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Moisture-Dependent Physical Properties of Pigeon Pea Grown in Nigeria

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Abstract: The effects of different moisture contents of 10, 15, 20 and 25% (wb) on the physical properties of pigeon pea (*Cajanus cajan* L.) grown in Nigeria were investigated. The axial dimensions, mean diameters, sphericity, surface area, porosity, true and bulk density, angle of repose and the coefficient of friction of pigeon pea were determined using standard methods. The physical properties of pigeon pea grains were significantly dependent on the moisture content with high correlation coefficients ($p<0.05$). The average length, width, thickness, arithmetic and geometric mean diameters, surface area, volume, thousand grain mass and angles of repose increased as the moisture content increased from 10% to 25%. Whereas the bulk density, true density and the porosity were found to decrease from 685.16 to 640.55 kg/m^3, 1361.11 to 755.56 kg/m^3 and 43.40% to 13.55% respectively as the moisture content increased from 10% to 25%. The static coefficient of friction of pigeon pea increased linearly over the three material surfaces – plywood, aluminum and galvanized sheet – with increasing moisture content. The aluminum surface had the lowest static coefficient of friction whereas the plywood gave the highest value at all moisture content levels.

Key words: Pigeon pea · Moisture content · Physical properties · Nigeria

INTRODUCTION

Pigeon pea (*Cajanus cajan* (L.) millsp.) is a multipurpose leguminous crop that can provide food, fuel wood and fodder for the small-scale farmer in subsistence agriculture and is widely cultivated in Nigeria [1, 2]. In most locations in Nigeria agro-ecological zones, resource-poor farmers have through evolutionary history incorporated pigeon pea production into their indigenous cropping systems as field crops, backyard or as field border crops [2]. Pigeon pea could be intercropped with maize without negative effects on the yield and yield components of maize [3]. Farmers, however, maintain varying degrees of sole and mixed culture with crops such as sorghum, millet, yam, cassava and sweet potatoes [4]. They further noted that Pigeon pea should play an important role in developing new strategic approaches to ensure food security and sustainable increase in agricultural productivity in Nigeria.

Although the importance of pigeon pea in human nutrition has been established [5-10], its production in Nigeria is still characterized as low and is restricted to some few parts of Nigeria agricultural zone. The processing operations are predominantly done manually. This has been attributed to lack of scientific data on the physical and mechanical properties of the grain grown in Nigeria [11]. A review of literatures showed that detailed measurement of the physical properties of pigeon pea in Nigeria at various moisture content levels has not been carried out. The effective planting, handling, processing and storage of legumes is largely dependent on the knowledge of the engineering properties of the seed, which will in turn aid in better design and fabrication of machines for different stages of their production and processing [12]. The physical properties of various agricultural products have been studied by some researchers such as hazelnut [13], almond [14], millet [15],

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Guna seed [16], coffee [17], wild plum [18], lentil seeds [19], sunflower seeds [20], chick pea seeds [21], green gram [22] and cotton [23].

The general objective of the study was to provide data on some moisture-dependent physical properties of pigeon pea grown in Nigeria necessary for the design of appropriate processing methods and machines. The specific objectives of this study were to determine some moisture-dependent physical properties of pigeon pea grown in Nigeria in the moisture content range of 10% to 25% wet basis (wb) and to develop predictive models for the physical properties investigated as a function of moisture content.

MATERIALS AND METHODS

Samples Preparation: Pigeon pea grains used for the study were purchased from a local market in Enugu state, South Eastern Nigeria and cleaned to remove foreign materials and impurities. The moisture content of the grains as brought in from the market was determined by drying the sample in an air circulating oven set at 105°C (±2) for 24 h as described by [24].

