© 2018 IJSRSET | Volume 4 | Issue 4 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section : Engineering and Technology

Moisture Dependent Physical Properties of Gmelina Fruits and Nuts

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ABSTRACT

Physical properties of crops are important parameters to be considered during the design and development of harvesting, separation, cleaning and processing machines. Therefore, this study was conducted to investigate some moisture-dependent physical properties of gmelina seeds, namely; seed dimensions, surface area, projected area, sphericity, bulk density, true density, porosity, and static coefficient of friction against different materials. The analysis of variance shows that, moisture content significantly ($P \leq 0.05$) affects all the physical properties studied, apart from the efficient of static friction. From the results, increasing moisture content from 30 to 51 % (w.b), the length, width, thickness, the geometric mean diameter, sphericity, surface area and volume of the nut increased significantly ($P<0.05$) from 12.99 to 15.47mm, 6.31to 9.19 mm, 5.49 to 7.42 mm, 7.66 to 10.18 mm, 59.07 to 65.92 %, 185.12 to 326.81 mm^2 and 238.09 to 558.49 mm^3 respectively. In addition, increasing moisture content from 30 to 51 % (w.b), the corresponding values for nut and fruit bulk density were 387 to 701 kg/m^3 and 327 to 615 kg/m^3 respectively; while the true density had 790 to 1065 kg/m^3 and 637 to 887 kg/m^3 respectively; whereas, the porosity decreased from 51.01 to 34.18 % and 48.67 to 30.67 % respectively for the nut and fruit. kg/m^3.. The static angle of friction was determined on four different contacting materials, plywood, robber, galvanized iron sheet, and formica surfaces. At all moisture contents, the maximum frictions are offered by plywood, followed by the rubber, galvanized iron and formica surfaces.

Keywords : Gmelina Fruit, Gmelina Nut, Physical Properties, Medicinal Plant, Moisture Content

I. INTRODUCTION

Gmelina arborea is a fast-growing tree, which grows on different localities and prefers moist fertile valleys, they attain moderate to large height up to 40 m and 140 cm in diameter [1]. Gmelina seeds are already proven to produce oil [2], this fact itself is already useful information for researchers who seek to find alternative sources of oil. The ability of the oil to fit depends on its constituents, its compositions, rate of production and availability of the processing technology [3]. The study of these constituents is important for their effective uses, [3] reported kinetics and optimization of gmelina seed oil using response surface methods, in which an optimal yield of 49.90% was predicted. The fruits, leaves and seeds extracts of G. arborea has been reported by many authors from various locations to contain nutrients, mineral constituents and phytochemicals like alkaloids, steroids, carbohydrates, anthraquinone, glycosides, triterpenoids, saponinns gums, mucilages, tannins, phenolic compounds and flavonoids and proteins [4]; [5].

In order to design equipment for the handling, conveying, separation, drying, aeration, storing and processing of wheat grains, it is necessary to determine their physical properties as a function of moisture content. The knowledge of some important physical properties such as shape, size, volume, surface area, thousand grain weights, density, porosity, angle of repose, of different grains is necessary for the design of various separating, handling, storing and drying systems [22]. In addition, the gravimetric parameters under the physical properties are very useful in the sizing of fruit and seed hopper and storage facilities. The rate of heat and mass transfer of moisture during aeration and drying depend on the density and porosity of grains. Higher power is required to drive the aeration fans for the removal of water vapour from a low porous grain beds [6]. Geometric properties can be used for electrostatic separation from undesirable materials [7]; and drying behaviour of the grain can be predicted from its shape [8]. Angle of repose plays an important role in designing the equipment for solid flow and storage. Knowledge of the frictional properties is valuable in designing machines effective in dehulling and packaging [6]. 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 [9]. Knowledge of frictional properties is needed for design of storage and handling equipment [10]; [11]. The angle of repose determines the maximum angle of a pile of grain with the horizontal plane. It is important in the filling of a flat storage facility when grain is not piled at a uniform bed depth but rather is peaked [7].

