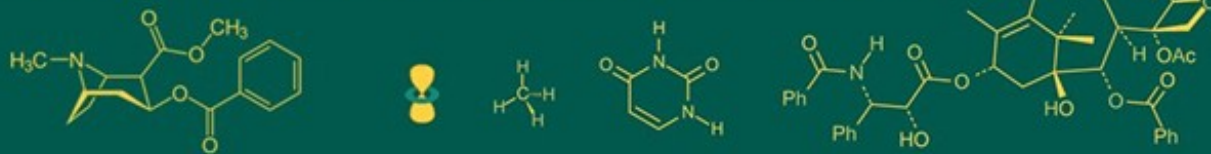


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Engineering properties of soybean (variety PDKV-Amba) for design of tractor operated soybean dryer

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ABSTRACT

Soybean (*Glycine max*) is a leguminous vegetable of the Pea family that grows in tropical, subtropical and temperate climates. Characterizing the physical properties of agricultural grains is vital for optimizing post-harvest operations. The present study investigated the engineering properties of soybean grain (PDKV-Amba) at different moisture content 5.94 % to 35.28 % (wb). The results indicated a direct correlation between increasing moisture content and an increase in all measured physical attributes. The length (7.26 to 7.62 mm), width (6.18 to 6.52 mm), thickness (5.16 to 5.52 mm), arithmetic mean diameter (6.20 to 6.56 mm), geometric mean diameter (6.03 to 6.38 mm), roundness (0.80 to 0.81), sphericity (0.83 to 0.84), aspect ratio (0.85 to 0.86), surface area of grain (114.12 to 127.79 mm²), projected area (35.22 to 39.06 mm²), volume of grain (121.16 to 143.85 mm³), thousand grain weight (144.20 to 167.07 g), porosity (21.93 to 34.76 %), and angle of repose (25.34 to 27.030) were found to be increased with increased in moisture content from 5.94 % to 35.28 % (wb). In contrast, bulk density decreased from 781.19 to 648.99 kg/m³ and true density decreased from 1000.66 to 994.73 kg/m³ as moisture content increased. Understanding these moisture dependent physical properties is crucial for the effective design of post-harvest processing equipment and optimizing storage conditions for soybean seeds.

Keywords: Soybean, Engineering properties, Moisture content, Density

Introduction

Soybean and Cotton are the major kharif crop grown by farmer in Vidarbha region of Maharashtra state of India. Soybean occupies 49.91% area of kharif crop in Vidarbha. Soybean has good quality of protein but rarely used in human food and mostly used for animal feed. Major use of soybean in India is for oil. It is a leguminous vegetable of the Pea family that grows in tropical, subtropical and temperate climates. Soybean has a high protein content of 40% by weight, 32% carbohydrate, 20% fat, 5% minerals, and 3% fiber and other trace substances. It is used as sources of protein in human food, animal feed and in industries (Adekunle *et al.*, 2006) [1]. Approximately, 85% of the world's soybean crop is processed into soybean meal and vegetable oil (Endres, 2001) [2].

PDKV Amba variety of Soybean is recently released by Dr. Panjabrao Deshmukh Agricultural University, Akola (MS), India particularly for Vidarbha region according to climate and growing pattern of Vidarbha region. Number of researchers have studied and published data on properties of grain and soybean also. But no research has been conducted on PDKV-Amba variety of Soybean. Number of post-harvest equipment including dryer have been developed by researcher for different grains by considering the properties of grains. To develop appropriate equipment for harvesting, handling, conveying cleaning, delivering, separation, packing, storing, drying, mechanical oil extraction and proceeding of agricultural products, their physical properties have to be known (Aviara *et al.*, 1999; Mohsenin, 1980) [3, 4]. In recent years, some studies on the physical and mechanical properties which appear to be important in the storage of granular products have been conducted intensively (Karababa, 2006; Baryeh, 2001; Bäumlér *et al.*, 2006) [6, 5, 7]. The knowledge of physical properties, during drying, is also relevant for the correct post-harvest management. Information about size, volume, porosity, density and others are basic information for projection and monitoring of drying and storage of several agricultural products (Hauth *et al.*, 2018) [8].

Major problem of post-harvest operations of Soybean in Vidarbha region is drying of soybean due to climate change. Harvesting period of soybean is August to September when rains are occurred due to climate change. Therefore, moisture content of soybean are very high sometimes upto 30 to 35 %, which deteriorates the quality of soybean. The tractor operated mobile batch type dryer are need of farmer in Vidarbha region of Maharashtra, India. Therefore, work on design and development of dryer for soybean drying has been started at Dr. PDKV, Akola. For the design of this dryer engineering properties of PDKV Amba variety of soybean was evaluated. Therefore, the engineering properties of soybean (variety PDKV Amba) and their relation with moisture content have been studied.

2. Materials and methods

The soybean cultivar, PDKV Amba, used for this study, was obtained from the Central Research Station, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola (India). Soybean grains were used to determine their engineering properties at various moisture contents. Prior to recording observation, soybean grains were cleaned manually. The initial moisture content of the soybean grains was measured using the oven-drying method at $105 \pm 5^\circ\text{C}$ for duration of 24 hours. Samples were moistened with a calculated quantity of water by using following equation (1) and conditioned to raise their moisture content to the desired three different levels. (Nimkar *et al.*, 2005) [9]

$$W_1(100 + M_2) = W_2(100 + M_1) \quad \text{..... (1)}$$

where: W_1 , W_2 = initial and final weight of soybean grain (g) and M_1 , M_2 = initial and final moisture content of soybean grain (%) on wet basis.

