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Moisture-dependent physical properties of locust bean (*Parkia biglobosa*) seeds

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Key words

bulk density; locust bean; porosity; production process; static friction

Abstract

Seed moisture content is significant in the handling and processing of seeds. This work therefore determined the physical properties of Locust bean seeds as functions of seed moisture content in the moisture range of 5.9 – 28.2% dry basis. Mohsenin, Stepanoff and ASAE standard methods were used in determining the properties. Increases in seed dimensions vitz length = 10.2±1.0 – 11.3±0.9 mm; width = 8.5±0.8 – 9.1±0.6 mm; surface area = 191.2±24.6 – 208.3±26.3 mm^2; geometric mean diameter = 7.78±0.49 – 8.12±0.03 and arithmetic mean diameter = 8.06±0.56 – 8.34±0.49 mm were recorded. Seed thickness = 5.49±0.43 – 5.26±0.62 mm; sphericity = 0.75±0.04 – 0.71±0.03; true density = 1251.96±55.5 - 1222±62.16 kgm-3 and porosity = 48.4±2.14 – 41.9±3.78 decreased. Static coefficient of friction increased on plywood (0.5±0.02 – 0.6±0.01), glass (0.4±0.05 – 0.5±0.01) and decreased on aluminium (0.5±0.02 – 0.5±0.04). A data of the physical properties of Locust bean; Parkia biglobosa was developed. This is useful for the design and development of equipment necessary for its handling and processing.

Introduction

The Locust bean tree (*Parkia*) (Figure 1), has long been widely recognized as an important indigenous multipurpose fruit tree in many countries of sub-Saharan Africa. It is commonly called the 'African Locust Bean'. In Nigeria, *Parkia biglobosa* is found in the savannah zones with the bulk of it in the Guinea savannah because of its ecological and environmental requirements which are easily met in these areas. Oni et al.(1998) stated that *Parkia biglobosa* was not cultivated in the past, but grew naturally in dotted form in the savannah. It is cultivated nowadays due to its multipurpose uses by transplanting wild ones from the nursery to the field. The seed is the most important part of the tree and a source of a fermented, natural and nutritious condiment that features frequently in the traditional diets of the people of both rural and urban dwellings in at least seventeen West African countries including Nigeria. The locust bean seed is flat, spherical in shape and it is blackish brown in color. It is covered with hard, smooth testa (seed coat) which makes the raw seed very hard and inedible (Booth and Wickens, 1988). During processing, dehulling of the seed is made difficult and laborious (Figure 2a) because of the hardness of the testa (Diawara et al., 2000). Alabi et. al. (2005) reported that the locust bean is rich in lipid, protein, carbohydrate, soluble sugars, ascorbic acid and oil. The oil content is suitable for consumption since it contains very low acid and iodine contents. It has very high saponification value, hence it is useful in

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Figure 1: Locust bean tree (*Parkia biglobosa*)

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Figure 2a: Seeds dehulling, washing and separation

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Figure 2b: Main cooking process

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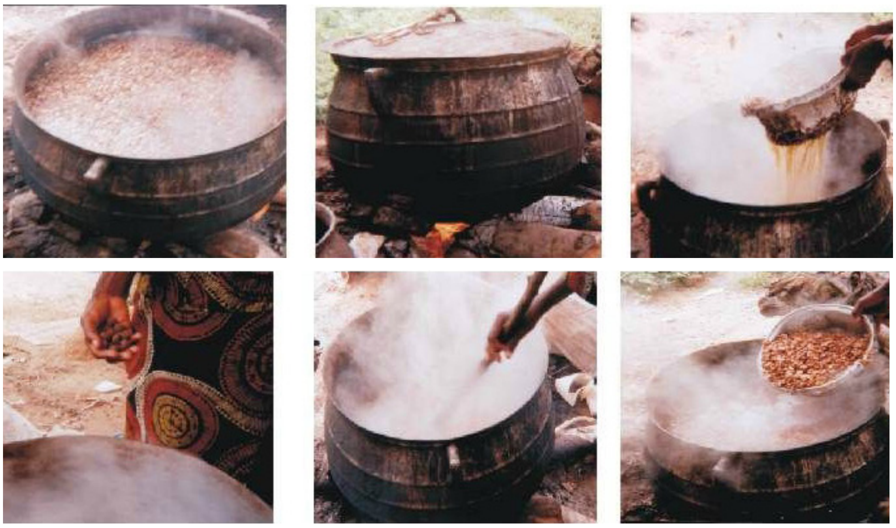

Photo credit: Adefemi-ola, X.B. and Sadiku, O.A. in Ibadan, Nigeria.