Because of the significant effect of moisture content on the properties of grains as noted by [24-26], the physical properties of the grain was accessed at four different moisture content levels of 10, 15, 20 and 25% (wb) in order to relate the properties to moisture content. In order to attain the desired moisture levels for the study, moisture levels lower than the initial moisture content of the sample were attained by drying the grains at low temperature (40°C) to give a sample mass *B* as calculated below [27]:

$$B = A(100 - a)/(100 - b) \quad (1)$$

And moisture levels higher than the initial moisture content of the sample were attained by adding the required amount of distilled water, *Q* as calculated from equation 2. The samples were kept in refrigerator at 5°C (±2) for 5 days for the moisture to distribute uniformly throughout the sample. Before use, the required quantity of seeds were taken out of the refrigerator and allowed to warm up to room temperature for about two hours [22]. The moisture content after equilibration was determined at the time of each experiment using the method described above [24]. The physical properties described below were determined at each moisture content level.

$$Q = A(b - a)/(100 - b) \quad (2)$$

where,

A is the initial mass of the sample in kg, *B* the final mass of the sample after drying in kg, *a* the initial moisture content of sample in% w.b., *b* the final (desired) moisture content of sample in% w.b., *Q* the mass of water to be added in kg.

Determination of Physical Properties

Grain Size: To determine the average size of the grain, a sample of 100 randomly selected pigeon pea grains were used for each moisture content level. Their three principal dimensions, length (L), width (W) and thickness (T) were measured using a digital vernier caliper to an accuracy of 0.01 mm. The geometric mean diameter, D_m of the grain was calculated using the following relationship [22]:

$$D_m = (LWT)^{1/3} \quad (3)$$

The arithmetic mean diameter, D_a, was calculated using the equation described by [28], equation 5:

$$D_a = (L + W + T)/3 \quad (4)$$

where,

L, W and T represent the length, width and thickness of the grain respectively.

The degree of sphericity as expressed by [29] was used to calculate the sphericity of the grain as shown in equation 6.

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

Grain Mass: One thousand seed weight was determined using an electronic balance reading to 0.001 g at each moisture content level.

Densities: The Bulk density was determined by filling a cylindrical container of known volume with the grains, striking off excess grains without compaction and then weighing the cylinder. The ratio of weight of the grains and volume of the cylinder gave the bulk density, P_b (kgm^{-3}). To calculate the true density, ρ_t of the grain, the unit mass of each sample was determined by weighing using an electronic balance reading to an accuracy of 0.01 g. The true volume, *V* (cm^3), as a function of moisture content was determined using the liquid displacement method [30]. True density, ρ_t (kgm^{-3}) of the samples were calculated by dividing the unit mass of each sample by its true volume.

Porosity: Porosity of the bulk grain is the ratio of the volume of internal pores within the grains to its bulk volume and was determined as follows [22]:

$$\varepsilon = 100[1 - (\rho_b/\rho_f)] \quad (6)$$

where,
ε is the porosity in%.

Volume and Surface Area: The principal dimensions were used to calculate the volume (V) and surface area (S) of a single grain of pigeon pea using equations 7 and 8 described by [31]:

$$V = \frac{\pi BL^2}{6(2L - B)} \quad (7)$$

$$S = \frac{\pi BL^2}{2L - B} \quad (8)$$

where,

Angles of Repose: The filling angle of repose is the angle with the horizontal at which the material will stand when piled [32]. This was determined using a topless and bottomless plastic cylinder of 15 cm diameter and 25 cm height. The cylinder was placed at the centre of a raised circular plate having a diameter of 35 cm and filled with the grain. The cylinder was raised slowly until it formed a cone on the circular plate. The height of the cone was measured and the filling angle of repose, (θ_f), calculated using the following equation [33]:

$$\theta_f = \text{Arc tan } (2H / D) \quad (9)$$

To determine the funneling angle of repose, θ, a fiberglass box of 20 x 20 x 20 cm, having a removable front panel was used. The box was filled with the grain and then the front panel quickly removed allowing the seeds to flow and assume a natural slope [34]. The funneling angle of repose, θ_e was calculated from the measurement of the depth of the free surface of the sample at the centre, using equation 10 [35]:

$$\theta_e = \text{Arc tan } (2H / X) \quad (10)$$

where,

H is the height of the cone; D is the diameter of the cone; X is the adjacent of the slope

