Effect of moisture content on the physical properties of mung bean varieties grown in Abakaliki, Ebonyi State, Nigeria

Ikegwu Onyekachi John*, Onuedo Gladys Ifeyinwa

(Department of Food Science and Technology, Ebonyi State University, PMB 053, Abakaliki, Nigeria)

Abstract**:** Some selected physical properties of five varieties of mung bean grain seeds (EBSUpant1, EBSUpant2, EBSUpant3, EBSUpant4, and EBSUpant5) grown by the Department of Crop and Landscape Management, Ebonyi State University, Abakaliki, such as geometric properties (linear dimensions, sphericity, geometric and arithmetic mean diameters and surface area), gravimetric properties (true density, bulk density and porosity) and frictional properties (angles of repose and coefficient of friction) were determined as a function of moisture content in the range of 8.59% to 21.48%, 8.35% to 20.90,% 8.48% to 21.2%0, 8.69% to 21.73%, and 8.88% to 22.20% (w.b.), respectively. The results showed that the mean values of all geometric properties except sphericity, increased with increasing moisture content. EBSUpant3 had the highest value of geometric properties among the mung bean varieties. The arithmetic and geometric diameters were lower than the length and higher than the width and thickness for the five varieties studied. Among the varieties, EBSUpant2 had the highest values of gravimetric properties, in all moisture contents studied. The maximum and minimum values of bulk density were obtained for EBSUpant1 (712.08 kg m^{-3}) and EBSUpant4 (650.05 kg m^{-3}). The angles of repose ranged from 25.72 to 29.88 °, 25.64 to 29.70 °, 25.68 to 29.79 °, 25.75 to 29.96 ° and 25.81 to 30.12 ° for EBSUpant1, EBSUpant2, EBSUpant3, EBSUpant4, and EBSUpant5 respectively. At all moisture contents, the coefficient of static friction was the greatest against galvanized iron sheet (0.378-0.435), followed by plywood (0.362-0.403), and the least for stainless steel sheet (0.352-0.395). Among mung bean seed varieties, EBSUpant3 and EBSUpant5 showed the least and the greatest static coefficients of friction in all moisture contents studied, respectively.

Keywords: mung bean seed: geometric properties, gravimetric properties, frictional properties

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1 Introduction

Food legumes like beans, peas, mung bean and lentils belong to the family "*Leguminosae*", also called "*Fabaceae*". They are mainly grown for their edible seeds, and thus also named as grain legumes. They play an important role in human nutrition because they are rich source of protein, calories, certain minerals and vitamins (Deshpande, 1992).

Mungbean is used in several food products, both as a whole seed and in processed form. Whole seeds are sold for use in soup mixes or to produce bean sprouts for salads. Mungbeans flour is used for soup bases or sometimes for bean flour. Like most legumes, mung beans are relatively high in protein, around 25% of the seed by weight. The amino acid profile of mung beans, similar to other beans, is complementary to cereal grains.

The marketing values of agricultural product such as mung bean depend in its physical qualities after the

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***Corresponding author: Ikegwu Onyekachi John,** Department of Food Science and Technology, Ebonyi State University, PMB 053, Abakaliki, Nigeria. E-mail: ikegwukachi@gmail.com.

harvesting. To achieve this, the knowledge of the physical properties of mung bean is of fundamental importance during the harvesting, transporting and design of equipment used in post harvesting processing operations of these products (Ghadge and Prased, 2012). Several researchers (Owolarafe et al., 2005; Dash et al., 2008; Naderiboldaji et al., 2008) studied the physical properties of different agricultural products for the above purpose. These researchers determined the size and shape of the investigated products by measuring the three principal axial dimensions. The porosity and specific gravity are important for studies involving heat and mass transfer and air movement through the bulk grain. The specific gravity could be defined as the ratio of the mass of a body to its volume. This concept applied to the individual grain, it determines the real specific gravity of the individual grain. When this concept is applied to the bulk grain determines the bulk density. According to Mohsenin (1986), porosity is defined as the ratio of the inter-granular void space volume and the volume of the bulk grain. The volume of seed was calculated from the arithmetic mean, geometric mean and equivalent sphere effective diameters (Dutta et al., 1988). Water displacement method was used by a number of investigators (Oje and Ugbor 1991; Joshi et al., 1993) in determining true density. The inclined plane method (Aviara et al., 2005) was commonly used by investigators in studying the coefficient of friction of agricultural products on different structural surfaces. Dutta et al. (1988) and Aviara et al. (1999) used a specially constructed box with removable front panel to determine the angle of repose of gram and guna seeds.

The static and dynamic friction coefficients, such as grains on the equipment wall and on the silo wall surfaces are necessaries and fundamentals for a rational and safe design of grain moving, processing and storage equipment. (Ghadge et al., 2008; Mohsenin, 1986). This property develops an important role on silo wall pressure and grain flowing behaviours. The friction coefficient is defined as the ratio of the friction forces (forces due to the resistance of movement) to the normal force on surface of the material used in the wall. For biological products, according to Mohsenin (1986), two types of friction coefficient are considered; the static coefficient determined by the force capable to initiate the movement and the dynamic coefficient determined by the force needed to maintain the movement of the grains in contact with the wall surface which depends on the type and nature of the material in contact.

Nigeria and indeed Ebonyi State is not known for mung bean production. The Department of Crop Science and Land Scape Management, Ebonyi State University, Abakaliki, Nigeria, have introduced new varieties of mung bean. The physical properties of the new varieties of mung bean introduced by the Department of Crop Science and Land Scape Management, Ebonyi State University, have not been studied. Therefore, there is need to evaluate some moisture dependent physical properties of five new varieties of mung bean seeds grown in Abakaliki, Ebonyi State, Nigeria, so as to design a machine suitable for handling, dehulling, and other processes involved in the field of post-harvest technology. This basic information of this study will be of value not only to engineers but also Food Scientists, Processors of plant and animal breeders etc.

2 Material and methods

2.1 Sample preparation

A bulk quantity of selected mung bean seed variety EBSUpant1, EBSUpant2, EBSUpant3, EBSUpant4, and EBSUpant5 were obtained from the Department of Crop Science and Landscape Management, Ebonyi State University, Abakaliki, Nigeria. The seeds were cleaned manually to remove all foreign matter such as dust, dirt, stones and chaff as well as immature, broken grains. The initial moisture content of the seed samples was measured following a standard oven method (AOAC, 2002). To obtain seed samples with higher moisture contents, the seeds were conditioned to four desired moisture contents by adding calculated amounts of distilled water on the grains using the rewetting formula (Equation 1). The samples were then poured into 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 distribute uniformly throughout the sample. Before starting a test, the required quantity of the grain was taken out of the refrigerator and allowed to warm up to the room temperature for about 2 h (Singh and Goswami, 1996). All the physical properties of the grains were determined at four moisture levels of 8.59%, 12.89%, 17.18%, and 21.48% w.b. for EBSUpant1: 8.36%, 12.54%, 16.72%, and 20.90% w.b. for EBSUpant2: 8.48%, 12.72%, 16.96%, and 21.20% w.b. for EBSUpant3: 8.69%, 13.04%, 17.38%, and 21.73% w.b. for EBSUpant4 and 8.88%, 13.32%, 17.76%, and 22.20% w.b. for EBSUpant5, with five replications at each level.

