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The Effect of Moisture Content on Some Physical and Engineering Properties of Locust Beans

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--ABSTRACT---
Locust bean is a perennial edible crop and important source of food that must be processed for preservation and availability throughout the year. Physical and mechanical properties of locust beans are necessary for the design of equipment to handle, transport, process and store the crop. The properties were evaluated as a function of moisture content of locust beans. The locust seeds were tested for size and shape, true density, bulk density, porosity, sphericity, static coefficient of friction on plywood, aluminium and stainless, angle of repose and specific heat atmoisture conten to franging from 10.50 and 20.76 % (dry basis). The average length, width, thickness and geometric mean diameter of the locust beans were 12.04, 8.36, 5.04 and 7.50 mm respectively, while the true density, bulk density, porosity, surface area and sphere city were, 1166.09 kg/m^3 ,729.90 kg/m^3, 37.37 %, 204.25 mm^{2}and 0.67, respectively. The respective values of static coefficient of friction for plywood, stainless and aluminium were 0.56, 0.51 and 0.48 while the angle of repose was 40.17^o.The higher friction of coefficient was observed on plywood and the lowest on aluminium. The specific heat was observed to be 3.8 kJ/kg/Kat moisture content of 10.50 %.The information provided in this study will be useful for locust bean seed processing machine design and fabrication as well as industrial processing and structural design of storage bin of the seed.

Keywords: *Locust bean seed, moisture content, friction surfaces, physical and engineering properties.*

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I. INTRODUCTION

The locust bean tree is a perennial and an important food tree that plays a very vital role in the rural economics of West African countries [1]. The African locust bean, *Parkiabiglobosa*(Jacq) Benth, is a perennial leguminous tree, found growing wildly in forested and savanna belts in Nigeria [2]. Fermented *Parkia* seeds are locally used in traditional soup seasoning, medicinal preparations and food additives [3]. In addition, boiled water obtained during fermentation process of locust beanseed is used in controlling termite infestation at the local level. In spite of this practice, few reports exist on the termiticidal properties of aqueous solution of locust beanseed.

The high cost of animal protein has directed the interest of people towards several leguminous seed protein as potential source of vegetable protein for human consumption and livestock feed [4]. Among the plant species, grain legumes are considered as the major source of dietary proteins. They are consumed worldwide, especially in developing countries where consumption of animal protein may be limited as a result of economic, social, cultural or religion factors. African locust bean seed (*Parkiabiglobosa*) is very rich in protein and belong to the sub-family *Mimosoideae* and family *Leguminosea*. The locust bean tree are found from thelower Sudan Savanna Southwest to the derivedSavanna and the lowland forest where mean annual rainfall may be less than 400 mm [5] .The tree has the capacity to withstand drought conditions because of its deep tap root system and ability to resist transpiration.

The leaf is rich in nitrogen and use as manure. The yellow pulp surrounding the seed is edible in many forms and the seeds are made into condiments called ‘iru’, in Yoruba, ‘dawadawa’ in Hausa which is used extensively as flavoring and additives to soup and stew. The seed contain 54% fat and 30% protein in addition to vitamins and minerals such as calcium, potassium and phosphorous [6]. Dadawa cube is a seasoning that is produced from a mixrure of locust bean and soya bean, this combination makes the seasoning to be more nutritious if consumed [7] .

Machine and equipment design for handling processing and storage of some tropical agricultural products (locust bean seed) generally have low efficiency. This is as a result of insufficiency and unavailability of adequate data on physical and engineering properties of these products [8]. Hence, some of the physical and engineering properties that are determined to improve the efficiency of processing equipment are; porosity, density, sphericity, shape and size, colour, surface area, angle of repose, and frictional property [9].

The survey that was locally conducted in some parts of Oyo State on the production process of locust bean seed indicated that most of the depulping processes are carried out with the aid of locally woven basket or perforated calabash. The decorticated locust beans are placed in the basket or perforated calabash and submerged in a gentle flowing river, stream or pond. The mixture of seed and pulp is stirred with the hands to push out slurry pulp through the pore spaces of the basket into the flowing water medium [10]. This manual depulping operation can be seen as labour intensive, time consuming and required large volume of water, thereby polluting the water body. Also, the ease of depulping operation is a function of availability of still running stream [11] . Therefore, the need to determine some engineering and physical properties of locust bean seed which will reduce high dependency on large volume of water is desirable.