Static Coefficient of Friction: The static coefficient of friction, μ was determined for three different structural materials, namely, plywood, galvanized sheet and aluminum sheet using the method described by by [22, 36]. A plastic cylinder of 100 mm diameter and 50 mm height was placed on an adjustable tilting plate having the test surface firmly placed on it. The plastic cylinder was filled with the sample of about 150±2 g. The cylinder was raised slightly so as not to touch the surface (about 5 mm). The structural surface with the cylinder resting on it was inclined gradually, using a screw device, until the box just started to slide down. The angle of tilt was read from a graduated scale and the tangent of this angle recorded as the static angle of friction on that surface (equation 11).

$$\mu_s = \tan\alpha \quad (11)$$

Statistical Analysis: Descriptive statistics were used to analyze the data obtained for each of the properties studied at different moisture content level using GenStat Discovery Edition 4. Predictive models were developed to establish relationship between the physical properties and moisture content using regression analysis. Each test was performed four times and the mean values determined.

RESULTS AND DISCUSSION

The mean axial dimensions, arithmetic and geometric mean diameters, sphericity, surface area, volume, densities and 1000 grain mass of pigeon pea samples at four different moisture content levels of 10, 15, 20 and 25% (wb) are presented in Tables 1(a) and (b) while the porosity, angles of repose and coefficient of static friction of on three different surfaces are shown in Table 1(c). Generally, it was observed that the values recorded for most of the physical properties studied increased with increasing moisture content from 10 - 25% (wb).

Grain Dimensions: Mean values of the three principal dimensions of pigeon pea grains, namely length, width and thickness, determined in this study at different moisture contents are presented in Table 1a. Each principal dimension increased as the moisture content

Table 1(a): Some physical properties of Pigeon pea at different moisture contents.

				Average diameters, cm		
MC w.b., %	Length, cm	Width, cm	Thickness, cm	Geometric mean, D_g	Arithmetic mean, D_a	Sphericity, %
10	0.63 (0.02)	0.62 (0.02)	0.43 (0.02)	0.55 (0.01)	0.56 (0.01)	87.3 (0.50)
15	0.65 (0.02)	0.63 (0.02)	0.45 (0.02)	0.57 (0.01)	0.58 (0.01)	87.7 (0.79)
20	0.68 (0.02)	0.66 (0.02)	0.45 (0.02)	0.58 (0.01)	0.60 (0.01)	85.3 (0.70)
25	0.69 (0.02)	0.67 (0.02)	0.46 (0.02)	0.60 (0.01)	0.61 (0.01)	86.9 (0.36)

Standard deviation values are in parentheses.

Table 1(b): Some physical properties of Pigeon pea at different moisture contents

				Densities	
MC w.b., %	1000 grain mass, g	Surface Area, cm^2	Volume	Bulk	True
10	167.6 (0.98)	0.88 (0.04)	0.146 (0.004)	685.16 (12.19)	1361.11 (62.55)
15	172.4 (0.85)	0.91 (0.02)	0.152 (0.003)	646.34 (2.35)	1037.04 (64.15)
20	176.8 (0.53)	0.99 (0.04)	0.164 (0.004)	653.84 (4.86)	1161.11 (66.94)
25	181.6 (0.70)	1.02 (0.04)	0.170 (0.002)	640.55 (5.24)	755.56 (76.98)

Standard deviation values are in parentheses.

Table 1(c): Some physical properties of Pigeon pea at different moisture contents

		Angle of Repose		Coefficient of Static Friction		
MC w.b., %	Porosity	Funneling Angle of Repose	Filling Angle of Repose	Plywood	Aluminum Sheet	Galvanized Sheet
10	43.40 (0.41)	25.16 (2.56)	26.70 (0.50)	0.39 (0.02)	0.33 (0.03)	0.37 (0.02)
15	44.00 (0.09)	25.94 (2.26)	27.23 (0.45)	0.41 (0.02)	0.35 (0.02)	0.38 (0.04)
20	36.90 (1.39)	26.45 (1.93)	27.57 (0.40)	0.44 (0.05)	0.36 (0.05)	0.39 (0.02)
25	13.55 (0.48)	31.50 (0.89)	28.07 (0.40)	0.45 (0.02)	0.39 (0.02)	0.40 (0.07)

Standard deviation values are in parentheses.