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

where, W_w is the mass of water added (g), W_t is the total seeds mass (g), M_i is the initial moisture content of sample (w.b.%) and M_f is the desired moisture content of sample (w.b.%).

2.2 Determination of spatial dimensions of the grains

To determine the average size of the grain, 20 grains before and after conditioning were randomly picked and their three axial dimensions namely, major *L*, medium *W* and minor *T* were measured using a digital caliper with a sensitivity of 0.01 mm. The longest dimension of the grain was clipped with a venier caliper and the readings were taken to obtain the length value of the grain. The side of the grain was clipped with a venier caliper and the readings taken for the width value. Finally, the caliper was used to clip the dimension that opposes the length and width of the grain to get the thickness of the grain.

2.3 Determination of arithmetic mean, geometric mean and sphericity of the grains

The average diameter of grain was calculated by using the arithmetic mean and geometric mean of the three axial dimensions. The arithmetic mean diameter D_a (mm), geometric mean diameter D_g (mm) and sphericity Φ (decimal) of the grain were calculated by using the following relationships (Mohsenin, 1986; Unal et al., 2006).

$$D_a = (L+W+T)/3 \tag{2}$$

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

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

where, L is the length of grain (mm), W is the width of grain (mm) and T is the thickness of grain (mm).

2.4 Surface area determination

The surface area was calculated using the relationship (Equation 5) by McCabe et al. (2005) as:

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

where, D_g is the geometric mean dimension (mm) and S_a is the surface area (mm^2).

2.5 Determination of gravimetric properties

2.5.1 Thousand grain mass

The thousand grain mass was determined by means of a digital electronic balance having an accuracy of 0.001 g. This was carried out by counting 100 grains and weighing them in an electronic balance and then multiplying by 10 to give the mass of 1000 grains (Gayin et al., 2009).

2.5.2 Determination of bulk and true densities

The methods described by Mohsenin (1986) and Singh and Goswami (1996) were used to determine the bulk and true (kernel) densities of mung bean grain at different moisture levels. The bulk density was determined by filling a circular container of 500 ml in volume with the grain from a height of 150 mm at a constant rate and then weighing the contents. No separate manual compaction of grains was done. The bulk density was calculated from the mass of the grains and the volume of the container.

The true density was determined using the toluene (C_7H_8) displacement method. Toluene was used in place of water because it is absorbed by seeds to a lesser extent. The volume of toluene displaced was found by immersing a weighed quantity of grain in the toluene using a measuring cylinder.

$$\rho_t = \frac{Mass\ of\ mung\ bean\ grain\ (g)}{volume\ of\ toluene\ displaced\ (mL)} \qquad (6)$$

where, ρ_t is the true density (g mL^{-1}).

2.5.3 Determination of porosity

The porosity of mung bean at various moisture contents was calculated from bulk and true densities using the relationship given by Mohsenin (1986) as follows:

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \qquad (7)$$

where, ε is the porosity (%) and ρ_b is the bulk density (g mL^{-1}).

2.6 Determination of frictional properties

2.6.1 Determination of angle of repose

The angle of repose was determined by using a topless and bottomless cylinder of 10 cm diameter and 15 cm height. The cylinder was placed on a table and filled it with grains and raised slowly until it forms a cone. The diameter and height of cone was recorded. The angle of repose, θ was calculated by using the formula (Tunde-Akintunde and Akintunde, 2007) as:

$$\theta = tan^{-1}\,({}^{2H}/_{D}) \qquad (8)$$

where, θ is the angle of repose (deg.), H is the height (mm) and D is the diameter of the cone (mm).

2.6.2 Determination of static coefficient of friction

The static coefficient of friction of mung bean against three different structural materials, namely galvanized iron sheet, stainless steel, and plywood was determined. A polyvinylchloride cylindrical pipe of 50 mm diameter and 100 mm height was placed on an adjustable tilting plate, faced with the test surface and filled with the grain sample. The cylinder was raised slightly so as not to touch the surface. The structural surface with the cylinder resting on it were raised gradually with a screw device until the cylinder just started to slide down and the angle of tilt was read from a graduated scale (Singh and Goswami, 1996). The coefficient of friction μ was calculated from the following relationship:

$$\mu = \tan\alpha \qquad (9)$$

where, α is angle of inclination.

2.7 Statistical analysis

All the data generated were subjected to a One-Way Analysis of Variance (ANOVA) in CRD, and the Duncan's Multiple Range test were used to separate the mean using SPSS software package (Version, 20.0). Significance was accepted at $p<0.05$, unless otherwise specified.