The aim of this project is to determine effect of moisture content onphysicaland mechanical properties of locust beans cultivated in Ogbomoso, Nigeria. The parameters measured were bulk and true density, shape and size, surface area, porosity and sphericity, also angle of repose, specific heat and static coefficient of friction on three surface materials.In this study, existing drafting table and apparatus for determining angle of repose were modified to be suitable in carrying out the testing analyses.

II. MATERIALS AND METHODS

2.1 Sample preparation

Locust bean pods were harvested in September 2013 from the research farm in Ladoke Akintola University of Technology, Ogbomoso ($8^o07'$ N, $4^o16'$E) in Nigeria.The available species (*Parkiabiglobosa*) used in the study is the prevalent variety in the studied region. This work was carried out in the Laboratory of Crop Processing and Storageof Department of Agricultural Engineering in the institution. The pods were manually depoded and the yellow pulp was removed by washing in a nearby flowing stream, the seeds were put in a basket to drain the water. The moisture content of the locust bean seed after harvesting was 20.76% dry basis. The moisture content of samples was measured at 103±5℃ by drying them in an oven for 24 h [12].

2.2 Physical properties of locust bean seed

The samples were placed in a polythene bags and sealed. The sealed samples were kept in a curing room for two days to enable the moisture content to distribute uniformly through the seeds. After the locust bean seeds reached equilibrium moisture, each sample was placed in a dessicator. Before each test, the required quantity of the samples was taken out of the dessicator and allowed to warm to room temperature. The amount of moisture to be added over the level of

equilibrium moisture was calculated using equation (1) as expressed by [13].

$$Q = W_i \frac{M_f - M_i}{100 - M_f} \qquad (1)$$

Where Q = equilibrium moisture content

W_i= weight of the sample

M_f= final moisture content

M_i= initial moisture content

The physical and engineering properties of locust bean seed were investigated at these five moisture levels 20.76, 18.06, 16.83, 13.98 and 10.50% dry basis. For locust beans moisture content considered, 100 seeds were selected at random from the basket, dried down to the desired moisture content and the length, width and thickness were measured in three mutually perpendicular directions as shown in Fig. 1, using a Vernier caliper at 0.001 mm accuracy, where a, b and c are the dimensions of the seed in form length, width and thickness respectively.

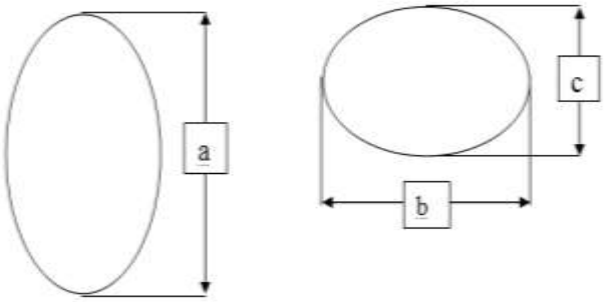


Fig. 1: The three principal axes of the locust bean seed

Some researchers [9], [14], [15] and [12] have measured these dimensions for other grains and seeds in a similar way to determine size and shape properties. Seed mass was measured with an electronic weighing balance of 0.01g accuracy. The geometric mean diameter, D_g of the three axial dimensions was calculated using equation (2) by [12] and [16]:

$$D_g = (LWT)^{1/3} \quad (2)$$

The sphericity(φ), seed volume (V) and surface area (S)of the samples depending on the shape of the seed were determined using Equations (3), (4) and (5) as described by [17]; [18]; [19] and [13].

$$\varphi = \frac{(LWT)^{1/3}}{L} \quad (3)$$

[17] and [16] also expressed the relationship of sphericity, φ seed volume, V and seed surface area, S_a as shown in equations (4 to 7):

$$V = \frac{\pi B^2 L^2}{6(2L-B)} \quad (4)$$

$$S_a = \frac{\pi B L^2}{2L-B} \quad (5)$$

Where, $B = (WT)^{0.5}$ (6)