Table 2: Regression equations for grain dimensions

Dimension	Regression Equation	R^2
Length	L = 0.0042Mc + 0.589	0.969
Width	W = 0.0036Mc + 0.582	0.953
Thickness	T = 0.0018Mc + 0.416	0.853

L-Length, W-Width, T-Thickness, Mc-Moisture content

increased. This could be due to the fact that upon moisture absorption, the grains expanded in length, width and thickness. The mean values for the length, width and thickness of the pigeon pea increased from 0.63 to 0.69 cm, 0.62 to 0.67 cm and 0.43 to 0.46 cm, respectively, as the moisture content increased from 10% to 25% (w.b.). The regression analysis carried out showed strong correlation between the dimensions and the moisture content (Table 2). The correlation coefficients determined for the length, width and thickness were 0.969, 0.953 and 0.853 respectively.

Geometric and Arithmetic Mean Diameters: The mean geometric and arithmetic mean diameters are presented in Table 1(a). The mean values recorded increased from 0.55 to 0.60 cm and 0.56 to 0.61 cm for the geometric and arithmetic mean diameters respectively as the moisture content increased from 10 – 25% (wb). The relationship between the arithmetic (AR_D) and geometric mean diameters (GM_D) with the moisture content (Mc) appeared linear as can be seen from Table 3. The correlation coefficients were 0.980 and 0.985 for the arithmetic and geometric mean diameter respectively. These properties are particularly important in the design of harvesting, threshing and separating machines [32]. Figures 1(a) and (b) shows the graph of the mean diameters as a function of moisture level.

Sphericity: The mean values of the sphericity at different moisture levels of 10, 15, 20 and 25% (wb) are as presented in Table 1b. The sphericity of the grains decreased linearly from 87.3 to 85.3% as the moisture content increased from 10% to 25% (w.b.). This suggests that as the grain gained moisture, its shape departed from

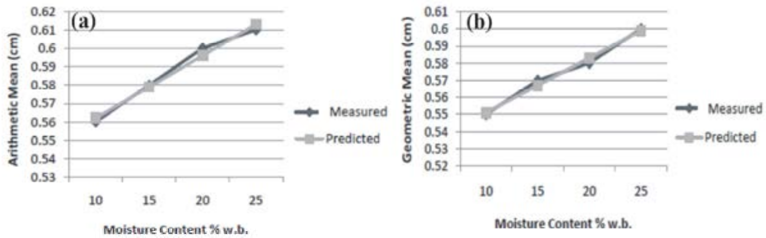

Fig. 1: Mean diameters of Pigeon Pea as a function of moisture content.

Table 3: Predictive models for pigeon pea properties as a function of moisture content

Properties	Regression Equation	R^2
Arithmetic mean diameter	$AR_D = 0.0034Mc + 0.528$	0.980
Geometric mean diameter	$GM_D = 0.0032Mc + 0.519$	0.985
Sphericity	$(\Phi) = -0.072Mc + 88.06$	0.195
A thousand grain mass	$M_{1000} = 0.928Mc + 158.36$	0.999
Surface area	$S = 0.01Mc + 0.775$	0.962
Volume	$V = 0.00168Mc + 0.1286$	0.981
Bulk density	$\rho_b = -2.4724Mc + 697.782$	0.860
True density	$\rho_t = -30.4374Mc + 1565.172$	0.882
Porosity	$\varepsilon = -1.933Mc + 68.29$	0.761
Funneling angle of repose	$\theta_e = 0.402Mc + 20.19$	0.792
Filling angle of repose	$\theta_f = 0.092Mc + 25.79$	0.998

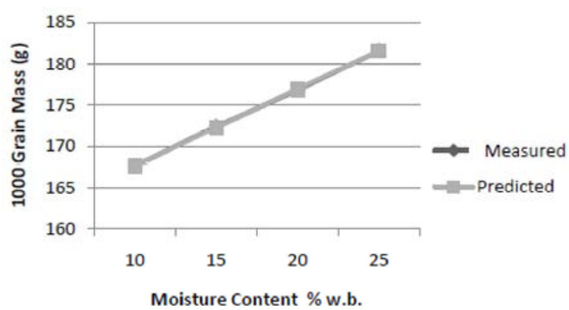

Fig. 2: Variation of M_{1000} of Pigeon Pea with moisture content.