Subsequently, the samples were transferred into individual polyethylene bags, which were then sealed securely. The samples were kept at 5°C in a refrigerator for seven days to allow uniform moisture distribution throughout the grain. Before starting a test, the required quantity of grain was taken out of the refrigerator and allowed to warm up to the room temperature for about 2 h. (Singh *et al.*, 1996) [10]

To determine the dimensions, a random sample of one hundred soybean grains was selected. For each soybean grain three principal dimensions, namely length, width and thickness were measured using a vernier caliper having the least count of 0.01 mm. Arithmetic mean diameter, geometric mean diameter, roundness, sphericity, aspect ratio, surface area, projected area, volume, moisture content, thousand-grain weight, bulk density, true density, porosity, angle of repose of soybean grain were measured at different level of moisture content.

Determination of physical properties of soybean grain

The length (L) is the distance from the tip of the seed to the kernel crown. The width (W) is defined as the widest point, taken parallel to the flat surface of the kernel. The thickness (T) is the distance between the two opposite faces of the kernels described by Pordesimo *et al.* (1990) [11]. After taking the measurements, the shape parameters were calculated.

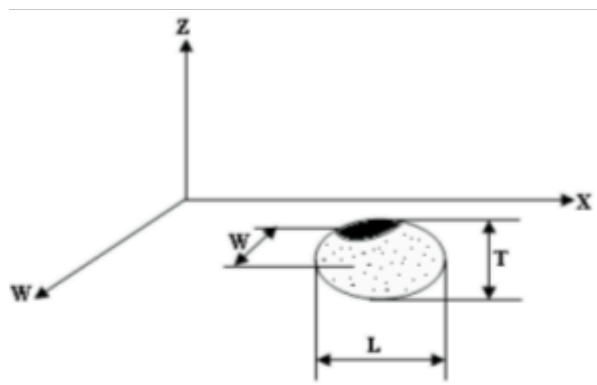


Figure 1. Characteristic dimensions of a soybean grain

Using these measurements, the following shape parameters were computed:

Arithmetic mean diameter (D_a)

The arithmetic mean diameter was determined as the average of the grain's three principal dimensions, using the formula from Baryeh (2002) [12]:

$$D_a = \frac{L+W+T}{3} \quad \text{..... (2)}$$

Where:

D_a = Arithmetic mean diameter (mm)

L, W, T = Length, width, thickness of the soybean grain (mm)

Geometric mean diameter (D_g)

The geometric mean diameter was determined by taking the cube root of the product of the three principal dimensions:

$$D_g = (LWT)^{1/3} \quad \text{..... (3)}$$

Where:

D_g = Geometric mean diameter (mm)

Roundness (R)

Roundness was calculated using the formula described by Baryeh (2002) [12].

$$R = \frac{\left(\frac{W}{L} + \frac{T}{L} + \frac{T}{W}\right)}{3} \quad \text{..... (4)}$$

Sphericity (ϕ)

Sphericity describes how closely the grain resembles a sphere and was calculated as per Mohsenin (1986) [13] and Baryeh (2002) [12]

$$\phi = \frac{(LWT)^{1/3}}{L} \quad \text{..... (5)}$$

Where:

ϕ = Sphericity (%)

Aspect ratio (R_a)

Aspect ratio, indicating the shape elongation, was computed using the formula by Omobuwajo *et al.* (1999) [14]

$$R_a = \frac{W}{L} \quad \text{..... (6)}$$

Where:

R_a = aspect ratio of grain

Surface area (S_a)

Surface area was calculated using the geometric mean diameter, as provided by Baryeh (2002) [12]

$$S_a = \pi D_g^2 \quad \text{..... (7)}$$

Where:

S_a = surface area of grain (mm^2)

Projected area (A_p)

The projected area was calculated using the empirical formula suggested by Mirzabe *et al.* (2013) [15]

$$A_p = \frac{\pi WL}{4} \quad \text{..... (8)}$$

Volume (V)

Volume was determined using a standard formula involving the geometric mean diameter, as per Mohsenin (1986) [13]

$$V = \frac{\pi}{6} D_g^3 \quad \text{..... (9)}$$

Where:

V = Volume of grain (mm^3)

Moisture Content Determination

Initially, the samples were cleaned by removing dust, debris, and broken grains. The moisture content of both the original and moistened samples was measured in triplicate using the hot air oven method at 105°C for 72 hours, following Bako *et al.* (2019) [16].

$$\text{Moisture content \% (wb)} = \frac{\text{Initial weight (g)} - \text{Final weight (g)}}{\text{Initial weight (g)}} \times 100 \quad \text{..... (10)}$$

Thousand-grain weight (M_{1000})

A set of 1,000 grains was counted from the cleaned sample and weighed using a Mettler electronic balance with 0.01 g precision. The measurement was repeated three times.