3 Results and discussion

3.1 Spatial dimensions, diameters, surface areas, volume, and sphericity of mung bean varieties

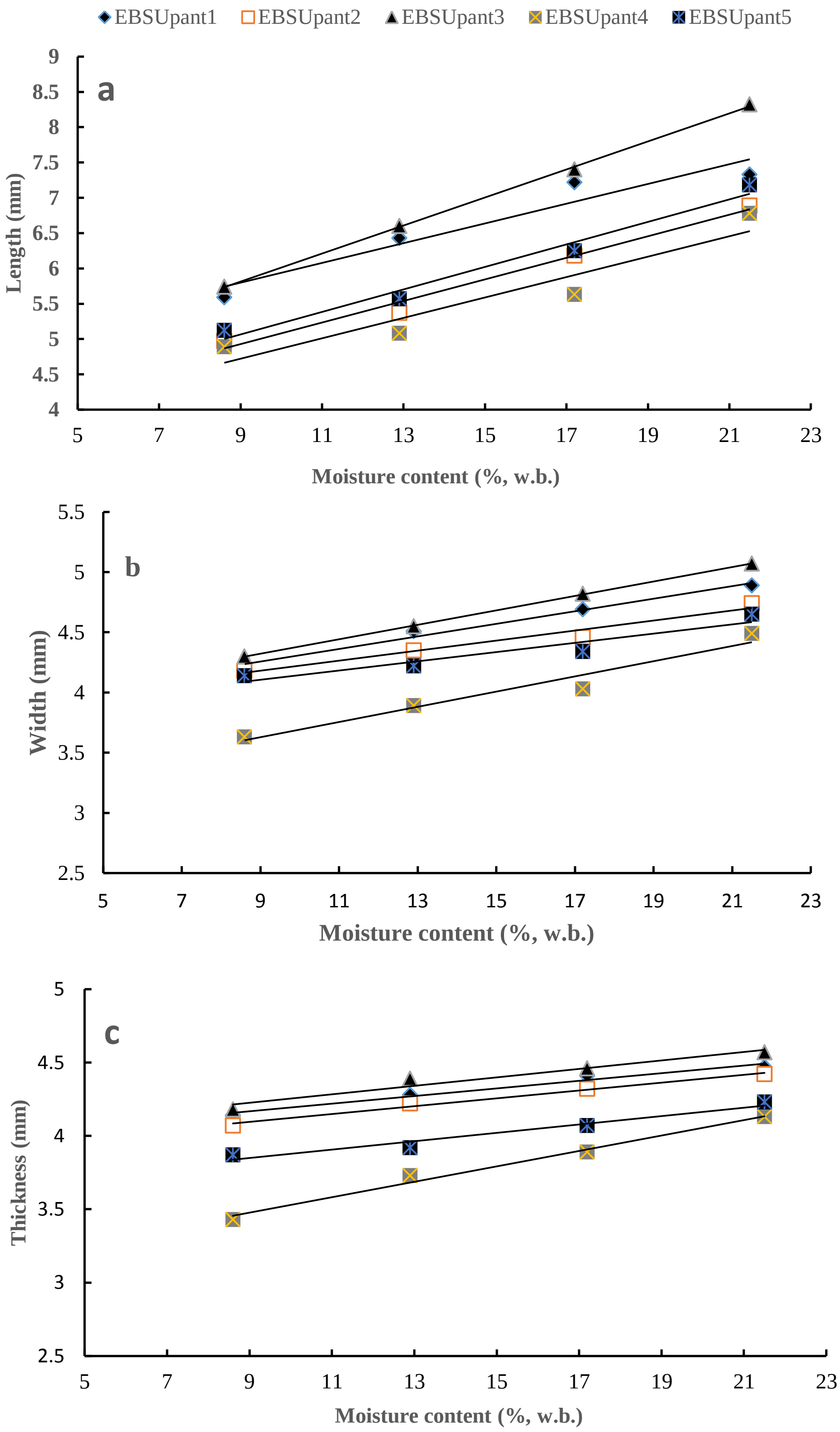
3.1.1 Spatial dimensions

The results of the axial dimensions (length, width and thickness) of mung bean seeds at different moisture contents are shown in Figure 1. As it can be seen, these parameters for all five mung bean seed varieties increased with increase in moisture content. Mean values of length ranged from 5.59 to 7.33 mm, 4.97 to 6.89 mm, 5.74 to 8.32 mm, 4.89 to 6.78 mm, and from 5.12 to 7.18 mm. The width varied from 4.20 to 4.89 mm, 4.18 to 4.74 mm, 4.30 to 5.07 mm, 3.63 to 4.49 mm, and 4.14 to 4.65 mm, whereas the thickness values were between 4.14 to 4.47 mm, 4.07 to 4.42 mm, 4.18 to 4.57 mm, 3.43 to 4.13 mm, and 3.87 to 4.23 mm for the EBSUpant1, EBSUpant2, EBSUpant3, EBSUpant4 and EBSUpant5 varieties, respectively.

The increase in the linear dimensions could be due to an expansion of the grains as a result of the moisture addition. The length, width and thickness dimensions recorded significant differences at 5% with the highest occurring between 20.90% and 22.20% w.b. for all the varieties studied. Ozturk et al. (2009) and Tavakoli et al. (2011) made similar findings for the common bean and soy bean respectively.

3.1.2 Arithmetic and geometric diameters

Table 1 shows the mean value and standard error of geometric and arithmetic diameters, of mung bean seeds of five varieties at different moisture contents in the range of 8.35% to 22.20% (w.b.).



(a) length, (b) width, (c) thickness

Figure 1 Dimensional properties of mung bean seeds as a function variety and moisture content

As it can be seen, significant increase (p<0.05) were observed among geometric and arithmetic diameters with increase in moisture content. These differences could be the result of the individual properties of mung bean seed varieties, environmental and growth conditions. The value of geometric mean diameter of mung bean seeds was the greatest for EBSUpant3 (4.690 to 5.777 mm), then EBSUpant1 (4.598 to 5.431 mm), EBSUpant2 (4.389 to 5.246 mm), EBSUpant5 (4.345 to 5.208 mm) and the lowest for the EBSUpant4 (3.934 to 5.010 mm). In addition, as it can be seen in Table 1, the variation of arithmetic mean diameter of mung bean seeds for EBSUpant1, EBSUpant2, EBSUpant3, EBSUpant4 and EBSUpant5 varieties ranged from 4.643 to 5.563, 4.410 to 5.350, 4.740 to 5.987, 3.983 to 5.133, and 4.377 to 5.353 mm, as moisture content increased from: 8.59% to 21.48%, 8.35% to 20.90%, 8.48% to 21.20%, 8.69% to 21.73%, and 8.88% to 22.20% (w.b.), respectively. The arithmetic and geometric diameters were lower than the length and higher than the width and thickness for the five varieties studied.

3.1.3 Sphericity

The values of sphericity were calculated individually (by Mohsenin method) using the data on geometric mean diameter and the major axis (L) of the grain and the results obtained are presented in Figure 2.

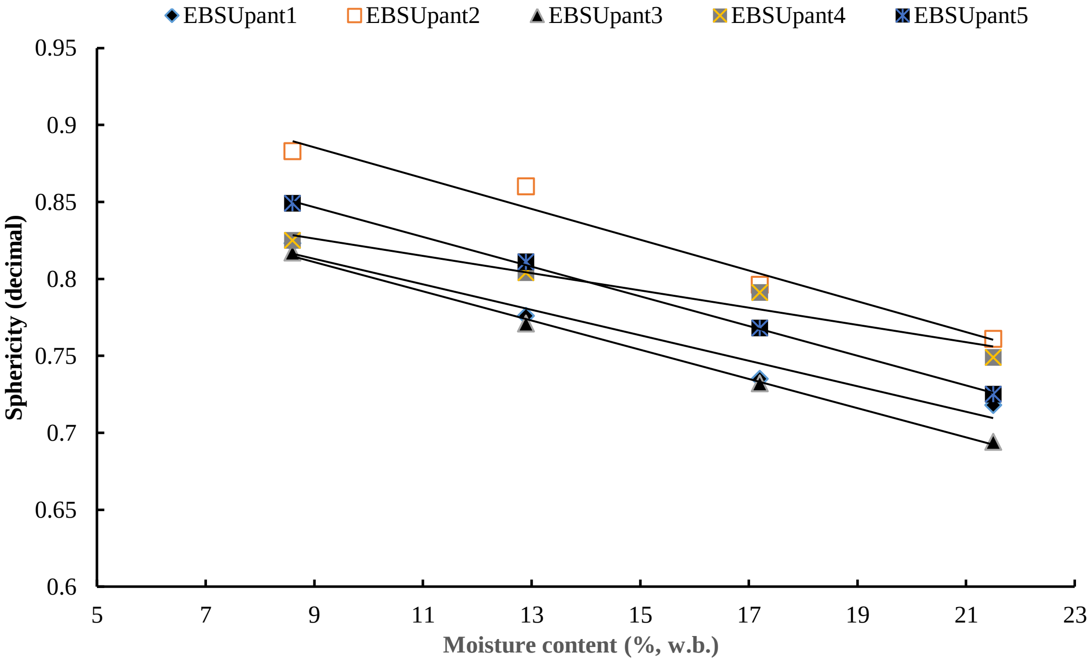


Figure 2 Effect of moisture content on sphericity of five mung bean seed varieties

The results indicated that the sphericity of the grains decreased from 0.823 to 0.741, 0.883 to 0.761, 0.817 to 0.694, 0.804 to 0.739, and 0.849 to 0.725 in the specified moisture levels for EBSUpant1 (8.59% to 21.48%), EBSUpant2 (8.35% to 20.90%), EBSUpant3 (8.48% to 21.20%), EBSUpant4 (8.69% to 21.73%), and EBSUpant5 (8.88% to 22.20%) w.b. respectively. EBSUpant3 had the least sphericity value among all the mung bean seed varieties studied. The decrease in all the varieties suggests a departure from the spherical shape as the seed moisture content increased from 8.35 to 22.20% (w.b.). Significant differences (p<0.05) were recorded for sphericity between all means with the highest occurring at the lowest moisture content of all the varieties studied. Kibar and Öztürk (2008) also found the sphericity of soybean to linearly decrease with increasing moisture content.