The surface area, S was also given by [20] in equation (7):

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

The bulk density (γ), was determined by using an empty cylindrical container of 100 ml volume (V_c) and predetermined weight (W_i) of the container was filled with locust bean seeds. The bulk density container was filled to 5 cm above the top and the seeds were tapped 20 times vertically on table and leveled with a flat ruler to obtain uniformity and final weight (W_f), recorded [17]. The bulk density was calculated using equation (8). All measurements were replicated five times at the moisture content considered and the average values were recorded. $\gamma = \frac{W_f - W_i}{V_c}$ (8)

The true density (ρ) was carried out using water displacement technique [14] (Dutta *et al.*, 1988). The dried weight of samples was first measured and then the samples were submerged into water and displacement volume was determined using equation (9):

$$\rho = \frac{m_s + m_w}{V_s + V_w} \quad (9)$$

According to [9] and [17], the porosity ($\in$),of the seed was determined using equations 10 and 11, these show relationship of true and bulk densities.

$$\in = \frac{\rho - \gamma}{\rho} \quad (10)$$

$$\in = 1 - \frac{\gamma}{\rho} \times 100 \quad (11)$$

whereγ is the bulk density and ρ is the true density.

2.3 Description of Modified Apparatus

There are two apparatuses that were modified to measure both the angle of repose and coefficient of friction on three surface materials and these are described as follows:

A drafting table presented in Fig. 2 was constructed and used to determine the static coefficient of friction with respect to three friction surfaces: plywood, aluminium sheet and stainless steel. It was modified by using 0.013 m plywood to construct 0.58 m × 0.53 m tabletop and 0.051×0.051 m frame was used to build the stand. At the centre of the tabletop, a slab of 0.47×0.33 m, on which different surface materials (stainless steel and aluminium plate) were attached was cut . A screw of 10.88 mm diameter was made to pass through an affixed knot at an angle (approximately 60̊ to the horizontal) under the tabletop to raise the slab effectively as the screw is turned manually through the knot [8]. The angle of inclination was measured with the use of an attached protractor at the point of hinge joint of the slab with tabletop.

Themodified apparatus presented in Fig. 3, was made up of0.013 m thickness of plywood to make a box of0.17 × 0.17 × 0.20 m. A piece of 3 mm glass was installed to one side of the box to serve as a window. A hole of 0.13m diameter was drilled at the centre base of the box through which a funnel with 13 cm diameter was installed. Adjustable screw legs supporting a circular platform of diameter 0.12 m was made using a pipe of 0.025m diameter which houses another pipe of 0.02m diameter, the length of the pipe is 0.105 m and at 2/3 of the length from the base, a hole of 5 mm diameter was drilled on the bigger pipe. Three of such pipes were made and were screwed to the base of the box. Three holes of 0.02 m were drilled on 0.13 m diameter funnel through which the three adjustable legs passed to hold the platform. The adjustable plate was raised to a certain height in the box to allow the seeds to follow [20]. Then the box was filled with the sample and stopper was removed from the funnel opening making the seed to flow, hence forming a heap on the platform as shown in Fig.4.

Fig.2: A drafting table to determine coefficient of static frictionFig. 3: An apparatus for measuring angle of repose

2.4 Mechanical Properties Of Locust Bean Seed

The coefficient of friction of the seed was determined at desired moisture content on three surfaces such as; plywood, aluminium and stainless. The seeds were first placed on the plywood and raised by the screw until the seed started to slide, then the inclination angle was measured using the drafting table shown in Fig.2. The same procedure was used for other surfaces by following the method described by [18]

The coefficient of friction of the seeds was calculated using Eq. (12).

$$\mu = \tan\theta \quad (12)$$

Where μ is the coefficient of friction, and θ is an angle of inclination.

