

The porosity of soybeans at the different moisture content was found to increase from 40.07% to 41.9% with the increase in moisture content from 7.37% to 15.80% (db). The similar trend for porosity was reported by Isik (2007). The relationship between the porosity ($\acute{\varepsilon}$) and moisture content (M_c) for soybean can be represented by the following equation:

$$\acute{\varepsilon} = 38.304 + 0.221M_c \qquad R^2 = 0.956 \qquad (14)$$

where, $\acute{\varepsilon}$ is the porosity of the grains.

3.3 Angle of repose

The experimental data obtained for angle of repose of soybean is given in Table 2. The angle of repose increases linearly with the increase in moisture content. The value of angle of repose increases from 26.35 to 30.96 degrees as moisture content increases from 7.37% to 15.80% (db). The percent of the increase in angle of repose is 17.49. Similar increasing trend was reported by Munde (1997) for green gram. The relationship between angle of repose (θ) and moisture content (M_c) can be expressed by regression equations as:

$$\theta = 22.129 + 0.552M_c \qquad R^2 = 0.990 \qquad (15)$$

3.4 Static coefficient of friction

At all moisture contents, the static coefficient of friction was the highest for soybean against wood and least for glass. As the moisture content of soybean increased, the static coefficient of friction increased linearly. At 7.37% (db) moisture content static coefficient of friction of soybean was 0.70 on wood, 0.53 on glass (Table 3). Similar trend was represented by Polat et al. (2006) for wooden material and glass.

Table 3 Values of static coefficient of friction for soybean against different surfaces

Moisture content/%(db)	Glass	Wood
7.37	0.53±0.026 $(0.56)^{max}$ $(0.51)^{min}$	0.70±0.017 $(0.71)^{max}$ $(0.68)^{min}$
10.92	0.55±0.017 $(0.56)^{max}$ $(0.53)^{min}$	0.72±0.02 $(0.74)^{max}$ $(0.70)^{min}$
15.80	0.57±0.017 $(0.59)^{max}$ $(0.56)^{min}$	0.78±0.026 $(0.80)^{max}$ $(0.75)^{min}$

The relationships between static coefficient of friction of soybean at different moisture content were found in Table 4.

Table 4 The relationship between moisture content and static coefficients of friction

Surfaces	Equations	Coefficient of determination (R^2)
Glass	$\mu = 0.497 + 0.005M_c$	0.992
Wood	$\mu = 0.624 + 0.010M_c$	0.964

4 Conclusions

The average length, width and thickness of soybean grains ranged from 6.55 to 6.73 mm, 5.56 to 5.64 mm and 4.53 to 4.63 mm as the moisture content increased from 7.37% to 15.80% (db), respectively.

The geometric mean diameter increased from 5.44 to 5.57 mm. The thousand grain mass increased from 103.57 to 109.67 g and the sphericity increased from 0.8324 to 0.8415 with the increase in moisture content from 7.37% to 15.80% (db). The bulk density decreased from 749.1 to 644.4 kg m^{-3}, whereas the true density decreased from 1,250 to 1,111.11 kg m^{-3}. While porosity increased from 40.07% to 41.90% with the increase in moisture content from 7.37% to 15.80% (db).

The angle of repose increased linearly from 26.35 to 30.96 degrees with the increase in moisture content. The static coefficient of friction increased for both surfaces, namely, glass (0.53 to 0.57) and wood (0.70 to 0.78).

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