Bulk density (ρ_b)

Bulk density was assessed by filling a 20 ml test tube with soybean grains and weighing the contents using an electronic balance. The bulk density was determined by dividing the mass of the kernels by the volume of the container, as described by Garnayak *et al.* (2008) [17]. Bulk density was then calculated as:

$$\rho_b = \frac{M}{V} \quad \text{..... (11)}$$

Where:

ρ_b = Bulk density (kg/m^3)

M = Mass of grain (kg)

V = Volume of container (m^3)

True Density (ρ_t)

True density was determined by water displacement method. A known quantity of soybean grains was added into a 100 ml measuring cylinder containing 50 ml of distilled water. The rise in water level indicated the displaced volume. This test was repeated three times and the true density was calculated using (Pradhan *et al.*, 2013) [18].

$$\rho_t = \frac{M}{V} \dots\dots (12)$$

Where:

ρ_t = True density of soybean grain (kg/m^3),

M = Mass of soybean grain (kg)

V = Volume of displacement of water (m^3).

Porosity (ρ_o)

Porosity represents the percentage of air space between grains in a bulk sample and was calculated using equation (Mohsenin, 1986) [13]

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

= (13)

Where:

ρ_o = porosity of soybean grain (%),

ρ_b = bulk density of soybean grain (kg/m^3),

ρ_t = true density of soybean g(kg/m^3).

Angle of Repose (θ)

The angle of repose was determined by filling an open-ended cylinder (15 cm diameter, 30 cm height) placed at the center of a 70 cm diameter plate. After filling, the cylinder was lifted vertically to allow the grains to form a cone. The height (H) of the cone was measured, and the angle was computed using equation (Umogbai, 2009; Davies, 2009) [20, 19]

$$\theta = \tan^{-1}\left(\frac{2H}{D}\right) \dots\dots (14)$$

Where:

θ = Angle of repose (degrees)

H = Height of the grain cone (mm)

D = Diameter of the base (mm)

3. Results and discussion

The results of experiments for engineering properties of soybean grain are presented as follows.

1. Length, width and thickness

The average dimensions of soybean grain, namely length, width, thickness measured at different moisture content of 5.94, 15.02, 25.75

and 35.28 % (wb) are presented in Table 1. It was observed that the average length (L) of the soybean grain ranged from 7.26 to 7.62 mm, the width (W) ranged from 6.18 to 6.52 mm and the thickness (T) ranged from 5.16 to 5.52 mm, as the level of moisture content increased from 5.94 to 35.28 % (wb). As per the result we can say that the values of length, width and thickness increases as the level of moisture content increases. Similar results are reported for soybean by Kibar *et al.* (2008) [21] and Shirkole *et al.* (2011) [22], for maize by Sangamithra *et al.* (2016) [23], and for lentil by Amin *et al.* (2004) [24]. The relationships in Length (L), Width (W), Thickness (T) of soybean grain with respect to their moisture content (M) given using the following regression equation:

$$L = 7.144 + 0.013M \quad R^2 = 0.919 \quad (15)$$

$$W = 6.153 + 0.011M \quad R^2 = 0.912 \quad (16)$$

$$T = 5.052 + 0.012M \quad R^2 = 0.961 \quad (17)$$

where:

L , W and T = length, width and thickness (mm),

M = moisture content, (%) wb

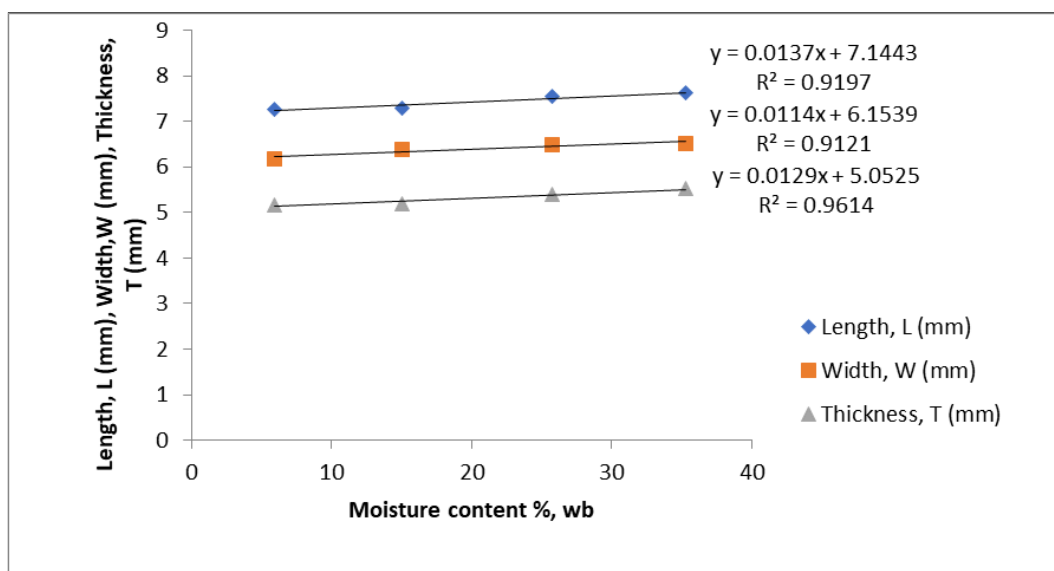


Figure 1. Effect of moisture content on length, width and thickness of soybean grain

3.2 Sphericity

The sphericity of soybean grains increased from 0.83 to 0.84 as the moisture content increased from 5.94% to 35.28% (wb). Similar results have been reported for soybean (Unde *et al.*, 1996) [25], vetch

seed (Yalcin *et al.*, 2004) [26] and moth gram (Nimkaret *et al.*, 2005) [9]. The regression equation between the sphericity and the moisture content was obtained as:

$$\phi = 0.831 + 0.0003M \quad R^2 = 0.579 \dots\dots (18)$$

where: S = sphericity, (%) and M = moisture content, (%) wb

3. Surface area

The surface area of the soybean grains increased from 114.12 mm² to 127.79 mm² as the moisture content increased from 5.94% to 35.28% (wb). Similar trend has been reported for guna seed (Aviara *et al.*,