Figure 2c: Parboiling

the soap industry (Diawara et al., 2000). Oni (1997) reported that the locust bean has medicinal benefits which are derived mostly from the regular consumption of the fermented locust bean product.

The production process of locust bean had always been manual and cumbersome, thus requiring mechanization. This necessitates the determination of the physical properties of locust bean seed. Processing locust beans into the fermented product involves: shelling of the pods; sorting the seeds; soaking the seeds in water and drying for pulp removal; soaking and parboiling for de-hulling (removal of seed coat); further parboiling for final stage of fermentation (Figure 2b and 2c) . Frictional properties of agricultural materials are a necessity in predicting the lateral pressure on a retaining wall in storage bins or design of bins and hoppers for gravity flow. Dynamic and static effect of friction of grains on engineering material surfaces (e.g. wood, galvanized metal, glass etc.) are required for the prediction of motion of the material in the design of handling equipment. Bulk density, true density and porosity can be useful in sizing grain hoppers and storage facilities. Grain bed with low porosity will have greater resistance to water vapor escape during the drying process, which may lead to higher power to drive the aeration fans. The static coefficient of friction is used to determine the angle at which chutes must be positioned in order to achieve consistent flow of materials through the chute. The process of hydration (addition of water) is commonly used in the processing of cereal grain and the seeds of pulses, especially in locust beans processing as earlier stated. As a result of this, a number of important changes in the structure of the raw materials take place in the course of hydration and they are mainly associated with increased water content (Andrejko and Kaminska, 2005). Therefore it is necessary to determine the physical properties of locust bean as a function of seed moisture variation.

The physical properties of different seeds and grains as a function of their moisture content have been determined by researchers such as Altuntas et al. (2005) for fenugreek (*Trigonella foenum-graecum*); Coskuner and Karababa (2007) for coriander (*Coriandrum sativum*); Isik and Izil (2007) for dent corn (*Zea mays var. indentata*); Kiani Deh Kiani et al. (2008) for red bean (*Vigna angularis*); Zewdu and Solomon (2008) for grass pea (*Lathyrus sativus*); Tavakoli et al. (2009) for soybean (*Glycine max*); Shafiee et al. (2009) for dragon's head seed (*Dracocephalum moldavica*) and Razavi and Fathi (2009) for grape (*Vitis vinifera*). Others are Bamgboye and Adejumo, (2010) for roselle seed (*Hibiscus sabdariffa*) and Nalbandi et al. (2010) for Turgenia latifolia.

Materials and methods

Sample collection and preparation

Samples were collected from Saki in the savanna areas of the northern part of Oyo State, Nigeria. The initial moisture content of the dried seeds was determined by the ASAE standard (S 352.2) involving oven-drying method at 103 ± 1 ^{0}C for 72 hours. The samples of other desired moisture content levels (11.1, 16.6, 22 and 28.2 %) were prepared by adding calculated amounts of distilled water using equation 1 (Eq.1) (Mohsenin, 1986).

$$Q = \frac{W_i (m_f - m_i)}{100 - m_f} \qquad \text{(Eq.1)}$$

The whole seed bulk was cleaned manually to remove all foreign matter and damaged seeds. All sample lots were stored afterwards in a refrigerator at 5 °C for five days (Akbarpour et al., 2009; Davies, 2010) to allow for uniform distribution of moisture within the seed bulk. For each experiment, the required quantity of seeds was taken out from each sample lot in the refrigerator for two hours to equilibrate with room temperature.

Size and shape

The length (L), width (W) and thickness (T) of each of thirty randomly selected seeds from each moisture level were determined using a vernier caliper with 0.02 mm accuracy (Andrejko and Kaminska, 2005; Zewdu and Solomon, 2008; Nalbandi et al., 2010). The arithmetic mean (Da) and geometric mean (Dg) diameters, surface area (S) and Sphericity (ϕ) were calculated using equations 2,3,4 and 5 respectively (Mohsenin, 1986; Tavakoli, 2009).

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

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

$$S = \pi D_g^{2} \qquad \text{(Eq. 4)}$$

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

Seed mass, seed volume and thousand grain mass

These properties are determined using Mohsenin's (1986) standard methods and replicated five times for each moisture content level. Toluene (C_7H_8) was used as the fluid medium for determining seed volume because it is not readily absorbed by the seeds.