The static angle of repose of the seed was studied using a modified apparatus presented in Fig. 3.Then the box was filled with the sample and stopper was removed from the funnel opening making the seed to flow, hence forming a heap on the platform as shown in Fig.3. This demonstrated the diagrammatic system of measuring the angle of repose when the seeds were filled in the apparatus.The static angle of repose was determined using Eq. (13)

$$Rep^{o} = \tan -1 \frac{2(H_c - H_p)}{D_p} \qquad (13)$$

Where H_c= height of the triangle, H_p = height of the platform, D_p = diameter of the platform

Where H_p is the height of platform from the base of box, D_p is the diameter of the circular platform and $H_c$is the height of conical heap from the base of the box.The height (H) of the heap was then determined as described in equation (14):

$$H = H_c - H_p \qquad (14)$$

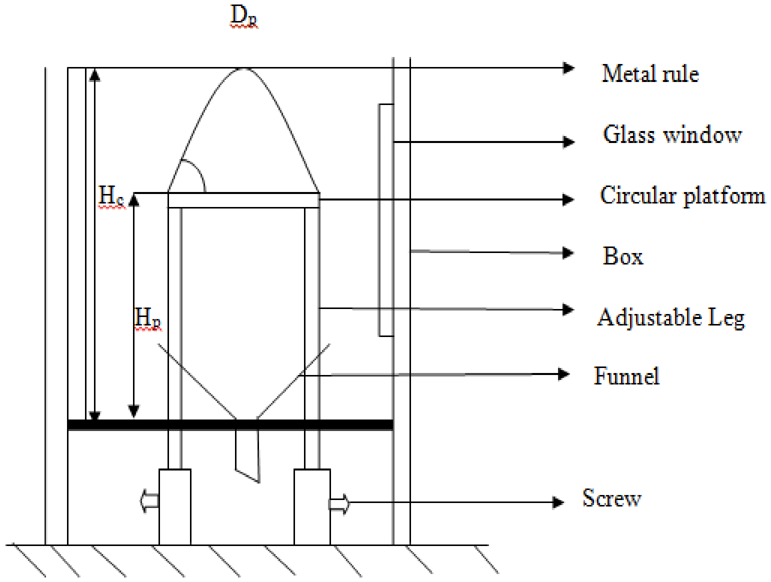


Fig. 4: Design diagram of modified apparatus to measure angle of repose

2.5 Heat Capacity of Locust Bean Seed

The specific heat of the seeds was determined using copper calorimeter with the method of sample-water mixture. A certain quantity of seeds with known initial temperature was weighed boiled to the maximum temperature. The water of known weight and initial temperature were poured into weighed calorimeter. The final temperature of the boiled sample was measured and recorded, and then mixed with the water in calorimeter, covered and stirred until the equilibrium temperature was reached. Then the specific heat of the seeds was computed using the equation (15) described by [21].

$$C_s = \frac{(M_cC_c + M_wC_w)(T_e - T_{wi})}{M_s(T_{si} - T_e)} \qquad (15)$$

where C_s = Specific heat of the sample (J/kg/K)
M_c, M_s, M_w = Mass of calorimeter, sample and water respectively (kg)
C_c, C_w = Specific heat of calorimeter and water respectively (J/kg/K)
T_e = Equilibrium temperature (K)
T_{wi} = Initial temperature of water (K)
T_{si} = Initial temperature of sample (K)

2.6 Statistical Analysis

Finally, all the experiments were replicated three times and averages were calculated. All the data were analyzed statistically for various parameters using Design expert 6.8 version using one factorial design. Different mathematical equations that show relationship between moisture content and experimented properties were derived and ANOVA was also used to determine the level of significance at 99% confidence level.

II. RESULTS AND DISCUSSIONS

3.1 Dimensional Properties

Table 1 demonstrated the mean, maximum and minimum values of all the properties investigated.The coefficient of variation was calculated to determine the level of each property. The parameters are significant at 99 % confidence level because the cumulative values are less than 0.99 levels. Table 2 presented the dimensions of locust bean seed at different moisture contents ranging from 20.76 to 10.50 %. It was observed that as moisture content increased, the dimensions also increased. This shows the expansion of the seed due to absorption of moisture by the cellular walls of the seed. There is significant difference between the values at P<0.01. As reported by [13] the values of length, width and thickness were 8.27, 8.74 and 9.01 mm respectively in rice grain which were lower than the results obtained in this study. The mathematical equations generated statistically show the relationship between the axial dimensions (L, W, T and D_g) and moisture content of the seed as given in equation (16-19):

$$L = 7.46 + 0.29MC \quad (R^2 = 0.9048) \qquad (16)$$
$$W = 4.24 + 1.27MC \quad (R^2 = 0.9967) \qquad (17)$$
$$T = 1.03 + 0.28MC \quad (R^2 = 0.9689) \qquad (18)$$
$$D_g = 1.77 + 0.375MC \quad (R^2 = 0.8173) \qquad (19)$$