that of sphere due to the differential dimensional changes in the three major dimensions. The decrease in sphericity of the grains agreed with that reported by [37] for Kano White variety of bambara groundnut, [38] for faba bean, [39] for barbunia and [40] for cowpea. However, the relationship between the sphericity (Φ) and the moisture content (Mc) of the grain showed a very weak correlation coefficient of 0.195 as can be seen in Table 3.

Grain Mass: The thousand grain mass of pigeon pea increased linearly from 167.6 to 181.6 g as the moisture content increased from 10 to 25% w.b. (Table 1b). Similar result was reported by [41] for soybean and [39] for barbunia. The thousand grain mass of cereal grains is a useful index to milling outturn in measuring the relative amount of dockage or foreign material in a given lot of grain. The relationship between 1000 grain mass (M_{1000}) and the moisture content (Mc) is shown in Table 3. Fig. 2 shows a graph of M_{1000} as a function of moisture content.

Surface Area and Volume: The surface area of pigeon pea grains increased with increase in moisture content from 0.88 to 1.02 cm^2. This shows that the surface area increased linearly with increasing moisture content. The surface area affects the rate of moisture loss during drying of grains and other particulate materials. Similar trend has been reported by [42] for linseed, [43] for red kidney bean grains and [44] for jatropha seed. The variation of moisture content (Mc) and surface area (S) can be expressed mathematically as shown in Table 3. The relationship showed a high correlation coefficient of 0.962. Fig. 3(a) shows the measured and the predicted values as generated using the regression equation.

The volume also increased from 0.15 to 0.17 cm^3 as the moisture content increased from 10 to 25%, indicating that the volume-moisture relationship was linear. The volumetric expansion observed may be adduced to moisture absorption which increases the axial dimensions of the grain [40]. The relationship between the volume (V) and the moisture content (MC), expressed in form of an equation is shown in Table 3 having a correlation coefficient of 0.981. Fig. 3(b) shows the measured and the predicted volume of the pigeon pea. The rate of heat transfer to the material significantly depends on the heat transfer surface. The smaller the volume of material per unit surface, the better its condition for rapid heat transfer.

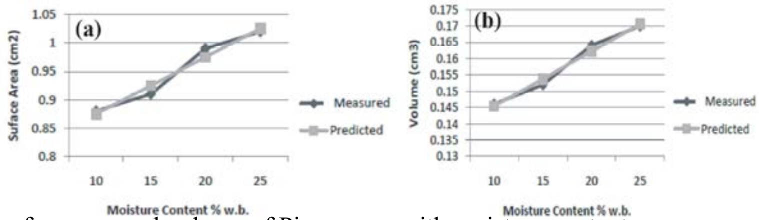

Fig. 3: Variation of in surface area and volume of Pigeon pea with moisture content.

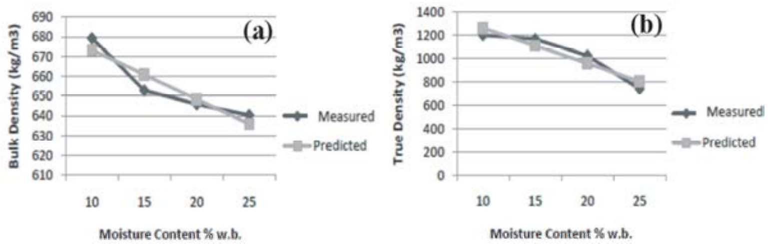

Fig. 4: Bulk and true density of Pigeon pea as a function of moisture content.

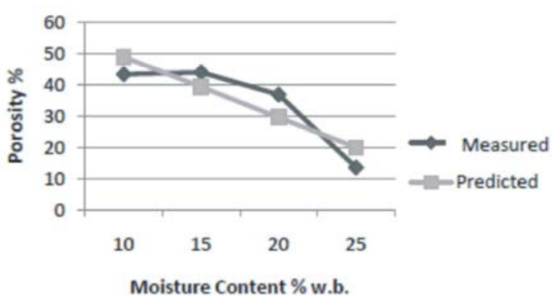

Fig. 5: Porosity of Pigeon pea as a function of moisture content.