Bulk density, true density and porosity

Bulk and true densities for all the samples are determined by the beaker filling and toluene displacement methods respectively as described by Mohsenin (1986), Ahmadi et al. (2009), Nalbandi et al. (2010) and Sadiku and Bamgboye (2014). Each experiment was replicated five times for each moisture level. Bulk and true densities are calculated using equations 6 and 7 respectively.

$$\rho_t = m/v \qquad \text{(Eq. 6)}$$

$$\rho_b = m/v \qquad \text{(Eq. 7)}$$

Porosity was determined empirically using the value of bulk and true densities in equation 8. (Heiderbeigi et al., 2008)

$$\varepsilon = ((\rho_t - \rho_b) / \rho_t) \times 100 \qquad \text{(Eq. 8)}$$

Static coefficient of friction and angles of repose

The static coefficient of friction (µ) was determined using the tilting surface method on seven surfaces namely plywood, rubber, galvanized sheet, stainless steel, mild steel, aluminum and glass. These test surfaces were placed on a tilting surface one after the other while the experiment was replicated five times for each material surface at each moisture content level. The tilting surface was designed and fabricated for the purpose of this experiment (Nalbandi et al., 2010).

The static angle of repose (θ_s) was measured using a wooden box half full of locust bean seeds mounted on a tilting surface, described by Mohsenin, (1986) and Nalbandi et al. (2010). The dynamic angle of repose (θ_d) was determined using the hollow cylinder method and applying trigonometry rules (Mohsenin, 1986; Razavi et al., 2009) for the calculation as in equation 9.

$$\theta_f = [\tan^{-1} (2H)]/D \qquad \text{(Eq. 9)}$$

Coefficient and angle of internal friction, coefficient of mobility and hopper side wall angle

These properties were measured using methods described by Stepanoff (1969) and Irtwange (2000).

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Table 1: Variations in physical properties of locust bean with different moisture content

		Moisture content levels % (d.b)				
Property	**Dimension**	**5.9**	**11.1**	**16.6**	**22**	**28.2**
Length (L)	mm	10.24b±1.02	10.49b±0.73	10.6b±0.85	10.69b±0.64	11.29a±0.85
Width (W)	mm	8.45b±0.83	8.33b±0.78	8.44b±0.79	8.55b±0.79	9.08a±0.56
Thickness (T)	mm	5.49a±0.43	5.11b±0.51	5.14b±0.58	5.2b±0.62	5.26b±0.62
GMD (D_g)	mm	7.78b±0.49	7.61b±0.46	7.69b±0.48	7.73b±0.38	8.12a±0.03
AMD (D_a)	mm	8.06b±0.56	7.97b±0.47	8.06b±0.51	8.16b±0.43	8.34a±0.49
Sphericity (ϕ)		0.75a±0.04	0.72b±0.03	0.72b±0.04	0.72b±0.03	0.71b±0.03
Surface Area (S)	mm^2	191.15b±24.6	182.96b±22.3	186.95b±25.2	191.91b±22.6	208.29a±26.3
Seed mass (M_s)	g	0.24b±0.004	0.25b±0.003	0.25b±0.01	0.26a±0.01	0.26a±0.008
Seed volume (V_s)	mm^3	195.6b±9.39	215.26a±7.56	210.96a±9.10	207.78b±15.0	206.1b±8.56
TGM (M_{tg})	g	247.6c±9.8	263.6b±8.6	275.4b±15.6	277.4a± 6.4	284.2a±4.7

GMD=Geometric mean diameter; AMD = Arithmetic mean diameter; TGM = Thousand grain mass. Values with different letters (a-c) along the same row are statistically significant ($p<0.05$).

The coefficient of internal friction was calculated as:

$$\mu_i = \frac{(w_2 - w_1)}{W} \tag{Eq. 10}$$

The angle of internal friction was calculated as:

$$\varphi_i = \tan^{-1} \mu_i \tag{Eq. 11}$$

Coefficient of mobility

Coefficient of mobility (m_c) was calculated using the formula given by Stepanoff (1969) and Irtwange (2000).

$$m_c = 1 + 2\mu_i^2 - 2\mu_i (1 + \mu_i^2)^{1/2} \tag{Eq. 12}$$

Hopper side wall angle (slope)

Stepanoff (1969) stated that the slope angle (β) of the side wall of an hopper must be greater than the angle of internal friction of a material for easy flow of the material and it is calculated using equation 13, which was also used by Irtwange (2000).

$$\beta = 45^\circ + \varphi_i /2 \tag{Eq. 13}$$

The results were analyzed using Analysis of variance (ANOVA) and Duncan multiple range test (DMRT).