The results indicate that there is important positive relationship between moisture content and axial dimensions of the seed. These results are in conformity with other agro-granular materials reported by researchers; [22] for rapeseed, [23] for popcorn kernels and [13] for rice grain.

Table 1: Some physical properties of locust beans (*Parkiabiglobosa*)

Property	Mean	Maximum	Minimum	CV (%)
Length (mm)	12.04	13.18	10.11	84
Width (mm)	8.36	10.02	6.05	72
Thickness (mm)	5.40	6.98	4.02	74
Equivalent diameter(mm)	7.50	9.51	6.15	82
Sphericity (%)	0.67	0.74	0.61	91
Surface area (mm^2)	204.24	284.13	118.82	58
Bulk weight of seeds	23.0	24.31	22.47	98
Porosity (%)	37.40	39.17	35.7 7	96
Bulk density (kg/m^3)	729.90	739.55	721.69	96
True density (kg/m^3)	1166.09	1215.70	1123.58	96
Angle of repose (^{o})	40.77	44.17	36.87	94

The values are significant at 99 % confidence level
CV= coefficient of variation

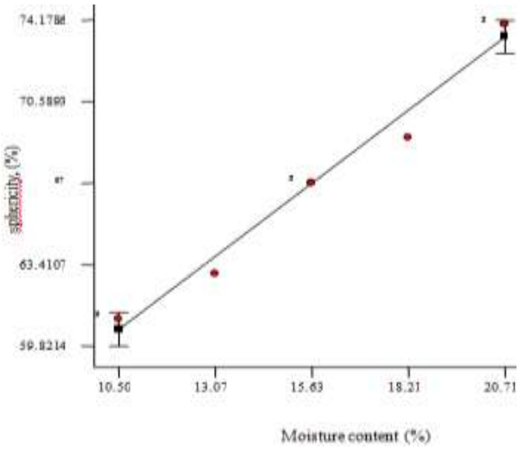
Table 2: Effect of moisture content variation on some properties

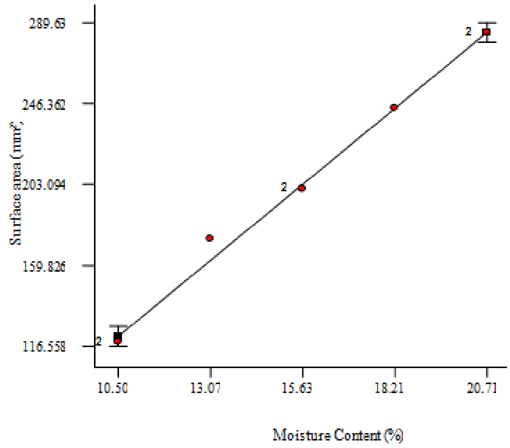
Moisture Content (%db)	Length,L(m)	Width,W(m)	Thickness,T(m)	Geometric mean diameter, D_g (m)	L/T	L/W	L/D_g		
10.50	10.11±0.41	6.05±0.11	4.02±0.22	6.15±0.79	2.515	1.671	1.64		
13.98	11.95±0.43	7.43±0.12	4.93±0.24	7.44±0.81	2.424	1.608	1.61		
16.83	12.02± 0.52	8.87±0.14	5.11±0.31	7.99±0.84	2.352	1.355	1.50		
18.06	12.92±0.57	9.45±0.16	5.98 ±0.36	8.81±0.87	2.161	1.367	1.47		
20.76	13.18± 0.59	10.02±0.17	6.98±0.39	9.51±0.92	1.888	1.315	1.39		