Densities

Bulk Density: The bulk density of pigeon pea varied from 685.16 to 640.28 kg/m^3, which indicates a decrease in bulk density with increasing moisture content (Table 1b). This trend could be attributed to the increase in mass of the grain owing to moisture gain which was however lower than the accompanying volumetric expansion and the structural properties of the grain [32]. The negative relationship between the bulk density and moisture content was also reported by [40] for three varieties of cowpea and [38] for faba bean. In precision agriculture, diverse approaches are used to determine the volume of grain in a combine hopper of which the knowledge of bulk density is necessary. The bulk density of grains is also useful in the design of silos and storage bins. The relationship between the bulk density (ρ_b) of the grains and the moisture content (Mc) is as shown in Table 3 with a high correlation coefficient of 0.860. Fig. 4(a) shows the measured and the predicted bulk density of the grains using the regression equation developed.

True Density: The true density of pigeon pea grains at different moisture contents of 10, 15, 20 and 25% varied from 1200 to 740 kg/m^3 (Table 1b). The effect of moisture content on the true density of the grain showed a decrease with increasing moisture content similar to that reported by [45] for beniseed. The decrease in the true density was mainly due to the larger increase in the volume of the grain compared to the lesser increase in the grain mass. Pneumatic sorting tables are used to separate seeds of cereal crops using the true density. Various impurities differ greatly in true density from the seeds of cereal crops. The moisture content (Mc) dependence of the true density (ρ_b) was described by the regression equation in Table 3. Fig. 4(b) shows a graph of the true density as a function of the moisture content.

Porosity: The porosity or the percent of pore space between the grains was found to decrease from 43.4% to 13.55% with increasing moisture content, from 10 – 25% (wb) (Table 1c). The reason for this decrease could be that as the pigeon pea grains gained moisture, the volume increased; thus the number of grains in a fixed volume decreased. Since the number of grains per unit volume decreased, the porosity also decreased. The inverse relationship was also observed by [27] for neem nut and [32] for cucurbit seed. The porosity is the most important factor for packing and it affects the resistance to airflow through bulk seeds. The relationship between the porosity (ε) and the moisture content (Mc) of the grains can be described by the equation in Table 3 and is shown in a graph (Fig. 5).

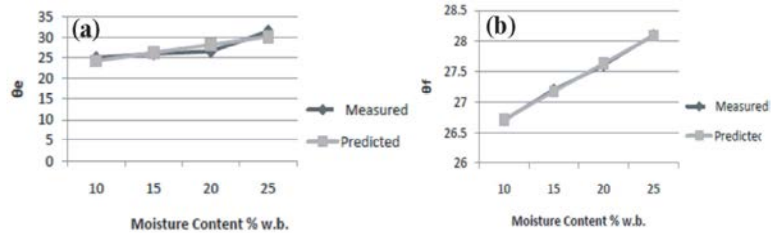

Fig. 6: Funneling and filling angle of repose as a function of moisture content.

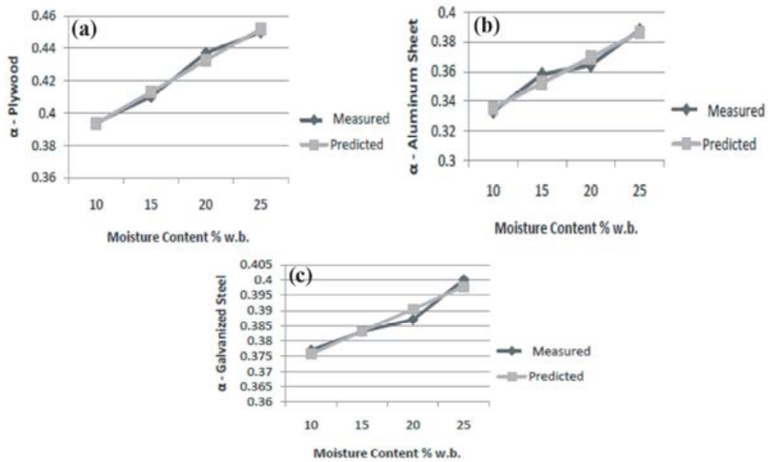

Fig. 7: Static coefficient of friction of Pigeon pea as a function of moisture content.