Results and discussion

Physical properties

Axial dimensions:

The statistically significant effect of seed moisture content on the length, width and thickness of locust bean seeds are shown in table 1 and table 2 shows the relationship between seed moisture content and the axial dimensions as per the regression equations. Both length and width of locust bean seed increased linearly with increasing seed moisture content in the range of 5.9 - 28.2% (d.b), while a decrease (in a polynomial trend) was recorded in the thickness.

The change in dimensions of locust bean seed, due to increase in moisture content is along its length and width axes. This is due to the filling of capillaries and voids in the seed with moisture, hence there is subsequent swelling of the seed. A similar trend was reported by Mohammad and Reza (2010) with sunflowers (*Helianthus annuus*). It is also due to the internal cell arrangement in the seeds which is in agreement with Nalbandi et al. (2010), on *Turgenia latifolia*. This shows that the shape and size of

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Table 2: Equations representing the relationship between seed moisture content and some physical properties of locust bean

Equation	**R²**
$L = 0.0418M + 9.9609$	0.889
$W = 0.0273M + 8.1127$	0.657
$T = -0.0019M^2 - 0.0693M + 5.7706$	0.636
$D_a = 0.0021M^2 - 0.0502M + 8.2826$	0.988
$D_g = 0.0024M^2 - 0.0676M + 8.0898$	0.962
$\Phi = -0.0033M^3 + 0.0329M^2 - 0.1038M + 0.824$	0.994
$S = 3.5786M^2 - 17.161M + 204.4$	0.981
$M_s = -9E\text{-}16M^3 - 0.0007M^2 + 0.0093M + 0.232$	0.918
$V_s = 2.1083M^3 - 21.946M^2 + 68.945M + 146.84$	0.961
$M_{tg} = -0.0695M^2 + 3.9273M + 227.64$	0.982
$\mu_{Plywood} = 0.0051M + 0.4449$	0.947
$\mu_{Glass} = 0.0005M^2 + 0.0221M + 0.3099$	0.993
$\mu_{Mild\ steel} = 2E\text{-}05M^4 - 0.0014M^3 + 0.0341M^2 - 0.3314M + 1.552$	1.000
$\mu_{Galvanized\ sheet} = -3E\text{-}05M^3 + 0.0019M^2 - 0.0295M + 0.6226$	0.712
$\mu_{Rubber} = -0.0003M^2 + 0.0156M + 0.3409$	0.782
$\mu_{Aluminium} = 1E - 05M^4 - 0.0007M^3 + 0.0167M^2 - 0.158M + 1.0231$	1.000
$\mu_{Stainless\ steel} = -5E\text{-}05M^3 + 0.0024M^2 - 0.033M + 0.672$	0.999

locust bean seeds is altered with increasing seed moisture content. This phenomenon determines the shape and size of screen holes (aperture) in the engineering design of separating or screening devices. Meanwhile, a linear increase in all the three axial dimensions for another locust bean variety (*Parkia filicoidea*) was reported by Sobukola and Onwuka (2010). This means that two varieties of the same seed will behave differently when subjected to moisture acquisition. It shows that they have different internal cell arrangement and will not use the same screening or separating devices. The effects of moisture content on the three axial dimensions were statistically significant (p<0.05) (Table 1).

Geometric and Arithmetic mean diameters

The relationship between moisture content of locust beans (*Parkia biglobosa*) seeds and their average diameters are expressed with the second degree polynomial equations (Table 2), although the seed moisture effect on both diameters is statistically significant (p<0.05).

The values of both diameters depend on the values and trends of the three seed dimensions. The seed diameters are important in determining the size of screen holes used in the design of separating and size-reduction machines.

Sphericity

The sphericity for most agricultural seeds, as stated by Mohsenin (1986) is in the range 0.32 – 1.00. Though the sphericity for *Parkia biglobosa* seeds decreased from 0.75 to 0.71 as seed moisture increased from 5.9 to 28.2% (d.b), it falls within the standard range and it is relatively high. The higher the sphericity, the higher the tendency for a seed to easily roll on any of its three axes. Therefore, locust bean seeds roll easily on any of their axes because of their high sphericity. But the ability to roll reduces as moisture content of the seed increases. The decrease in sphericity is due to the decrease in the thickness of the seed as the seed increased in length and width. Similar result was reported by Zewdu and Solomon (2008) for Grass pea (*Lathyrus sativus*) and Tekin et al. (2006) for Bambara bean (*Vigna subterranea*). The relationship between moisture content and sphericity is expressed in a polynomial equation of the third degree (Table 2) and the seed moisture effect on it is statistically significant (Table 1) at p<0.05.