3.1.1 Sphericity

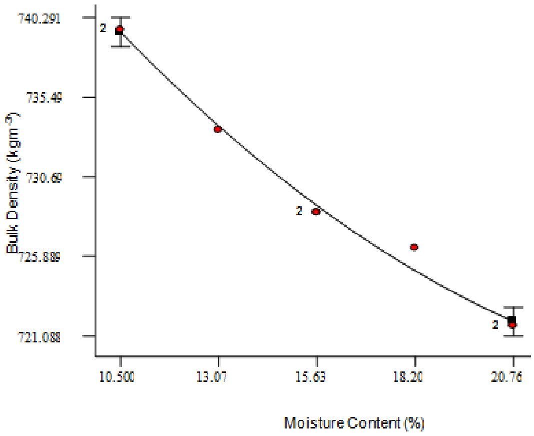
The sphericity of the seed increased with increasing moisture content. The sphericity of locust bean seeds calculated at different moisture content was found to increase from 61 to 74 % and the sphericity was statistically significant at 99 % confidence level as moisture content increased from 10.50 to 20.76 %. Seeds graded uniformly, according to size, provide uniform germination and usually give increased harvesting.The shape of the seeds was observed to be oblong and round since the geometric characteristic of the seed has the vertical diameter greater than the horizontal diameter and approaches circular shape. As reported by [13] similar trend for rice grain and [24] for African oil bean seed. The regression equation (20) represents the relationship between sphericity and moisture content.

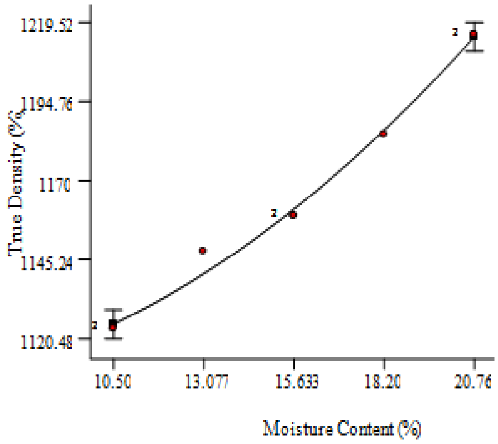
$$\varphi = 0.4737 + 1.26MC \quad (R^2 = 0.9836) \qquad (20)$$



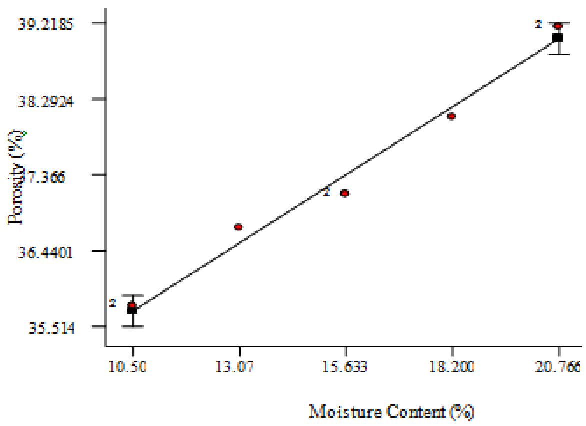


(a) **(b)**





(c) **(d)**



(e)

Fig. 5: Effects of moisture content on physical properties locust bean seed: a) sphericity b)surface area c) bulk density d) true density e) porosity

3.1.2 Surface Area

It can be seen from Fig. 5a that surface area of locust bean seed increases linearly from 118.82 to 284.13 $mm^2$and significant at 99 % confidence level as moisture content increases from 10.50 to 20.76 %. The increase in these values might be due to rate of adsorption of moisture by the seed and also depend on the three principal dimensions of the seeds. This result is in conformity with the values reported by [25] for hemp seed and [26] for cowpea seed. The mathematical representation of variation of surface area and moisture content is given in equation (21):

$$S_a = 450.63 + 15.83MC \quad (R^2 = 0.9946) \qquad (21)$$

3.1.3 Bulk and True Density

The effect of moisture content on bulk density is presented in Fig. 5b.The bulk density of the sample was observed to decrease from 739.55 kg/m^3 and 721.69 kg/m^3 as moisture content increase from 10.50 to 20.76 % dry basis. This might be attributed to increase in weight of the seed which might be lower than volumetric expansion of the bulk [27]. Similar trend was reported by [28] for sorghum seeds and equation (22) show the relationship between bulk density and moisture content.