1999) [3], for hemp seed (Sacilik *et al.*, 2003) [27], for soybean (Davies *et al.*, 2009) [28]. The relationship between the surface area and the moisture content was represented by the following equation:

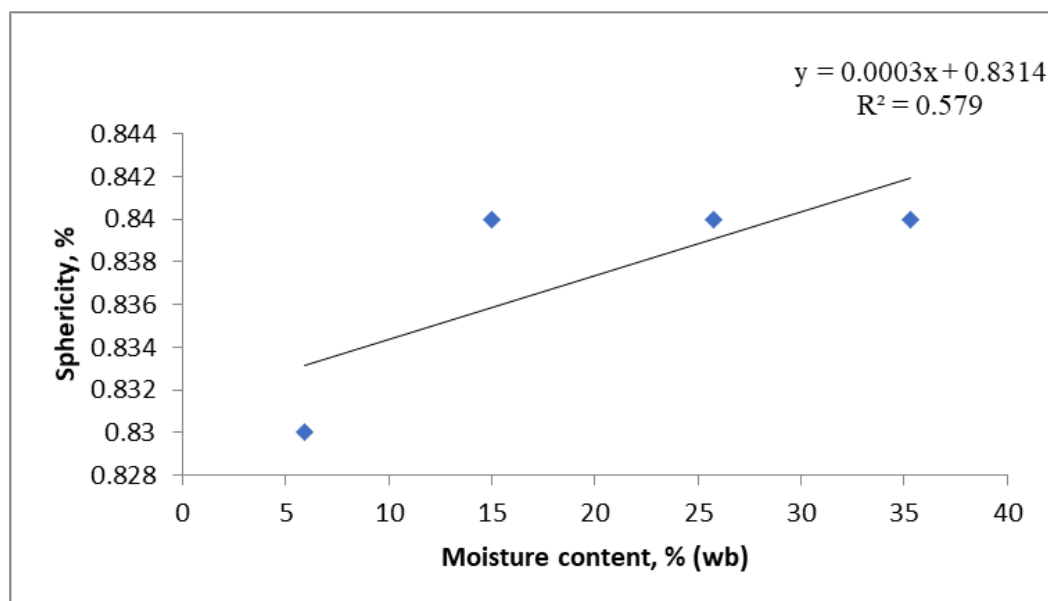


Figure 2. Effect of moisture content on sphericity of soybean grain

$$S_a = 110.9 + 0.487 M \quad R^2 = 0.985 \quad \text{..... (19)}$$

where: S = surface area, (mm²) and M = moisture content, (%)wb

3.4 Projected area

The projected area of soybean grain (Table 1) was increased from 35.22 to 39.06 mm², while the moisture content increased from 5.94 to 35.28 % (wb). Similar trends reported by Carman (1996) [29] for

lentil, Ogut (1998) [30] for white lupin and Tang *et al.* (1993) [31] for lentil. The relationship between the projected area and the moisture content was obtained as:

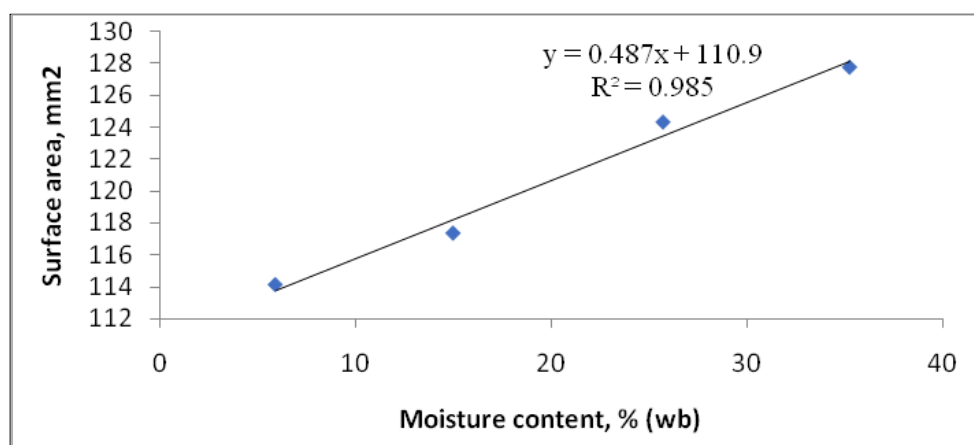


Figure 3. Effect of moisture content on surface area of soybean grain

$$A_p = 34.46 + 0.136 M \quad R^2 = 0.978 \quad \text{.....(20)}$$

where: A_p = projected area, (mm²) and M = moisture content, (%) wb

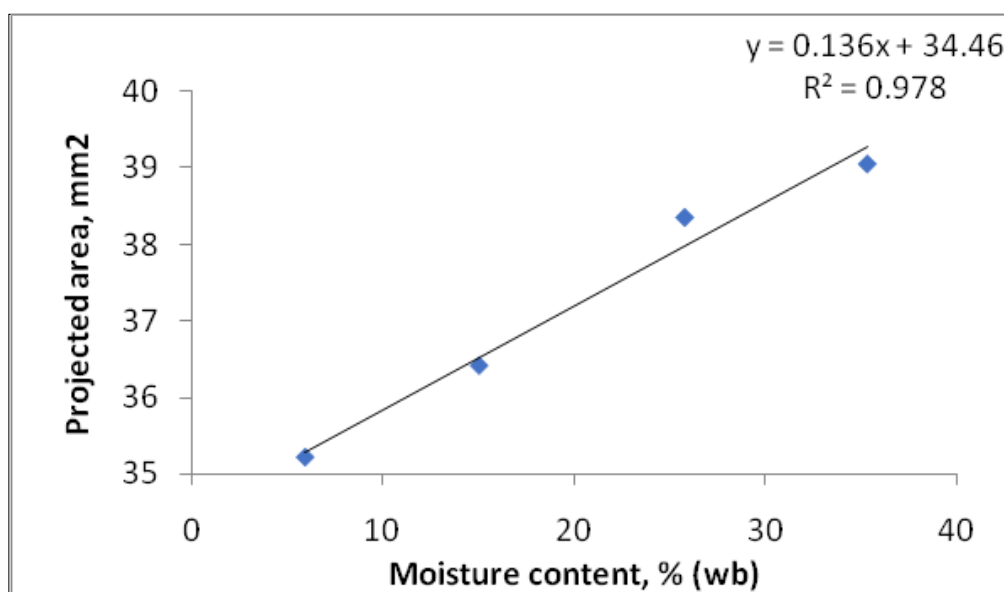


Figure 4. Effect of moisture content on projected area of soybean grains

3.5 Volume

The grain volume varied from 121.16 to 143.85 mm³ as the moisture content increased from 5.94 to 35.28 % (wb). The volumetric expansion observed may be added to moisture absorption which increases the axial dimension of the grain. (Davies *et al.*, 2011) [32]. Similar trend has been reported for pigeon pea (Obi *et al.*, 2014) [33], for

gram (Dutta *et al.*, 1988) [34], for soybean (Deshpande *et al.*, 1993), for moth gram (Nimkar *et al.*, 2005) [9]. The relationship between the volume and the moisture content was obtained as:

$$V = 115.8 + 0.807M \quad R^2 = 0.986 \quad (21)$$

where: V= volume, (mm³), M = moisture content, (%) wb

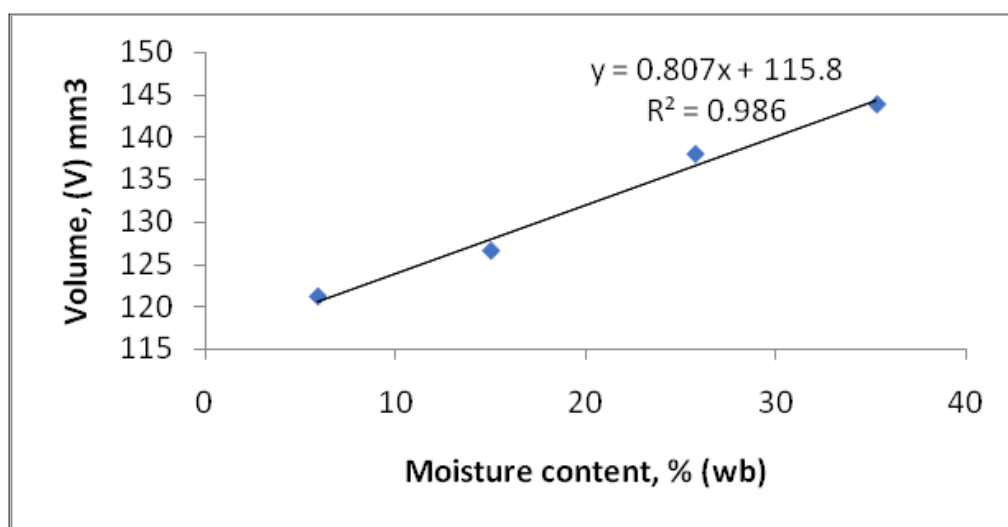


Figure 5. Effect of moisture content on volume of soybean grains

3.6 Thousand grain weight

The values of thousand grain weight varied from 144.20 to 167.07 g as the moisture content increased from 5.94 to 35.28 % (wb). This increase could be attributed to the moisture absorbed by the grain. Similar results of the effect of grain moisture on thousand grain weight reported by Nimkar *et al.*, (2005) [9] for moth gram, Kulkarni *et al.* (1993) [35], Deshpande *et al.*, (1993) and Shirkole *et al.*, (2011) [22] for soybean, Khan *et al.*, (2017) [36] for pigeon pea and Munde, (1999) [37] for black gram. The relationship between the thousand grain weight and the moisture content was obtained as below:

$$W = 0.835M + 137.3 \quad R^2 = 0.956 \quad (22)$$

where: W = weight (g), M = moisture content, (%) wb

3.7 Bulk density

The results of bulk density with increasing moisture content are shown in Table 1. The grain bulk density at different moisture levels varied from 781.19 to 648.99 kg/m³ with the moisture range of 5.94 to 35.28 % (wb) and indicated a decrease in bulk density with an increase in moisture content. The bulk volume of the grain sample expanded more significantly than the increase in its mass due to moisture absorption. Similar trend was found for green gram (Nimkar *et al.*, 2001) [38], soybean (Shirkole *et al.*, 2011) [22], moth gram (Nimkar *et al.*, 2005) [9], pigeon pea (Shepherd *et al.*, 1986) [39], Chickpea (Dutta *et al.*, 1988, Gupta and Prakash, 1990) [34]. The bulk density of soybean grain was found to bear the following relationship with moisture content:

$$\rho_b = 805.5 - 4.150M \quad R^2 = 0.936 \quad (23)$$

where: ρ_b = bulk density (kg/m³), M = moisture content, (%)wb

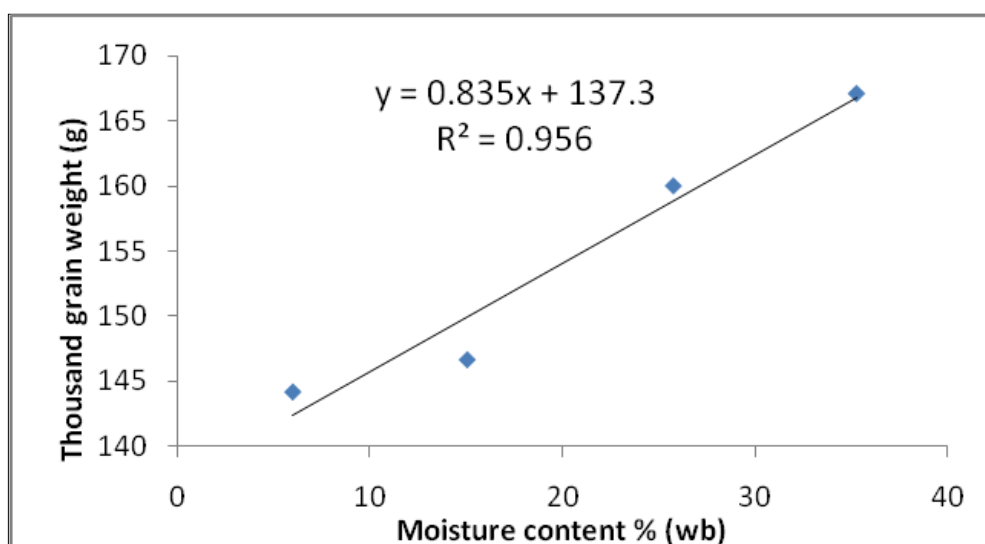


Figure 6. Effect of moisture content on thousand grain weight of soybean grains

8. True density

The true density decreased from 1000.66 to 994.73 kg/m³ when the moisture level increased from 5.94 to 35.28 % (wb) (Table 1). The results were similar to those reported for vetch seed (Yalcin *et al.*, 2004)

[26], soybean (Kibar *et al.*, 2008) [21], soybean (Davis and El-okene, 2009) [28], green gram (Nimkar *et al.*, 2001) [38], moth gram (Nimkar *et al.*, 2005) [9]. A regression equation is