Table 1 Mean and standard error (Mean ± SE) for geometric and arithmetic diameters of mung bean seed varieties as a function of moisture content

Variety	M_c (%, w.b.)	D_a (mm)	D_g (mm)
EBSUpant1	8.59	$4.643^d \pm 0.28$	$4.598^c \pm 0.51$
	12.89	$5.073^c \pm 0.54$	$4.988^b \pm 0.28$
	17.18	$5.440^b \pm 0.29$	$5.305^a \pm 0.28$
	21.48	$5.563^a \pm 0.40$	$5.431^a \pm 0.17$
EBSUpant2	8.35	$4.410^d \pm 0.42$	$4.389^d \pm 0.41$
	12.54	$4.650^c \pm 0.41$	$4.619^c \pm 0.40$
	16.72	$4.990^b \pm 0.29$	$4.920^b \pm 0.29$
	20.90	$5.350^a \pm 0.17$	$5.246^a \pm 0.17$
EBSUpant3	8.48	$4.740^d \pm 0.34$	$4.690^d \pm 0.35$
	12.72	$5.180^c \pm 0.39$	$5.089^c \pm 0.34$
	16.96	$5.560^b \pm 0.25$	$5.418^b \pm 0.26$
	21.20	$5.987^a \pm 0.56$	$5.777^a \pm 0.52$
EBSUpant4	8.69	$3.983^d \pm 0.18$	$3.934^c \pm 0.40$
	13.04	$4.233^c \pm 0.41$	$4.193^c \pm 0.18$
	17.38	$4.517^b \pm 0.19$	$4.452^b \pm 0.19$
	21.73	$5.133^a \pm 0.55$	$5.010^a \pm 0.55$
EBSUpant5	8.88	$4.377^c \pm 0.27$	$4.345^c \pm 0.40$
	13.32	$4.570^c \pm 0.30$	$4.517^b \pm 0.29$
	17.76	$4.887^b \pm 0.44$	$4.797^b \pm 0.42$
	22.20	$5.353^a \pm 0.35$	$5.208^a \pm 0.37$

3.1.4 Surface area

The surface area of mung bean seed of five varieties at different moisture contents in the range of 8.35 to 22.20 is presented in Figure 3. There was a linear increase for surface area with increasing moisture as seen in Figure 3.

From the figure, the value of surface area (by McCabe) was the greatest for EBSUpant3 (69.103 to 104.847 mm^2), then followed by EBSUpant1 (66.418 to 92.664 mm^2), EBSUpant2 (60.518 to 86.458 mm^2), EBSUpant5 (59.310 to 85.210 mm^2) and the lowest for EBSUpant4 (48.620 to 78.854 mm^2). Increases observed in the surface area could be due to increase in the axial dimensions as a result of moisture increase. Similar findings were observed by Davies and Zibokere (2011) and Seifi and Alimardani (2010) for three cowpea varieties with increasing moisture content.

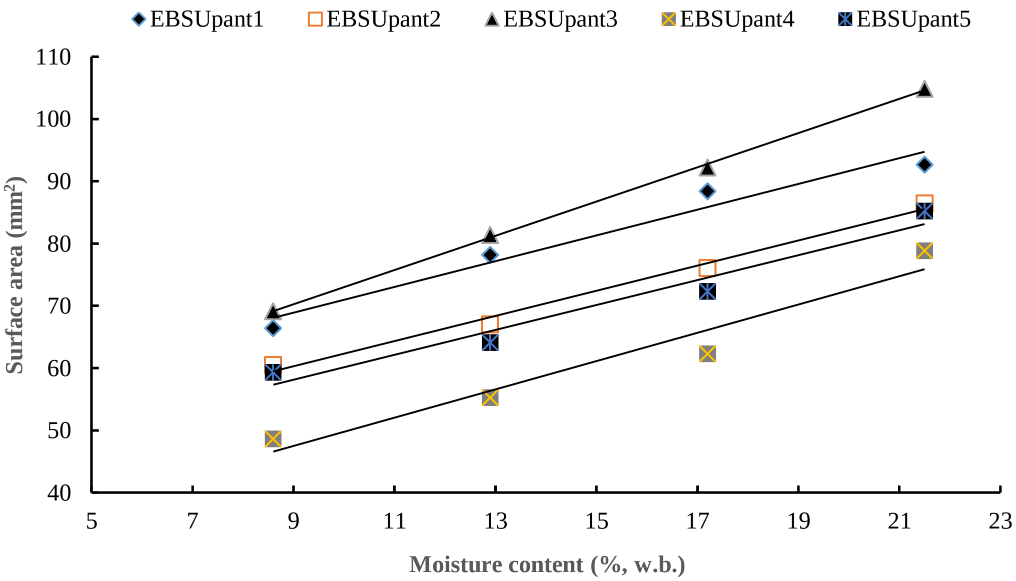


Figure 3 Effect of moisture content on surface area of five mung bean seed varieties

3.1.5 Grain volume

The results of the grain volume of mung bean seeds at different moisture contents are shown in Figure 4. As it can be seen, the grain volume for all five mung bean seed varieties increased with increase in moisture content.

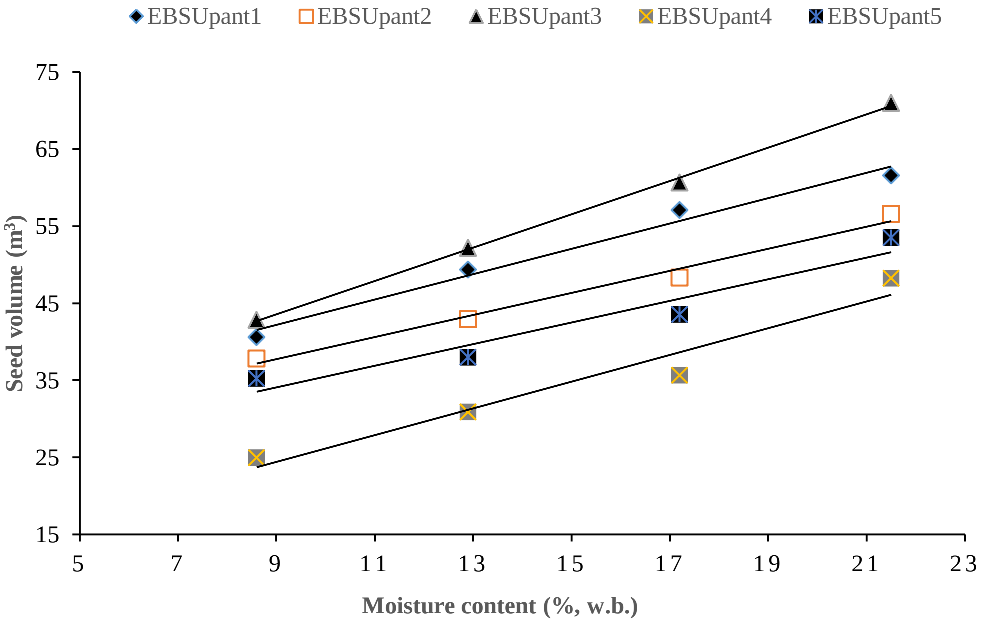


Figure 4 Effect of moisture content on seed volume of five mung bean seed varieties

Furthermore, the results showed that grain volume of seed varieties was the lowest for EBSUpant4 (24.937 to 48.232 m^3), followed by EBSUpant5 (35.258 to 53.495 m^3), EBSUpant2 (37.836 to 56.587 m^3), then EBSUpant1 (40.583 to 61.587 m^3) and the greatest was obtained for EBSUpant3 (42.826 to 71.009 m^3), as moisture content increased from 8.69% to 21.73%, 8.88% to 22.20%, 8.35% to 20.90%, 8.59% to 21.48%, and 8.48% to 21.20% (w.b.) respectively. This is explained by the increase in the grain dimensions as the grain moisture content increase. The change was significant at 5% level of significance. Linear increases in volume with increase in grain moisture content have been observed by Gharib-Zahedi et al. (2010) for black cumin (*Nigella sativa L.*)

seeds.