Many researchers have pervious worked on many physical properties of various crops, such as hemp seed [12], faba bean [13], lentil seeds [14], sunflower seeds [15] and linseed [16]. Some physical and aerodynamic properties of pistachio nut and its kernel as a function of moisture content in order to design processing equipment and facilities [17]. Because of the irregular nature of the shape and sizes of agricultural products, coefficient of variation (CV) may be used to characterize the quality of dispersion to the measured parameters about their means. Low CVs indicate more uniform dispersion [18].

There is dearth information on the physical properties of gmelina fruits and seeds, necessary for the design and development of handling, processing and planting equipment. Hence, current study was conducted on investigate some moisture dependent physical properties of gmelina fruits and seeds namely, dimensions, geometric mean, equivalent and arithmetic diameter, sphericity, thousand fruits and seeds weight, surface area, bulk density, true density, porosity, static and dynamic angle of repose and static coefficient of friction against different materials; which will provide relevant data for the design and development of handling, processing and planting equipment. Physical properties of the gmelina fruits and seeds increase the efficiency of the equipment.

Notations

L	length, mm	Φ	static coefficient of friction
W	width, mm	θs	static angle of repose, deg
T	thickness, mm	θ_d	dynamic angle of repose, deg
S	surface area, mm^2	D_g	geometric mean diameter, mm
V	volume, mm^3	R^2	coefficient of determination
M_i	initial moisture content, %	S_p	sphericity, %
M_f	final moisture content, %	Wt	total weight of sample, g
ρb	bulk density, gmm^{-3}	ρt	true density, kgm^{-3}
ε	porosity, %	Dp	diameter of the pile, mm
Hp	height of the pile, mm	ρb	bulk density in kg/m^3

Da	arithmetic diameter	DE	equivalent mean diameter, mm
Fr	flakiness ratio		

II. MATERIALS AND METHODS

2.1 Seed samples and processing

Healthy undamaged fruits of gmelina were collected from the ministry of agricultural and natural resources, Oleh, Delta state, Nigeria, between February-March 2018. Physical properties of intact fruits and nuts (the nuts were collected by wetting the fruits in muddy water for one week) were evaluated (Figures 1 and 2).

Figure 1: The gmelina fruit

Figure 2: The gmelina nuts

2.2 Moisture content determination and re-conditioning

The freshly collected fruits were sun dried to attend the desired moisture content, while the initial moisture content of seeds was determined by oven method [19]. Gmelina nut samples were sealed in polyethylene bags of 300 μ thickness, kept in a refrigerator at 4±1°C for a minimum period of 5 days to reach uniform moisture content. The moisture contents of the samples were equilibrated to 30, 36, 400, 45, and 51% wet basis (wb) as per the procedures of [19]. Before each experiment, samples were equilibrated at room temperature (30±2°C) for 1 hour and the moisture checked using the standard oven-dry method. The rewetting formula was used Equation 1, and to allow the moisture be absorbed by samples were placed in refrigerator.

$$\Delta M_w = W_t \frac{(M_f - M_i)}{100 - M_f} \qquad (1)$$

The tests were conducted in the laboratory at an ambient temperature of about 25 ±3°C and 70±5 Relative Humidity. All the properties measured were carried out in ten replications.

2.3 Seed dimensional properties

2.3.1 Size and shape

Length, width and thickness of 50 randomly selected fruit and nut were measured using digital vernier caliper with accuracy of 0.01 mm.

2.3.2 Geometric mean

The geometric mean was calculated by using equation (2) [7].

$$D_g = \sqrt[3]{L \times B \times T} \qquad (2)$$

2.3.3 Surface area

The surface area of the fruit and nut was determined according to the following equation [20].

$$S = \pi D_g^2 \qquad (3)$$

2.3.4 Volume

The surface area of the fruit and nut was determined according to the following equation

$$V = \frac{\pi Dg^3}{6} \qquad (4)$$

2.3.5 Sphericity

Sphericity, which is defined as the ratio between the surface area of the sphere having the same volume as that of the seed and the surface area of the seed [7].