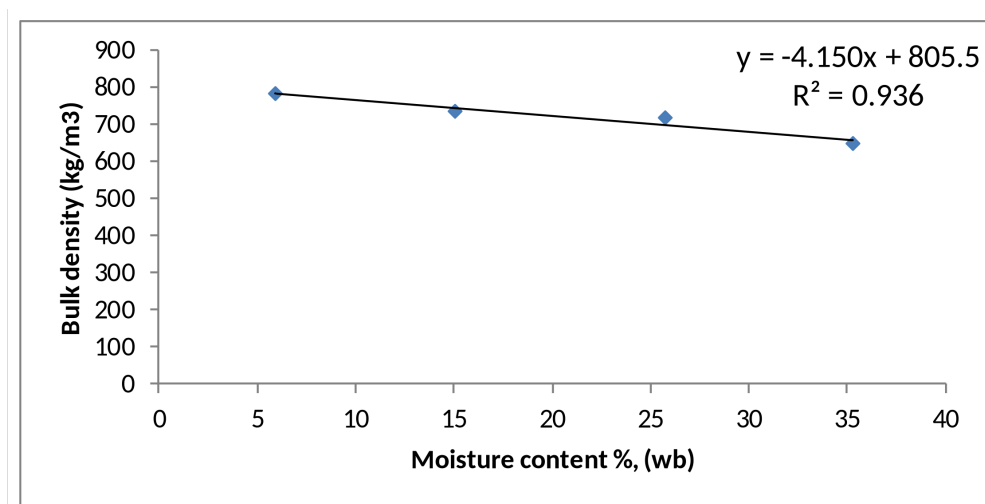


Figure 7. Effect of moisture content on bulk density of soybean grains

$$\rho_t = 1001 - 0.200M \quad R^2 = 0.999 \quad (24)$$

where: ρ_t = true density of soybean grains (kg/m³), M = moisture content, (%)wb

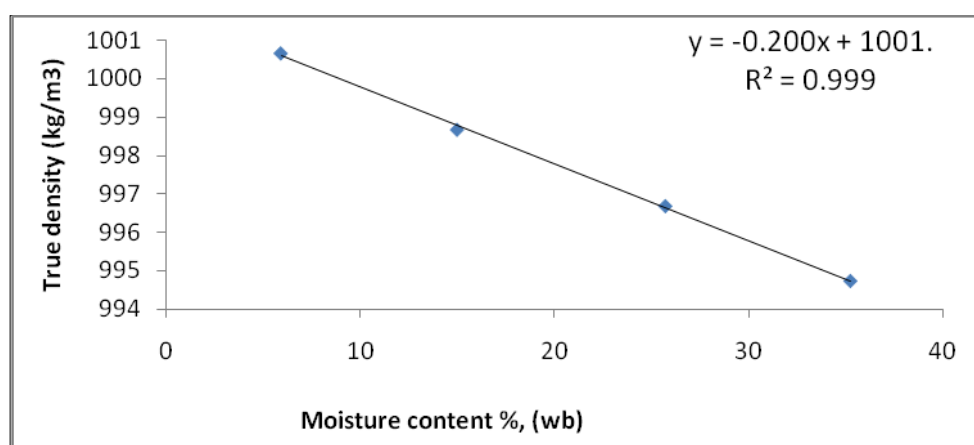


Figure 8. Effect of moisture content on true density of soybean grains

9. Porosity

The results obtained for change in porosity with moisture content are shown in Table 1. Porosity values of soybean grain were found to increase from 21.93 to 34.76 % with an increase in moisture content from 5.94 to 35.28% (wb). Similar observations of increase in bulk porosity with increase in grain moisture content have been reported

for sunflower seed by Gupta and Das, (1997), for vetch seed by Yalcin *et al.*, (2004) [26], for green gram by Nimkar *et al.*, (2001) [38], for moth gram by Nimkar *et al.*, (2005) [9], for soybean by Tavakoli *et al.*, (2009) [40]. The relationship between porosity and the moisture content of the grain was obtained

$$P_o = 19.56 + 0.401 M \quad R^2 = 0.932 \quad \dots (25)$$

where: P_o = porosity (%), M = moisture content, (%) wb

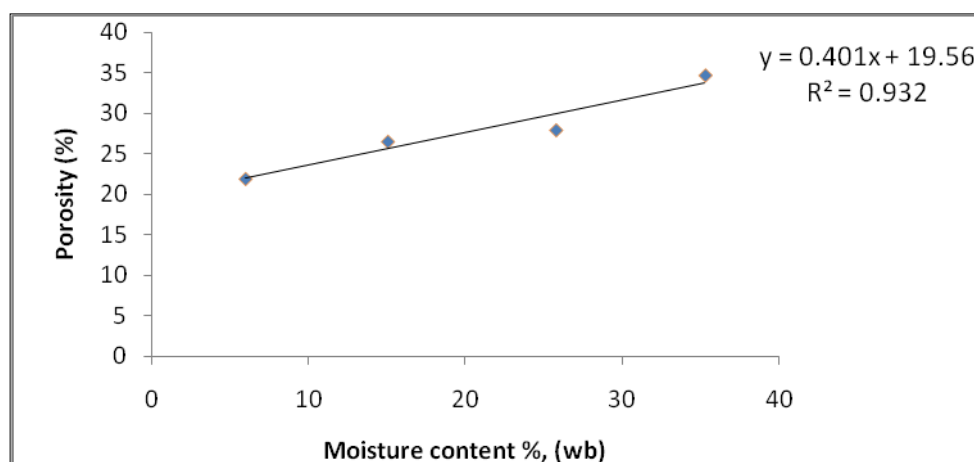


Figure 9. Effect of moisture content on porosity of soybean grains

3.10 Angle of repose

The angle of repose of soybean grain at different moisture contents are shown in Table 1. It increased from 25.34 to 27.03 ° in the moisture range of 5.94 to 35.28 % (wb). 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). Similar observations reported by Tavakoli *et al.*, (2009) [40] for soybean, Shepherd *et al.*, (1986) [39]

for pigeon pea, Amin *et al.*, (2004) [24] for lentil, Gupta *et al.* (1992) [41] for safflower, Munde (1999) [37] for black gram and Dutta *et al.*, (1988) [34] for chickpea. The values of the angle of repose (θ) for soybean grain bear the following relationship with its moisture content:

$$\theta = 25.18 + 0.054 M \quad R^2 \text{ of } 0.938 \quad \dots (26)$$

where: θ = angle of repose (degree), M = moisture content, (%) wb

The values presented are the mean of determination $\pm$ standard deviation

Table 1. Physical properties of soybean grains at different moisture content (Variety- PDKV Amba)

Moisture Content % (wb)	M1 (5.94)	M2 (15.02)	M3 (25.75)	M4 (35.28)
Length, L (mm)	7.26 $\pm$ 0.13	7.28 $\pm$ 0.26	7.54 $\pm$ 0.29	7.62 $\pm$ 0.29
Width, W (mm)	6.18 $\pm$ 0.27	6.37 $\pm$ 0.23	6.48 $\pm$ 0.20	6.52 $\pm$ 0.19
Thickness, T (mm)	5.16 $\pm$ 0.14	5.20 $\pm$ 0.28	5.39 $\pm$ 0.14	5.52 $\pm$ 0.23
Arithmetic Mean Diameter (mm)	6.20 $\pm$ 0.14	6.28 $\pm$ 0.22	6.47 $\pm$ 0.14	6.56 $\pm$ 0.17
Geometric Mean Diameter (mm)	6.03 $\pm$ 0.13	6.11 $\pm$ 0.22	6.29 $\pm$ 0.13	6.38 $\pm$ 0.16
Roundness	0.779 $\pm$ 0.02	0.802 $\pm$ 0.03	0.803 $\pm$ 0.02	0.810 $\pm$ 0.03
Sphericity (%)	0.83 $\pm$ 0.01	0.84 $\pm$ 0.02	0.84 $\pm$ 0.02	0.84 $\pm$ 0.02
Aspect ratio	0.851 $\pm$ 0.04	0.875 $\pm$ 0.03	0.861 $\pm$ 0.04	0.857 $\pm$ 0.03
Surface area, (mm ²)	114.12 $\pm$ 5.03	117.36 $\pm$ 8.35	124.34 $\pm$ 5.34	127.79 $\pm$ 6.39
Projected area, (mm ²)	35.22 $\pm$ 1.85	36.42 $\pm$ 2.30	38.36 $\pm$ 1.96	39.06 $\pm$ 2.20
Volume, (V) mm ³	121.16 $\pm$ 8.03	126.56 $\pm$ 13.73	137.98 $\pm$ 9.03	143.85 $\pm$ 10.93
Thousand grain wt. (g)	144.20 $\pm$ 0.20	146.67 $\pm$ 1.98	160.00 $\pm$ 1.31	167.07 $\pm$ 2.57
Bulk Density (kg/m ³)	781.19 $\pm$ 2.06	733.57 $\pm$ 2.80	717.94 $\pm$ 1.58	648.99 $\pm$ 3.66
True Density (kg/m ³)	1000.66 $\pm$ 1.15	998.67 $\pm$ 1.15	996.68 $\pm$ 1.14	994.73 $\pm$ 1.15
Porosity (%)	21.93 $\pm$ 0.13	26.55 $\pm$ 0.26	27.97 $\pm$ 0.13	34.76 $\pm$ 0.43
Angle of repose (°)	25.34 $\pm$ 1.00	26.25 $\pm$ 0.48	26.63 $\pm$ 0.56	27.03 $\pm$ 0.38