Regression equations and their coefficients of determination (R^2) obtained for principal dimensions, geometric and arithmetic mean diameters, and sphericity, surface area and grain volume of mung bean seeds as a function of moisture content are presented in Tables 2 and 3. It can be observed that all these physical properties for different varieties of mung bean seeds increased linearly with increase in moisture content. These linear behaviours are in accordance with similar results reported in literature for almond (Aydin, 2003) and mung bean (Unal et al., 2008).

Table 2 Equations representing relationship between length, width, thickness, geometric mean and arithmetic mean diameters and moisture content (M_c) for different varieties of mung bean seed

Variety	M_c (% w.b.)	Equation	R^2
EBSUpant1	8.59 – 21.48	$L = 0.120M_c + 4.539$	0.921
		$W = 0.045M_c + 3.785$	0.983
		$T = 0.022M_c + 3.933$	0.972
		$D_a = 0.062M_c + 4.085$	0.951
		$D_g = 0.056M_c + 4.094$	0.956
EBSUpant2	8.35 – 20.90	$L = 0.131M_c + 3.553$	0.983
		$W = 0.035M_c + 3.806$	0.965
		$T = 0.023M_c + 3.855$	0.988
		$D_a = 0.063M_c + 3.744$	0.992
		$D_g = 0.057M_c + 3.788$	0.994
EBSUpant3	8.48 – 21.20	$L = 0.170M_c + 4.026$	0.999
		$W = 0.051M_c + 3.782$	0.999
		$T = 0.024M_c + 3.966$	0.949
		$D_a = 0.082M_c + 3.924$	0.999
		$D_g = 0.071M_c + 3.987$	0.998
EBSUpant4	8.69 – 21.73	$L = 0.124M_c + 3.418$	0.892
		$W = 0.054M_c + 3.058$	0.949
		$T = 0.045M_c + 3.004$	0.987
		$D_a = 0.074M_c + 3.159$	0.948
		$D_g = 0.069M_c + 3.176$	0.957
EBSUpant5	8.88 – 22.20	$L = 0.137M_c + 3.629$	0.976
		$W = 0.033M_c + 3.76$	0.904
		$T = 0.024M_c + 3.592$	0.956
		$D_a = 0.064M_c + 3.661$	0.965
		$D_g = 0.057M_c + 3.712$	0.966

Table 3 Equations representing relationship between sphericity, surface area and seed volume and moisture content (M_c) for different varieties of mung bean seed

Variety	M_c (% w.b.)	Equation	R^2
EBSUpant1	8.59 – 21.48	$\phi = -0.007M_c + 0.887$	0.963
		$S_a = 1.779M_c + 50.26$	0.963
		$V = 1.414M_c + 27.39$	0.981
EBSUpant2	8.35 – 20.90	$\phi = -0.008M_c + 0.975$	0.970
		$S_a = 1.736M_c + 42.11$	0.989
		$V = 1.233M_c + 24.84$	0.985
EBSUpant3	8.48 – 21.20	$\phi = -0.008M_c + 0.896$	0.997
		$S_a = 2.361M_c + 45.55$	0.999
		$V = 1.860M_c + 24.11$	0.998
EBSUpant4	8.69 – 21.73	$\phi = -0.004M_c + 0.876$	0.942
		$S_a = 1.954M_c + 27.03$	0.944
		$V = 1.493M_c + 8.791$	0.948
EBSUpant5	8.88 – 22.20	$\phi = -0.008M_c + 0.933$	0.999
		$S_a = 1.717M_c + 40.16$	0.956
		$V = 1.205M_c + 21.48$	0.932

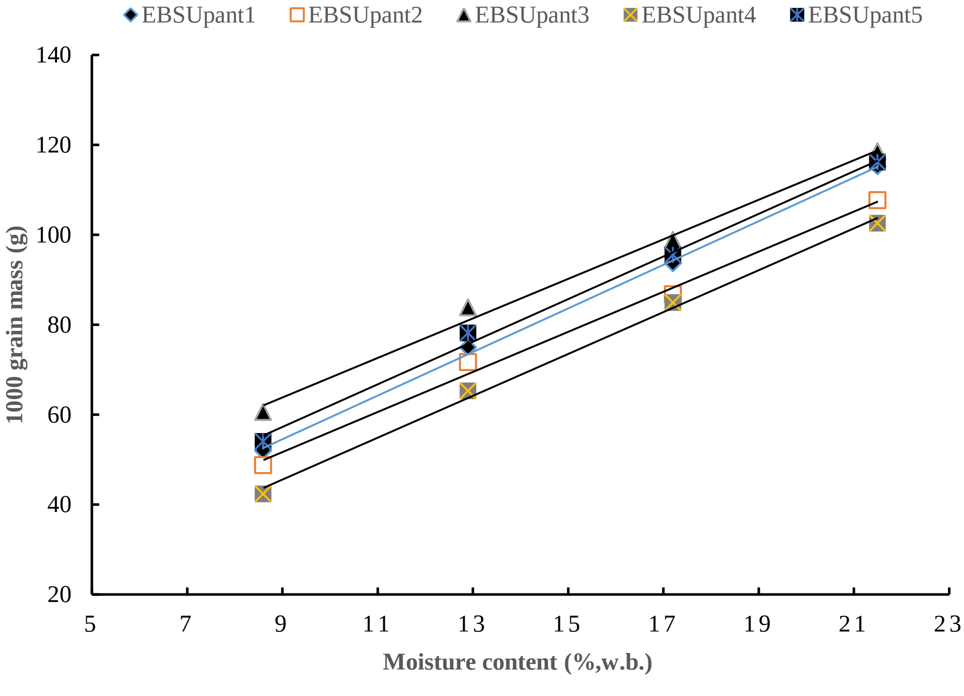


Figure 5 Effect of moisture content on 1000 grain mass of five mung bean seed varieties

3.2 Gravimetric properties of mung bean seeds

3.2.1 One thousand grain mass

The experimental values obtained for thousand grain mass of mung bean seed varieties are presented in Figure 5. It can be seen from Figure 5, that a thousand grain mass M_{1000} increased linearly as the moisture content increased. The value of one thousand grain mass of mung bean seeds was the greatest for EBSUpant3 (60.50 to 138.50 g), followed by EBSUpant5 (54.0 to 136.10 g), EBSUpant1 (51.90 to 133.40 g), then EBSUpant2 (48.70 to 127.6 g) and the lowest for the EBSUpant4 (42.30 to 104.20 g) as moisture content increased between 8.35% and 22.20% (w.b.).