Sphericity was determined using the following expression:

Fruit sphericity (due to its oval shape)

$$S_p = \frac{\sqrt[3]{LD^2}}{L} \times 100 \quad (5)$$

The nut sphericity

$$S_p = \frac{\sqrt[3]{L \times B \times T}}{L} \times 100 \quad (6)$$

2.4 Gravimetric properties

2.4.1 Density

The bulk material was obtained by containers with known volume (500 cm^3). In different moisture content levels, the gmelina fruits and nuts were poured into the container with from a constant high, striking the top level and then weighing the constants. Bulk density of the fruits and nuts were determined using equation 7, according to [21[.

$$\rho b = \frac{Ma}{V} \quad (7)$$

2.4.2 True density

The true density is a ratio of mass sample of grains to its pure volume. It was determined by the toluene displacement method as recommended by [7].

2.4.3 Porosity

The porosity was calculated from bulk and true densities using the relationship as follows [7].

$$\varepsilon = \left(1 - \frac{p_b}{p_t}\right) 100 \quad (8)$$

2.5 Frictional properties

2.5.1 Static coefficient of friction

The static coefficient of friction was determined against different surfaces: glass, plywood, asbestos, and galvanized iron. A hollow cylinder, both ends open, diameter 75 mm and depth of 50 mm, was filled with the fruits and seeds at the desired moisture content and placed on an adjustable tilting surface such that the cylinder did not touch the surface. Then the apparatus will be raised gradually until the filled cylinder just started to slide down [20]. The coefficient of friction is the ratio of the force of friction acting between two surfaces in contact, and the force needed to slid one over the other, and can be calculated with the equation below:

$$\mu = \tan\theta \quad (9)$$

2.5.2 Angle of repose

The angle of repose of the fruits and seeds was measured by emptying method in bottomless cylinder (diameter, 5 cm; height, 10 cm) [43].

$$\theta s = \tan^{-1}\frac{2Hp}{Dp}$$

Statistical analysis

The results of physical properties were subjected to analysis of variance (ANOVA) to evaluate a statistical significance of observed differences among treatment means at 95% confidence level using SPSS 20.0 software (IBM Corporation, USA), while regression analysis was performed using Microsoft Excel 2010 software. Five replications were taken for all the experiments, and average values taken.

III. RESULTS AND DISCUSSION

The analysis of variance (ANOVA) of the physical characteristics of gmelina fruit and nut are presented in Table 1. As shown in Table 1, moisture content significantly influenced ($P \leq 0.05$) all the twelve parameters (length, width, thickness, geometric mean, sphericity, surface area, volume, bulk density, true density, porosity, coefficient of static friction, and angle of repose) investigated; also the interaction of storage time and condition significantly influenced ($P \leq 0.05$) the breadth, size, surface area and

The regression equations for dimensional properties with respective coefficient of determination (R^2), which help to predict any dimensional parameter at specific moisture level, are given in Table 2. The high values of $R^2 \geq 0.96$ and the p-values from regression equations indicates that the plots described the data points reasonably, and there is strong relationship between moisture levels and the physical properties measured in the gmelina fruit and nut.

Table 1: Analysis of variance of effect of physical properties of gmelina fruit and nut with moisture content

Source	df	Length	Width	Thickness	Geometric mean	Sphericity	Surface area	volume
TP	1	5.32E-56*	7.32E-67*	2.56E-98*	4.29E-40*	2.76E-65*	7.80E-77*	7.78E-80*
MC	4	1.51E-09*	5.39E-25*	2.30E-17**	1.45E-11	7.68E-20*	4.85E-32*	5.96E-40*
TP x MC	4	0.1006^{ns}	5.11E-11*	2.30E-17*	0.01517*	1.16E-07*	8.56E-24*	5.97E-36*

* =Significant on the level of 5%, ns= non significant, TP = Tree part (fruit and nut), MC = moisture content
.

Table 1 continue

Source	df	Bulk density	True density	Porosity	Coefficient of friction	Angle of repose
TP	1	9.31E-06*	4.29E-06*	7.93E-04*	0.7702^{ns}	4.147E-02*
MC	4	9.91E-06*	1.34E-06*	5.66E-05*	0.0635^{ns}	7.47E-09*
TP x MC	4	0.135199^{ns}	0.21418^{ns}	0.88018^{ns}	4.59E-40*	0.08092^{ns}

* =Significant on the level of 5%, ns= non significant, TP = Tree part (fruit and nut), MC = moisture content.