$$\gamma = 718.53 - 0.37MC \quad (R^2 = 0.9929) \qquad (22)$$

The true density decreased from 1123.58 $kg/m^3$to 1215.70 kg/m^3as the moisture content increased from10.50 to 20.76% dry basis. The values are significant at 99 % confidence level and linear graph is presented in Fig. 5c. This effect was as a result of the higher rate of increase in volume than weight. The density values of locust bean can be used in design of storage bins, handling and transportation system of the seed. It can be useful in cleaning, sorting, grading and quality evaluation of the products [27]. The effect of moisture content on true density is represented in equation (23).

$$\rho = 1381.48 + 19.43MC \quad (R^2 = 0.9929) \qquad (23)$$

3.1.3 Porosity

The values of porosity varied from 35.77 to 39.17% at different moisture levels. The result indicated linear relationship between porosity and seed moisture content as shown in Fig. 5d. Differences between the values are significant at 99 % level. This occurs as a result of expansion and swelling of locust bean seed which might be due to more void spaces between the seeds and high bulk volume. Similar trends have been reported [13] and [29] for cactus pear. The interaction between porosity and moisture content is described in equation (24):

$$\epsilon = 42.43 + 0.33MC \quad (R^2 = 0.9833) \qquad (24)$$

3.1.4 Angle of repose

The experimental results for the angle of repose were observed to increase with respect to moisture as shown in Fig. 6a.The angle of repose increased as moisture content increased from 10.50 to 20.76% for all surfaces. This was found to increase significantly at 1 % probability from 36.87 to 44.17^o in the moisture range of 10.5 to 20.76 % dry basis. The angle of repose for locust bean was observed to increase linearly and has the following relationship with the moisture content:

$$Rep\,^o = 0.9804MC + 27.63, \quad (R^2 = 1.00) \qquad (25)$$

[30] and [20] found that the values of angle of repose for wheat increased from 37.28 to 47.33^o and 34.7 to 45.0^o in the moisture range of 8 to 18 % and 0 to 22%, respectively.

3.1.5 Static coefficient of friction

The static coefficient of friction of locust bean seeds on three surfaces (plywood, stainless steel and aluminium) against to moisture content levels ranging from 10.5 to 20.76 % wet basis are presented in Fig. 6b. The static coefficients of friction for plywood (parallel to the grain) was observed to be highest, followed by stainless and then aluminium. The static coefficient of friction increased against plywood (parallel to the grain), stainless steelwith5% probability level and aluminium with 1 % probability level with increase in moisture content. This was due to the increased adhesion between the seeds and the material surfaces at higher moisture content levels. As the moisture content increased from 10.50 to 20.76% wet basis, static coefficient of friction increased from 0.51 to 0.6 for plywood, 0.47 to 0.54 stainless and 0.45 to0.50 aluminium.