Surface area

The surface area for *Parkia bioglobosa* seeds significantly increased (p<0.05) from 191.1 to 208.2 mm^2 with increasing seed moisture content (5.9 - 28.2% d.b.) in a polynomial (second order) trend (Table 2). A similar result was reported for coriander (*Coriandrum sativum*) seeds by Coskuner and Karababa (2007). On the other hand, Sobukola and Onwuka (2010), reported a linear increase in surface area for *Parkia filicoidea* in response.

Seed mass

The seed mass increased with increase in moisture content in a polynomial (third order) trend. This is

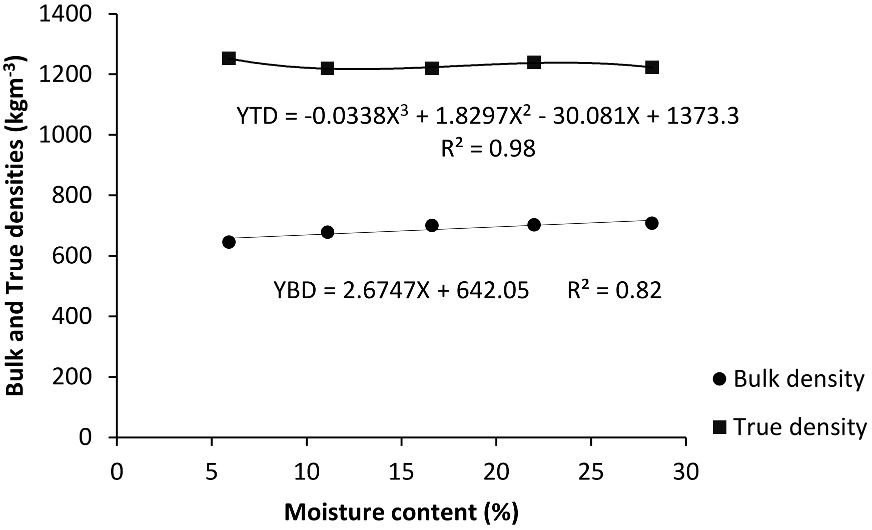

Figure 3: Influence of moisture content on bulk and true densities of locust bean

Table 3: Effect of moisture on porosity, bulk and true densities

MC (%)	BLKD (kgm^{-3})	TRD (kgm^{-3})	Porosity (%)
5.9	644.98c ± 7.92	1251.96a ± 55.50	48.40a ± 2.14
11.1	678.54b ± 9.79	1220.6a ± 40.25	44.36b ± 1.93
16.6	700.28a ± 8.62	1220.6a ± 40.25	42.58b ± 1.64
22	702.48a ± 9.92	1239.22a ± 85.88	43.10b ± 3.71
28.2	708.06a ± 12.05	1222.2a ± 62.16	41.91b ± 3.78

MC= Moisture content, BLKD = Bulk density, TRD = True density. Values in the same column followed by different letters (a-c) are significant ($p<0.05$).

due to the fact that drier seeds take in moisture more rapidly than wet seeds. The faster the colloids in the seed get saturated with water, the slower the rate of water intake. Since the intake of water increases the mass of the seed, there must be a sharp or rapid increase in the seed mass at the very early moisture levels.

Seed volume

Similar to seed mass, seed volume showed a rapid increase at the initial stage when the moisture level increased from 5.9 to 11.1% d.b but gradually decreased as moisture content increased to 28.2% d.b. The relationship between moisture content and seed volume for locust bean (*Parkia biglobosa*) was expressed by a third-degree polynomial equation (Table 2). Seed volume considerations have practical applications in production process such as separation and product loading.

Thousand grain mass (TGM)

Thousand grain mass significantly increased from 247.6 to 284.2 g and showed a second order polynomial relationship with variation in moisture content (Table 2). This is important in the design of conveyors, transport and storage equipment.

Gravimetric properties

Bulk and true densities

Bulk density increased linearly with increasing moisture content of seeds while the true density decreased in a third order polynomial trend (Figure 3). The reason for increase in bulk density was due to mass of seed increasing more rapidly than