Ampah et al. (2012) and Shirkole et al. (2011) found the 1000 seed mass of *Asontem* cowpea variety and soybean to increase with increase in moisture. The variation in M1000 with moisture content was significant (p<0.05).

From the equations representing relationship between thousand grain mass of mung bean seed varieties and moisture content (Table 4), it can be observed there was a linear relationship with very high value of R^2 of 0.998.

Table 4 Equations representing relationship between thousand grain mass and moisture content (M_c) for different varieties of mung bean seed

Variety	M_c (% w.b.)	Equation	R^2
EBSUpant1	8.59 – 21.48	$1000g = 4.169M_c + 10.92$	0.998
EBSUpant2	8.35 – 20.90	$1000g = 3.836M_c + 11.52$	0.994
EBSUpant3	8.48 – 21.20	$1000g = 3.780M_c + 24.25$	0.993
EBSUpant4	8.69 – 21.73	$1000g = 4.006M_c + 3.620$	0.996
EBSUpant5	8.88 – 22.20	$1000g = 4.074M_c + 14.63$	0.996

3.2.2 True density

The results for the true density of mung bean seeds measured at different moisture levels are shown in Figure 6a.

The highest value of true density obtained for EBSUpant2 variety was equal to 1453.0 kg m^{-3} at 20.90 (% w.b.), while EBSUpant1 (1353.0 kg m^{-3} at 21.48% w.b.) had the least true density value. The true density of mung bean seeds showed increasing trend with moisture content for all mung bean varieties. The variation in true density with moisture content was significant ($p < 0.05$). This increase indicates that there is a higher grain mass increase in comparison to its volume increase as its moisture content increases. This agrees with finding of Tekin et al. (2006) for Turkish Göynük bombay bean, and Aviara et al. (1999) for guna seeds.

3.2.3 Bulk density

The grain bulk density variation of mung bean seeds at different moisture levels is shown in Figure 6b.

As it can be seen (Figure 6b), all five mung bean varieties, EBSUpant1, EBSUpant2, EBSUpant3, EBSUpant4, and EBSUpant5, showed approximately a similar decrease in bulk density with increase in moisture content. Furthermore, the results showed that bulk density of seed varieties was the lowest for EBSUpant4 (650.05 to 433.99 kg m^{-3}), followed by EBSUpant2 (689.97 to 491.00 kg m^{-3}), EBSUpant5 (693.96 to 500.02 kg m^{-3}), then EBSUpant3 (699.95 to 503.96 kg m^{-3}), and the greatest was obtained for EBSUpant1 (712.08 to 512.03 kg m^{-3}) as moisture contents increased from: 8.69% to 21.73%, 8.35% to 20.90%, 8.88% to 22.20%, 8.48% to 21.20%, and 8.59% to 21.48% (w.b.), respectively. This is probably due to the higher rate of increase in seed volume than mass and due to structural properties of the mung bean seed. Nalbandi et al. (2010), Ampah et al. (2012) and Estefanía et al. (2013) reported that the bulk density values of wheat kernel, *Asontem* cowpea variety, and *chia (Salvia hispanica* L.*)* seeds decreased linearly with increasing moisture content. The relationship between bulk density and moisture content was statistically significant (p<0.05).

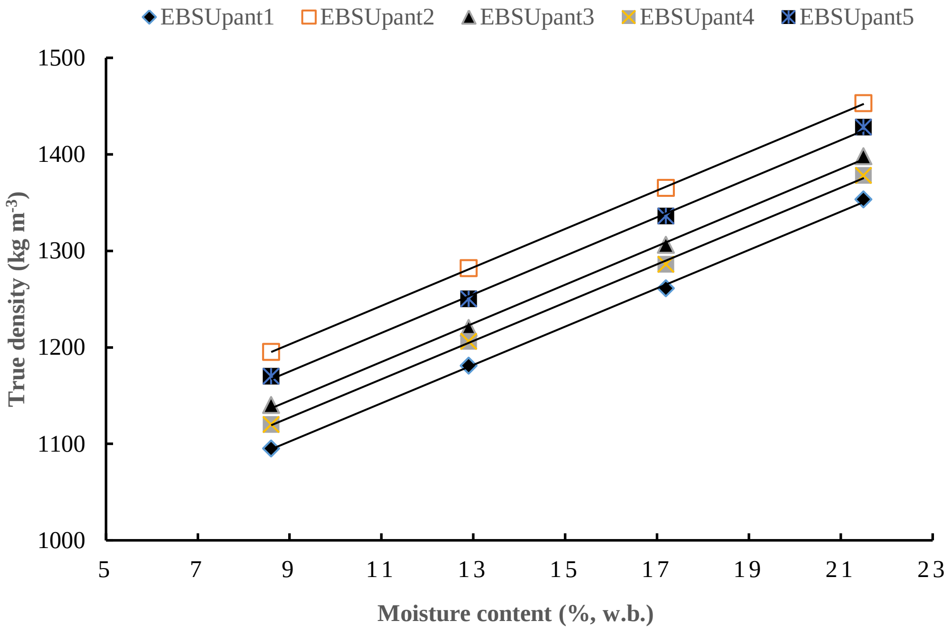
3.2.4 Porosity

The effect of moisture content on the porosity of mung bean seeds are presented in Figure 7.

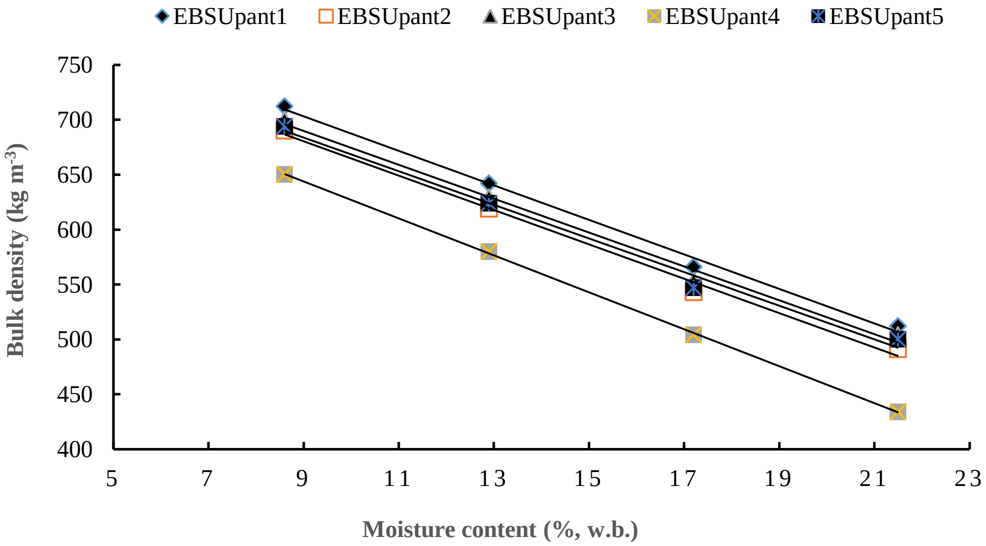
Since the porosity depends on the bulk as well as true densities, the magnitude of variation in porosity depends on these factors only. Thus, the porosity of mung bean seed for five varieties was found to slightly increase with increase in moisture content and this change was significant at a 5% level of significance. The results showed that porosity of mung bean seeds ranged from 42.26% to 66.21% for the EBSUpant2 variety, 41.96% to 68.51% for the EBSUpant4 variety, 40.69% to 64.98% for the EBSUpant5 variety, 38.60% to 63.95% for the

EBSUpant3 variety, and 34.97% to 62.16% for the EBSUpant1 variety as moisture content increased between 8.35% and 20.90%, 8.69% and 21.73%, 8.88% and 22.20%, 8.48% and 21.20% and 8.59% and 21.48% (w.b.). Similar observations of increase in bulk porosity with increase in grain moisture content have been reported by Kiani et al. (2008) red bean.