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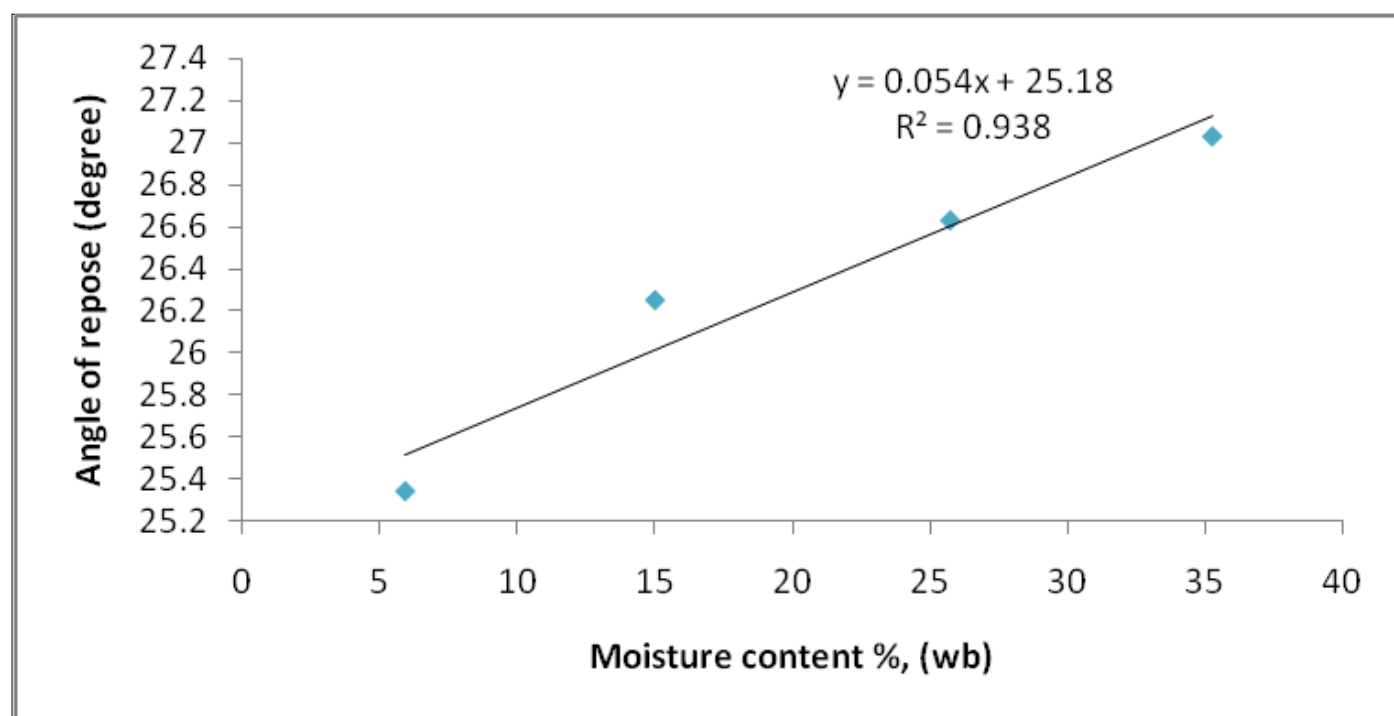


Figure 10. Effect of moisture content on angle of repose of soybean grains

4. Conclusions

This study analyzed the engineering properties of soybean grain (Amba variety) across a significant range of moisture content (5.94% to 35.28% wb). The findings demonstrate a clear and consistent relationship between moisture level and grain characteristics. Specifically, linear dimensions, roundness, sphericity, aspect ratio, surface and projected areas, volume, thousand grain weight, porosity, and angle of repose were found to increase with increasing moisture content. However, as moisture content increased, both bulk density and true density were found to decrease. The established relationships and the specific range of values determined in this research are critical for engineers and manufacturers involved in the design and optimization of machinery and systems for the effective handling, processing, and storage of soybean seeds.

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