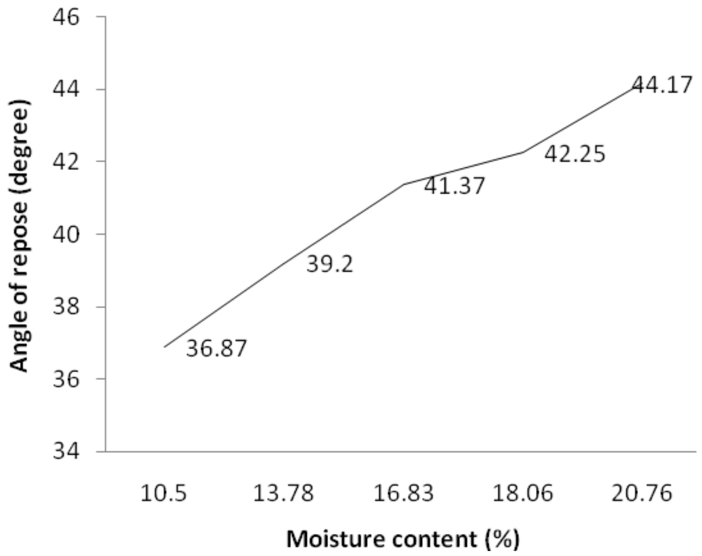


Fig 6a: Effect of moisture content on angle of repose

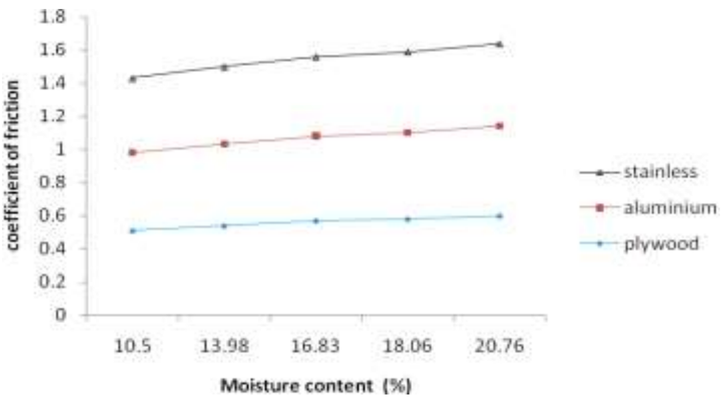


Fig 6b: Effect of moisture content on coefficient of friction on plywood, aluminium and stainless

The static coefficient of friction and angle of repose is necessary to design conveying machine and hoppers used in planters and milling machines which shows the flow of materials during processing. When seeds are ground in mills, the rupture force must be known in order to achieve desirable properties without unnecessary expenditure of energy. At all moisture contents, the higheststatic coefficient of friction were on plywood, followed by stainless steel and aluminium. This may be due to unpolished surface of plywood than other materials used. The linear relationships between static coefficient of friction (μ) and moisture content on plywood, stainless steel and aluminiumare presented in Table 3. The Adj. R^2 values of the three surfaces are also given in the table while Pred. R^2 values of respective surfaces are 0.9874, 0.9863, 0.9948. This indicates reasonable agreement between experimented and predicted values; hence there is adequate signal for the engineering properties to be used for design purposes

Table 3: Regression equations relating to static coefficient of friction of locust bean seed

Surfaces	Equation	R^2	Adj. R^2	Prob>F
Plywood	$\mu_P = 0.3152 + 0.0236MC$	0.9935	0.9908	0.0001*
Aluminium	$\mu_A = 0.4013 + 0.0061MC$	0.9910	0.9895	0.0001*
Stainless	$\mu_S = 0.1852 + 0.0463MC$	0.9993	0.9988	0.0001*

**significant at 99 % level*

Similar results were found by [31], [20], [30] and [32] for cotton, wheat, and sweet corn seeds respectively. [30] reported that the friction coefficient of three wheat varieties (shiraz, karoun and shiroudi) increased linearly against surfaces of three structural materials, namely, compressed plastic (0.43 – 0.53), galvanized iron (0.33 – 0.53) and plywood (0.35 – 0.41) as the moisture content increased from 8 to 18% wet basis. Finally, the specific heat capacity of locust bean seed at the desired moisture content was found to be 3.82 kJ/kg/Kat moisture content of 10.50 %.It is necessary to know the heat required to boil the samples to remove seed coats easily.

IV. CONCLUSIONS

In this study, some physical and engineering properties of locust beanseeds which may be useful for designing some of the equipment used for the crop processing, were investigated in the range of moisture content 10.50 to 20.76 % dry basis. The physical and other engineering properties depend on moisture content. The axial dimensions of locust bean seed increase with moisture content due to water adsorption by seed. The true density, sphericity, surface area, porosity, geometric mean diameter and angle of repose of the seed also increased with moisture content. The bulk decreased with an increase in moisture content of locust beans. The static coefficient of friction was highest for plywood, followed by stainless steel and aluminium. The specific heat capacity of locust bean seed at the desired moisture content was established. This work is recommended for locust beans processors, machine designer and fabricator.

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