The relation of bulk density and true density and porosity of mung bean seeds with respect to moisture content can be represented by equations given in Table 5. As the values of coefficient of determination (R^2) for all varieties were adequately high, it seems that the moisture content had a remarkable influence on the densities and porosity of mung bean seeds. It can be also noted that there is linear correlation between bulk/true density and moisture content.



(a) Effect of moisture content on true density of five mung bean seed varieties



(b) Effect of moisture content on bulk density of five mung bean seed varieties

Figure 6 Effects of different parameters on the density of five mung bean seed varieties

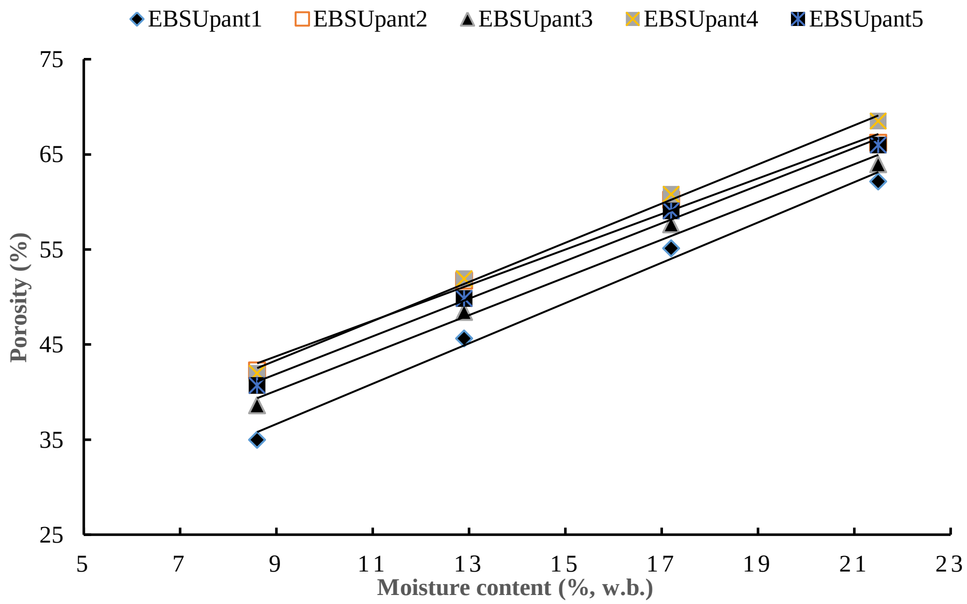


Figure 7 Effect of moisture content on porosity of five mung bean seed varieties

3.2.5 Angle of repose

The results obtained for angle of repose of five varieties mung bean seeds (e) with increase in grain moisture content are shown in Figure 8.

It was observed that angle of repose increases linearly with increase in moisture content for all mung bean seed varieties and this change was significant at a 5% level of significance. As it can be seen, the angle of repose of mung bean seed varieties was the greatest for EBSUpant5 (25.81 to 30.12°), followed by EBSUpant4 (25.75 to 29.96°), EBSUpant1 (25.72 to 29.88°), then EBSUpant3 (25.68 to 29.79°), and the lowest for the EBSUpant2 variety (25.64 to 29.70°), as moisture contents increased from: 8.88% to 22.20%, 8.69% to 21.73%, 8.59% to 21.48%, 8.48% to 21.20%, and 8.35% to 20.90% (w.b.), respectively. It seems that the increase in angle of repose with increase in moisture content is due to the higher moisture content and therefore higher stickiness of the surface of the seeds that confines the ease of seeds sliding on each other. It might also be due to an increase in surface roughness as well as size of individual grains which affect their ability to form a heap. Similar results on effect of grain moisture on angle of repose have been reported for three different cowpea varieties viz- *IAR-339-1, IT86D-1010 and Ife Brown.* (Davies and Zibokere, 2011) and maize (Barnwal et al., 2012). Unuigbe et al. (2013) found the angle of repose of *dika nut (Irvingia gabonesis)* to increase with increase in moisture content. They also reported that the increase in angle of repose may be due to the fact that an increase in moisture content increased the cohesion between the seeds, thus increasing inter-seed friction flow/movement.

The equations representing relationship between angle of repose of mung bean seeds and moisture content for each mung bean variety is presented in Table 6. As it can be observed, there was a linear relationship with very high correlation (R^2) between angle of repose and moisture content for all mung bean varieties.

3.2.6 Coefficient of static friction

The results obtained for coefficient of static friction of mung bean seeds on three test surfaces including galvanized iron sheet (μgi), plywood (μpl), and stainless steel sheet (μss) at various moisture levels were presented in Table 7. It can be seen from the Table 7, that the coefficient of static friction for each mung bean variety on all three structural surfaces increased as the moisture content increased.

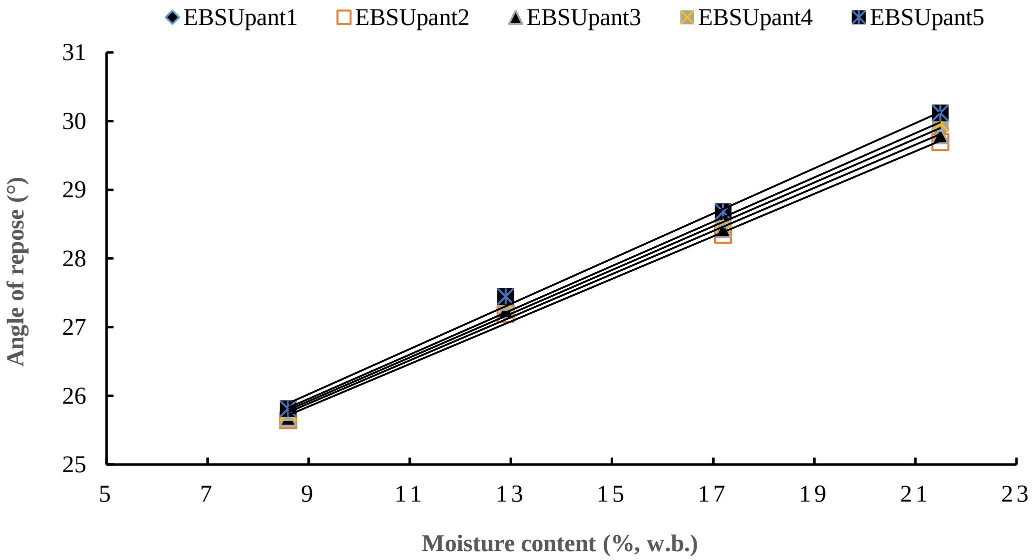


Figure 8 Effect of moisture content on angle of repose of five mung bean seed varieties