Angles of Repose

Funneling Angle of Repose: The values of the funneling angle of repose of pigeon pea was found to increase from 25.16° to 31.50° as the moisture content increased from 10% to 25% w.b (Table 1c). This increasing trend of the funneling angle of repose occurred because the surface layer of the moisture surrounding the particle hold the aggregate of grain together by the surface tension [46]. The trend could be 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 [32]. This property is important in designing equipment for mass flow and storage structures. The relationship of the funneling angle of repose (θ_e) for pigeon pea with the moisture content (Mc) is described by the equation in Table 3. Fig. 6(a) shows the measured and the predicted funneling angle of repose for pigeon pea using the developed regression equation.

Filling Angle of Repose: The filling angle of repose increased with increase in moisture content of pigeon pea. The mean values of the filling angle of repose was found to increase from 26.70 to 28.07° as the moisture content increased from 10% to 25% w.b (Table 1c). This increasing trend of the filling angle of repose could also be attributed to the surface tension caused by the layer of moisture surrounding the grains as was the case in the funneling angle of repose [46]. The values of the filling angle of repose (θ_f) for pigeon pea bear the following relationship with the moisture content (Mc) as described by the regression equation in Table 3. Fig. 6(b) shows the measured and the predicted values of the filling angle of repose as obtained using the equation.

Static Coefficient of Friction: It was observed that the static coefficient of friction of pigeon pea increased with an increase in moisture content on all the three surfaces studied – plywood, Aluminum and galvanized sheet (Table 3). The increase in static coefficient of friction with an increase in moisture content on all the surfaces could be attributed to the increased adhesion between the grain and the material surfaces at higher moisture content as well as due to the increase in the size of the grain as reported by [47]. The static coefficient of friction increased from 0.39 to 0.45, 0.33 to 0.39 and 0.37 to 0.40 for plywood, aluminum sheet and galvanized sheet, respectively. At all moisture content levels, the least static coefficient of friction was recorded on the aluminum sheet, followed by the galvanized sheet and then the plywood surface. This may be because of the aluminum surface is smoother and more polished than the other materials used [48]. The equation describing the

Table 4: Regression equation for static coefficient of friction

Surface	Regression Equation	R^2	
Plywood	$CS_{Pl} = 0.0039Mc + 0.3545$	0.983	
Aluminum		$CS_{Al} = 0.00342Mc + 0.3009$	0.955
Galvanized Sheet		$CS_{Gal} = 0.00146Mc + 0.3612$	0.936

CS_{Pl} = Coefficient of static friction on plywood surface; CS_{Al} = Coefficient of static friction on aluminum surface; CS_{Gal} = Coefficient of static friction on galvanized sheet

relationship between the static coefficient of friction on plywood, aluminum sheet and galvanized sheet surfaces with moisture content is shown in Table 4. Fig. 7(a) – (c) shows the measured and the predicted static coefficient of fiction on the three material surfaces.

CONCLUSIONS

The following conclusions were drawn from the investigation on the physical properties of pigeon pea grains within the moisture content range of 10 to 25% w.b. The mean dimensions, mean diameters, thousand grain mass and surface area of pigeon pea grains increased with increasing moisture level. The sphericity, bulk density and true density and the porosity decreased as the moisture content of the grains increased. The static coefficient of friction increased for all three surfaces, namely, plywood, aluminum sheet and galvanized sheet as the moisture content increased from 10 to 25% w.b. The highest friction was observed on plywood while the lowest was recorded on aluminum surface at all moisture levels. The filling angle of repose assumed higher values than the funneling angle of repose at all moisture content levels except at the 25% moisture level. The physical properties of pigeon pea grains were significantly dependent on the moisture content with high correlation coefficients.

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