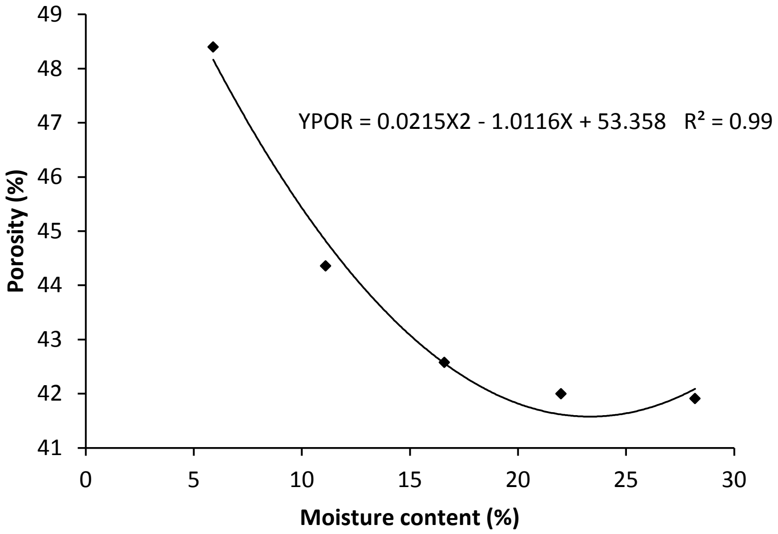

Figure 4: Porosity of locust bean as affected by moisture content

the volume of seeds while for true density, the volume of seed bulk increased more rapidly than the mass of the seed bulk. For the true density of locust beans, moisture content had no statistically significant effect but had significant effect on bulk density (Table 3). Similar results were reported by Milani et al. (2007) for Curcubit seeds. Decreases in both bulk and true densities were found for *Parkia filicoidea* by Sobukola and Onwuka (2010). Igbozulike and Aremu (2009) reported an increase in bulk density and a decrease in true density for *Garcinia* kola seeds as seed moisture content increased.

Porosity

Porosity depends on the values of both bulk and true densities (Milani et al., 2007). From Figure 4, the porosity for *Parkia biglobosa* decreased with increasing seed moisture content. In practical terms, the decreasing porosity with increasing seed moisture content means that pore spaces within the bulk of seeds reduced. Also, the seeds became very wet and sticky at high moisture levels thereby filling some of the voids with the water film on the seed surface; therefore porosity decreases. Reduced porosity hinders aeration. Therefore, drying the seeds in wet state will require more energy from the drying fan or blower. A decrease in porosity was reported for *Parkia filicodiea* by Sobukola and Onwuka, (2010) and for beniseed by Tunde-Akintunde and Akintunde (2007). The regression equation expressing the relationship between porosity and moisture content for *parkia biglobosa* is given in Table 2.

Frictional properties

Static coefficient of friction

Table 4 shows the summary of the values of static coefficient of friction of locust bean on seven different structural surfaces. Static coefficient of friction is needed in the choice of structural material for the design of machine components involving the flow of bulk granular materials. Comparing the value of static coefficient of friction at the two endpoints of the moisture range (5.9 and 28.2% d.b.), there was a general increase for all the structural surfaces except aluminum and stainless steel on which a decrease was recorded. The increase in static coefficient of friction was due to increased adhesion between the seeds and the rough surfaces of the test materials while the decrease was due to the smoothness and more polished surfaces of aluminum and stainless steel compared with other test materials. Meanwhile, the effect of seed moisture content on galvanized iron, aluminium and stainless steel was not statistically significant (p<0.05). Linear increase in static coefficient of friction for Parkia biglobosa seeds was found on plywood only, while its increases on glass, mild steel galvanized sheet and rubber were in a polynomial trend. Plywood recorded the highest value of static coefficient of friction (0.61), followed by rubber (0.60) at 28.2% moisture content level. Sobukola and Onwuka, (2010) recorded

Table 4: Effect of seed moisture content on static coefficient of friction of locust bean on different material surfaces

	Moisture content (%)				
	5.9	**11.1**	**16.6**	**22**	**28.2**
Plywood	0.48c ± 0.02	0.50bc ± 0.04	0.53b ± 0.03	0.54b ± 0.03	0.60a ± 0.01
Glass	0.04b ± 0.05	0.050b ± 0.04	0.54a ± 0.03	0.55a ± 0.07	0.54a ± 0.01
Mild steel	0.52a ± 0.04	0.46b ± 0.07	0.55a ± 0.02	0.52a ± 0.009	0.54a ± 0.02
Galvanized iron	0.51a ± 0.04	0.47a ± 0.03	0.51a ± 0.02	0.51a ± 0.04	0.52a ± 0.03
Rubber	0.41d ± 0.04	0.50c ± 0.03	0.56ab ± 0.03	0.51bc ± 0.04	0.60a ± 0.05
Aluminum	0.54a ± 0.02	0.52a ± 0.04	0.56a ± 0.043	0.53a ± 0.06	0.52a ± 0.04
Stainless steel	0.55ab ± 0.03	0.53ab ± 0.05	0.55ab ± 0.04	0.56a ± 0.02	0.50b ± 0.04