Table 5 Equations representing relationship between porosity, true and bulk densities and moisture content (M_c) for different varieties of mung bean seed

Variety	M_c (% w.b.)	Equation	R^2
EBSUpant1	8.59 – 21.48	*True density* = 17.08M_c + 923.6	0.999
		Bulk density = -13.52M_c + 844.6	0.995
		Porosity = 1.820M_c + 17.60	0.992
EBSUpant2	8.35 – 20.90	*True density* = 17.14M_c + 1023.0	0.999
		Bulk density = -13.45M_c + 821.2	0.994
		Porosity = 1.607M_c + 26.97	0.990
EBSUpant3	8.48 – 21.20	*True density* = 17.2M_c + 965	0.999
		Bulk density = -13.27M_c + 828.8	0.992
		Porosity = 1.705M_c + 22.31	0.992
EBSUpant4	8.69 – 21.73	*True density* = 17.08M_c + 948.6	0.999
		Bulk density = -14.48M_c + 795.4	0.999
		Porosity = 1.771M_c + 24.80	0.996
EBSUpant5	8.88 – 22.20	*True density* = 17.2M_c + 995	0.999
		Bulk density = -13.17M_c + 821.8	0.990
		Porosity = 1.701M_c + 24.11	0.995

Table 6 Equations representing relationship between angle of repose and moisture content (M_c) for different varieties of mung bean seed

Variety	M_c (% w.b.)	Equation	R^2
EBSUpant1	8.59 – 21.48	*Angle of repose* = 4.169M_c + 10.92	0.998
EBSUpant2	8.35 – 20.90	*Angle of repose* = 3.836M_c + 11.52	0.994
EBSUpant3	8.48 – 21.20	*Angle of repose* = 3.780M_c + 24.25	0.993
EBSUpant4	8.69 – 21.73	*Angle of repose* = 4.006M_c + 3.620	0.996
EBSUpant5	8.88 – 22.20	*Angle of repose* = 4.074M_c + 14.63	0.996

Table 7 Effect of moisture content on coefficient of static friction of five mung bean seed varieties

Variety	M_c (%, w.b.)	*Galvanized iron sheet*	*Plywood sheet*	*Stainless steel sheet*
EBSUpant1	8.59	0.378	0.363	0.352
	12.89	0.396	0.375	0.366
	17.18	0.414	0.388	0.379
	21.48	0.432	0.401	0.393
EBSUpant2	8.35	0.377	0.362	0.351
	12.54	0.395	0.374	0.364
	16.72	0.412	0.387	0.378
	20.90	0.430	0.400	0.391
EBSUpant3	8.48	0.378	0.362	0.351
	12.72	0.395	0.375	0.365
	16.96	0.413	0.388	0.379
	21.20	0.431	0.400	0.392
EBSUpant4	8.69	0.378	0.363	0.352
	13.04	0.397	0.376	0.366
	17.38	0.415	0.389	0.380
	21.73	0.433	0.402	0.394
EBSUpant5	8.88	0.379	0.363	0.353
	13.32	0.398	0.377	0.367
	17.76	0.417	0.390	0.381
	22.20	0.435	0.403	0.395

Table 8 Equations representing relationship between coefficient of static friction and moisture content (M_c) for different varieties of mung bean seed

Variety	M_c (% w.b.)	Surfaces	Equation	R^2
EBSUpant1	8.59 – 21.48	Galvanized iron sheet	$\mu gi = 0.003\ M_c + 0.342$	0.999
		Plywood	$\mu pl = 0.002\ M_c + 0.337$	0.999
		Stainless steel sheet	$\mu ss = 0.002\ M_c + 0.324$	0.999
EBSUpant2	8.35 – 20.90	Galvanized iron sheet	$\mu gi = 0.003\ M_c + 0.341$	0.999
		Plywood	$\mu pl = 0.002\ M_c + 0.336$	0.999
		Stainless steel sheet	$\mu ss = 0.002\ M_c + 0.324$	0.999
EBSUpant3	8.48 – 21.20	Galvanized iron sheet	$\mu gi = 0.003\ M_c + 0.342$	0.999
		Plywood	$\mu pl = 0.002\ M_c + 0.336$	0.999
		Stainless steel sheet	$\mu ss = 0.002\ M_c + 0.323$	0.999
EBSUpant4	8.69 – 21.73	Galvanized iron sheet	$\mu gi = 0.003\text{x}\ M_c + 0.341$	0.999
		Plywood	$\mu pl = 0.002\ M_c + 0.337$	1.000
		Stainless steel sheet	$\mu ss = 0.002\ M_c + 0.324$	1.000
EBSUpant5	8.88 – 22.20	Galvanized iron sheet	$\mu gi = 0.003\ M_c + 0.341$	0.996
		Plywood	$\mu pl = 0.002\ M_c + 0.336$	0.999
		Stainless steel sheet	$\mu ss = 0.002\ M_c + 0.325$	1.000

As presented in Table 7, on galvanized iron sheet surface at all moisture contents, the highest friction was obtained for EBSUpant5 (0.379 to 0.435) and the lowest for EBSUpant3 (0.378 to 0.431). The results obtained for friction coefficient of mung bean seeds on plywood surface, indicated that the highest value was for EBSUpant5 (0.365 to 0.403). In comparison with reported values of coefficient of static friction on plywood surface, the obtained values for mung bean seeds were greater than those for lentil seed (Amin et al., 2004) and lower than those for almond nut (Aydin, 2003). The greatest coefficient of friction on stainless steel surface was for EBSUpant1 (0.352 to 0.393), EBSUpant2 (0.351 to 0.391), EBSUpant3 (0.351 to 0.392), EBSUpant4 (0.352

to 0.394), and EBSUpant5 (0.353 to 0.395). As can be seen, the highest friction on all frictional surfaces at all moisture levels were offered by EBSUpant5 variety. It might be due to the higher moisture content of this variety. The results also showed that the highest static coefficient of friction was obtained on the galvanized iron surface, followed by plywood, and finally stainless steel surfaces.

The regression equations and their R^2 values obtained by fitting the experimental data of coefficient of static friction as a function of moisture content are listed in Table 8. It can be noted that the relationship of coefficient of static friction of mung bean seed with moisture content was linear for all friction surfaces and varieties. These linear behaviours are in accordance with similar reported results for pistachio (Razavi et al., 2007).

4 Conclusions

All the linear dimensions, geometric and arithmetic mean diameters, surface area and volume of mung bean seeds increase linearly with increase in seed moisture content, with high correlation. The bulk density decreased linearly with increasing moisture content for each variety, whereas true density increased linearly with increasing moisture content of all mung bean seed varieties. For all varieties, as the moisture content increased, the angle of reposes increased linearly. The porosity and angle of repose increased linearly while sphericity decreased with increase in moisture content.

The highest friction for all mung bean varieties was observed on galvanized iron surface, followed by plywood and the lowest on stainless steel at all moisture contents studied. The physical properties of seeds for different five mung bean seed varieties were significantly dependent on their moisture content. The information on engineering properties of five mung bean seed varieties, (EBSUpant1, EBSUpant2, EBSUpant3, EBSUpant4, and EBSUpant5) may be useful for designing of equipment for mung bean seed storage bin and processing equipment.

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