Table 2. Regression equations as a function of moisture content with their respective coefficient of determination (R2) and p-value (p) for physical properties of fruit and nut

Parameter	Part of gmelina	Linear equation	R^2	p-value
L	N	y = 0.1156 x + 9.5178	0.9969	7.17E-05
	N	y = 0.2437 x + 16.635	0.9843	8.39E-04
W	F	y = 0.1313 x + 2.1586	0.9365	0.0069
	N	y = 0.4074 x + 3.2475	0.9696	2.27E-03
T	N	y = 0.094 x + 2.7834	0.9693	2.30E-03
	F	Nil	Nil	Nil
S_p (%)	N	y = 0.3225 x + 49.372	0.9962	9.8E-05
	F	y = 0.7264 x + 52.551	0.9365	6.93E-03
D_g (mm)	N	y = 0.1179 x + 4.0958	0.9959	1.1E-04
	F	y = 0.3682 x + 6.8546	0.9766	0.00152
S_A (mm^2)	N	y = 6.632 x - 18.145	0.9893	4.7E-04
	F	y = 46.254 x - 375.75	0.9731	0.00189
V (mm^3)	N	y = 14.971 x - 226.45	0.9788	0.00132
	F	y = 241.19	0.976	0.00154

		x - 4240.5	5	
ρb	N	y = 15.547 x - 85.487	0.9921	2.9E-04
	F	y = 13.891 x - 91.407	0.9949	1.7E-04
ρt	N	y = 13.921 x + 357.8	0.9794	0.00127
	F	y = 12.051 x + 279.36	0.9932	2.4E-04
ε (%)	N	y = -0.8099 x + 74.393	0.9788	0.00131
	F	y = -0.8666 x + 74.413	0.9891	4.9E-03
Φ	N (Fm)	y = 0.0272 x + 0.2758	0.9605	0.00203
	N(GI)	y = 0.0523 x + 0.3133	0.9294	0.01696
	N (rubber)	y = 0.0638 x + 0.3415	0.9774	0.09756
	N(plywood)	y = 0.0672 x + 0.363	0.9677	0.00761
	F (Formica)	y = -0.01 x + 1.039	0.9897	1.2E-04
	F(GI)	y = -0.0076 x + 0.9396	0.9301	0.00135
	F (rubber)	y = -0.0073 x + 1.0259	0.9281	9.5E-04
	F(plywood)	y = -0.0088 x + 1.1607	0.9234	0.00127
θs	Nut	y = 0.8702x + 7.267	0.9971	6.5E-05
	Fruit	y = 0.8356 x + 21.459	0.9804	0.00116

N = nuts, F = fruits, GI = galvanized iron, fm = formaca

3.1 Dimensional parameters

3.1.1 Size and shape

From the ANOVA Table (Table 1), increasing the moisture content from 30 to 51 % (w.b), the length, width, thickness, the geometric mean diameter, sphericity, surface area and volume of the fruit and nut increased significantly ($P<0.05$). The means and standard deviation of the dimensions of gmelina fruit and nut at different moisture contents are given in Tables 3 and 4. From Table 3 and 4, it can be seen that the gmelina fruit and nut size and shape shrunk (decreased) monotonically with decrease in moisture content. Also sown in Table 2, the values increased as the moisture content increases from 30 to 51 % w.b. this could be attributed to the expansion of the fruit and nut due to uptake of water (moisture) into the intracellular spaces of the fruit and nut. The regression variation between length, width and thickness of eth fruit and nut with moisture content are represented by the regression equations in Table 2. Similar results were reported by [23] on high oleic sunflower seeds.

3.1.2 Geometric mean diameter and surface area

The geometric mean diameter and surface area of the fruit and nut increased significantly ($p < 0.05$) with an increase in the moisture content. The surface area and geometric mean diameter of the fruit was higher as compared to nut at all evaluated moisture contents. The surface area ranged from 185.12 to 326.81 mm^2 and 966.00 to 1920.68 mm^2 for the nut and fruit respectively; while the geometric mean diameter ranged from 7.66 to 10.18 mm, and 17.53 to 25.26 mm for the nut and nut and fruit respectively, as the moisture content increased from 30 to 51 %. Similar behavior was also observed for hemp seed [12].