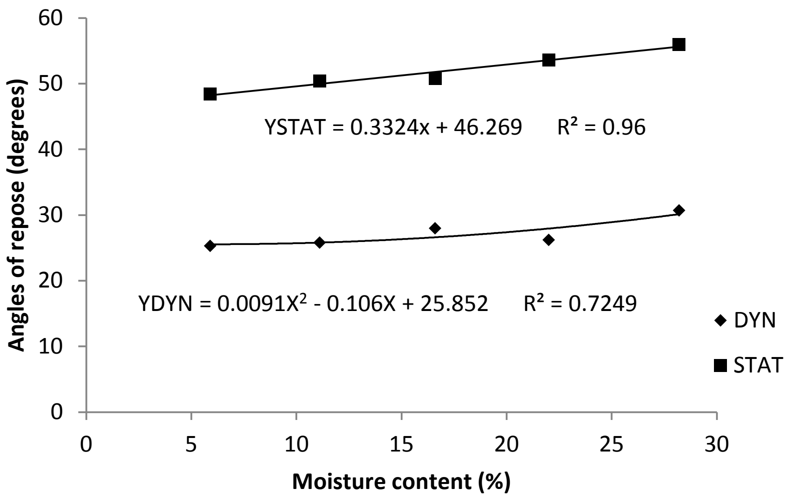

Figure 5: Effects of moisture content on the angles of repose of locust bean

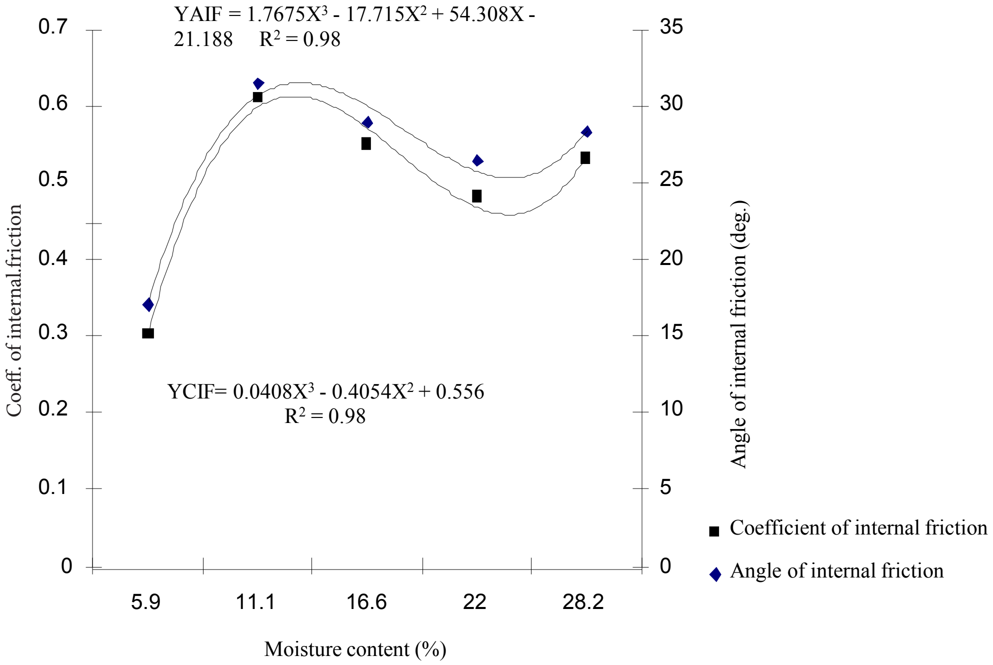

Figure 6: Effect of moisture content on coefficient and angle of internal friction of locust bean

the highest static coefficient of friction for *Parkia filicoidea* on plywood surface (1.00). Equations expressing the relationship between moisture content and static coefficient of friction on the different surfaces for *Parkia biglobosa* are shown in Table 2.