3.1.3 Sphericity and volume

This study showed that moisture content had significant ($p< 0.05$) effect on the fruit and nut sphericity. The sphericity and volume were higher in the fruit when compared with the nut. The sphericity of gmelina fruit increased from 73.03 to 88.22.5 % and 59.07 to 65.92 % respectively, when moisture content increased from 30 to 51 % w.b. (Table 3). A similar trend has been reported for faba bean grain [13], safflower seeds [15], and linseed [16]. The seed volume and area of seed, which are considered important during bulk handling and processing operation such as heat and mass transfer [18]. The increase in surface area, volume and sphericity could be attributed to the expansion of the fruit and nut as a result of increase in dimensions (length, width and thickness), as increase content increases from 20 to 51 % w.b.

Higher values of sphericity indicate higher tendency of the material to roll on any of its three axes [42], therefore, the ability of the fruit and nut to roll over flat surfaces decreases with decrease in moisture content. This tendency to either roll or slide is very important in the design of hoppers, dehulling and thresher equipment for the seed because most flat seeds slide easier than spherical seeds, which roll on structural surfaces [39].

Table 3: Dimensional properties of gemilna nut different moisture content

MC	Length (mm)	Width (mm)	Thickness (mm)	Geometric mean (mm)	Sphericity (%)	Surface area (mm^2)	volume (mm^3)
30	$12.99^{a}\pm0.82$	$6.31^{a}\pm0.40$	$5.49^{a}\pm0.35$	$7.66^{a}\pm0.48$	$59.07^{a}\pm0.32$	$185.12^{a}\pm23.39$	$238.09^{a}\pm45.29$
36	$13.71^{ab}\pm0.86$	$6.86^{b}\pm0.43$	$6.17^{b}\pm0.39$	$8.34^{b}\pm0.52$	$60.91^{b}\pm0.32$	$219.29^{b}\pm27.71$	$306.97^{b}\pm58.39$
40	$14.13^{bc}\pm0.89$	$7.22^{b}\pm0.45$	$6.70^{c}\pm0.42$	$8.81^{bc}\pm0.55$	$62.45^{c}\pm0.34$	$244.67^{bc}\pm30.92$	$361.78^{bc}\pm68.82$
45	$14.64^{c}\pm0.92$	$7.73^{c}\pm0.49$	$7.11^{d}\pm0.45$	$9.31^{c}\pm0.59$	$63.65^{d}\pm0.37$	$273.04^{c}\pm34.50$	$426.50^{c}\pm81.13$
51	$15.47^{d}\pm0.97$	$9.19^{d}\pm0.58$	$7.42^{d}\pm0.47$	$10.18^{d}\pm0.64$	$65.92^{e}\pm0.39$	$326.81^{d}\pm41.30$	$558.49^{d}\pm106.24$

Values are mean ± SD. Means with similar superscript in the same column did not differ significantly ($p \leq 0.05$). MC = Moisture content (% wb)

Table 4: Dimensional properties of gemilna fruit different moisture content

MC	Length (mm)	Width (mm)	Geometric mean (mm)	Sphericity (%)	Surface area (mm^2)	volume (mm^3)
30	$23.99^{a}\pm1.47$	$14.99^{a}\pm0.92$	$17.53^{a}\pm0.94$	$73.03^{a}\pm4.48$	$966.00^{a}\pm59.28$	$2823.95^{a}\pm173.30$
36	$25.30^{ab}\pm1.18$	$17.86^{b}\pm0.83$	$20.06^{b}\pm1.08$	$78.66^{b}\pm5.66$	$1274.31^{b}\pm59.35$	$4294.43^{b}\pm200.02$
40	$26.65^{b}\pm2.27$	$20.44^{c}\pm1.74$	$22.33^{c}\pm1.90$	$83.97^{bc}\pm7.16$	$1564.20^{c}\pm133.34$	$5811.03^{bc}\pm495.35$
45	$27.23^{b}\pm2.44$	$21.77^{c}\pm1.95$	$23.46^{c}\pm2.10$	$85.61^{c}\pm7.67$	$1739.47^{d}\pm155.91$	$6841.91^{c}\pm613.25$
51	$29.23^{c}\pm3.05$	$23.49^{d}\pm2.45$	$25.26^{d}\pm2.63$	$88.22^{c}\pm8.20$	$1920.68^{e}\pm200.13$	$7746.73^{c}\pm807.18$