Static and dynamic angles of repose

Mohsenin (1986) stated that the angle of repose determines the maximum angle of a pile of grain in the horizontal plane and it is important in the filling of a flat storage facility when grain is not piled at a uniform depth, but rather is "peaked". Both static and dynamic angles of repose of *Parkia biglobosa* increased with increase in the seed moisture content in the range of 5.9 - 28.2% (d.b). The static angle of repose was higher at each moisture content level than the dynamic angle of repose (Figure 3). The higher the sphericity, the higher the ability of

Table 4: Effect of moisture content on coefficient of mobility and hopper side wall slope

Moisture content %	Coefficient of mobility	Hopper side wall slope / angle (deg.)
5	0.55a ± 0.07	53.5c ± 1.82
11	0.318c ± 0.07	60.81a ± 2.67
16	0.347c ± 0.02	59.46ab ± 0.77
22	0.393b ± 0.03	58.22b ± 1.10
28	0.357bc ± 0.01	59.11d ± 0.48

the seeds to roll over their three axes on material surfaces, hence the lower the angle of repose. Also, the dryer the seeds, the less they stick together and the more easily they slide and roll over one another, and hence a low angle of repose. A reason for high angles of repose is the sticky nature of the seeds at high moisture content. At high moisture levels, the seeds of *Parkia biglobosa* tend to stick to one another because of the presence of excess water films on their surfaces. This hinders their free flow therefore, angle of repose will increase. The relationship between the angles of repose and moisture content is given in Figure 5.

Coefficient and angle of internal friction

Both coefficient and angle of internal friction followed the same pattern of a polynomial increase as moisture content of the seeds increased (Figure 6), with the angle of internal friction higher than the coefficient of internal friction at all moisture content levels. At higher moisture content levels, locust bean seeds stick together, resulting in enhanced stability and less flow ability. This definitely increased the value of coefficient of internal friction, which in turn increased the value of angle of internal friction. The angle and coefficient of internal friction are important in the design of hoppers and flow channels in processing machines and equipment for seeds. Equations for the relationship between moisture and coefficient and angle of internal friction are shown in Table 2.

Coefficient of mobility

The coefficient of mobility for *Parkia biglobosa* seeds decreased (Table 4) from 0.55 to 0.35 with increasing seed moisture content in the range 5.9 - 28.2% (d.b). The decrease in coefficient of mobility was due to the sticky surfaces of the seeds at high moisture content which hindered the freedom of the seeds to move easily. At high moisture levels, the seeds also tend to adhere to the surface on which they are, which constitutes a hindrance to the fluidity of the seeds. The equation representing the relationship between coefficient of mobility and moisture content is expressed in Table 2.

Irtwange, (2000) stated that, 'for easy flow of material, the slope angle of the side wall of hoppers must be greater than the angle of internal friction of the material'. The hopper side wall angle increased, following a similar trend with the angle of internal friction (Table 4). The hopper side wall slope at each moisture content level therefore suggests the angle for which the hopper side walls should be designed for Parkia biglobosa seeds at the specified moisture levels or range. The equation expressing the relationship between moisture and hopper side wall angle for locust bean is shown in Table 2.

Conclusion

The study was carried out to determine the influence of seed moisture content on some engineering properties of locust beans at 5.9, 11.1, 16.6, 22 and 28.2 % (dry basis) moisture levels. Physical, gravimetric, frictional, flow, and mechanical and thermal properties of locust bean and how they relate with moisture content were expressed using regression equations. A property data for the engineering design of necessary machines and equipment for the harvest, post-harvest handling and processing of locust bean was developed. The length and width of locust beans increased but the thickness decreased. The arithmetic and geometric mean diameters which describe the size of locust bean grain increased in a polynomial trend. An increase was obtained for surface area and a decrease was recorded for sphericity of locust bean as moisture content increased. The mass of a thousand locust bean grains also increased linearly. Individual seed mass increased linearly and a polynomial increase in seed volume was obtained. Bulk and true densities increased and decreased respectively. A polynomial decrease was however recorded for porosity.

Static coefficient of friction on plywood, glass, rubber, mild steel and galvanized metal sheet surfaces increased but a decrease was obtained on stainless steel and aluminum surfaces. Both static and dynamic angles of repose recorded a linear increase. The coefficient and angle of internal friction both increased in a polynomial trend and linear increase in both normal and shear stress was obtained under varying loads. Coefficient of mobility showed a linear decrease as the hopper side wall slope (or angle) increased linearly. At each moisture level, it was observed that the hopper side wall slope was higher than the angle of internal friction of the seeds which was necessary for easy flow of the seeds in the design of hoppers and delivery chutes or feeders. It was established that the effect of seed moisture in locust beans was statistically significant ($p<0.05$) on all the properties investigated except true density, static coefficient of friction on galvanized iron and aluminium surfaces. The equations for predicting the behavior of locust bean seeds at any moisture level were generated. With a property data generated from the results, it is therefore possible to design and develop equipment for different locust bean processing stages.

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Conflict of Interests

The authors hereby declare that there is no conflict of interests.

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