Values are mean ± SD. Means with similar superscript in the same column did not differ significantly ($p \leq 0.05$). MC = Moisture content (% wb)

3.2. Gravimetric properties

From the ANOVA table, significant difference ($p < 0.05$) was found in all gravimetric properties (bulk density, true density and porosity) for both the gmelina fruit and nut with the variation in moisture content (Table 1). The regression equations as a function of moisture content with their respective coefficient of determination (R^2) and p-valve for gravimetric properties of the fruit as well as the nut are given in Table 2. From the values of the coefficient of determination and p-value, it can be dictated that gravimetric properties of the gmelina fruit and nut are function of moisture content.

3.2.1 Bulk density

The relationship between the bulk density and moisture content of the gmelina fruit and nut was statistically significant at ($p < 0:05$). From the result, there was a linear decrease in bulk density with decrease in the moisture content of gmelina fruit and nut; in addition, the bulk density of fruit was lower than the nut for all the moisture levels investigated in this research (Figure 3). As shown in Figure 3, the bulk density of nut varied from 389.43 to 701 .09 kg/m^3 when moisture level was increased from 30 to 51 %. (wb); while the bulk density of the fruit varied from 327.29 to 615.41 kg/m^3 when moisture was increased from 30 to 51 %. (wb) respectively. The reason of this increase can be explained as follows: while the seeds absorb moisture, their individual volume and mass increases; consequently, the shape of the seed changes, and their bulk volume. This behavior causes the number of seeds occupying a fixed volume to decrease, but mass of seeds increased [24]. This result was further validated by an increase in porosity of both seed and kernel with an increase in the moisture content, as reported by [6]. The same trend has also been reported by [25] for terebinth fruits, and [26] for in black hull variety of sunflower.

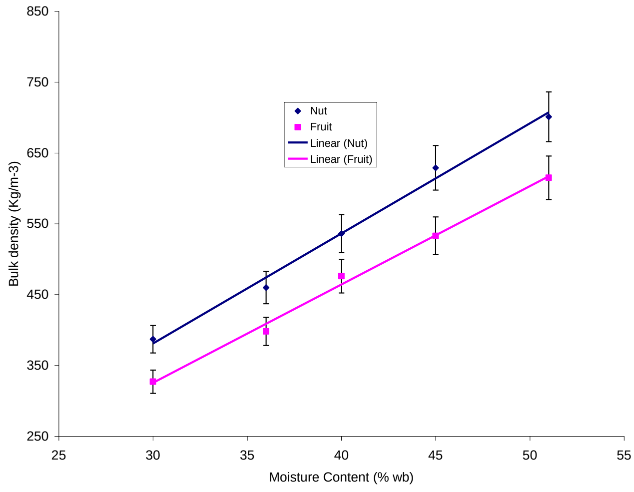

Figure 3: Effect of moisture content on density of gmelina fruit and nut.

3.2.2 True density

The relationship between the true density and moisture content of the gmelina fruit and nut was statistically significant ($p < 0:05$). The true density of gmelina nut at different moisture levels varied from 790 to 1065 kg/m^3, and 637.05 to 887.39 kg/m^3 for the fruit, as the moisture increased from 30 to 51 % (wb); which can be attributed to the increase in the fruit and nut volume, resulting from absorption of moisture. Figure 4 shows the variation between moisture content on true density of gmelina fruit and nut. The regression relationship between moisture content and the true density of the fruit and nut are shown in the regression equations in Table 2. Similar findings were reported for sunflower with an increase in value of true density from 706 to 765 kg/m^3 for a moisture content range of 4 to 20% d.b. [28] and for quinoa seeds the rise in the value was from 928 to 1188 kgm^3 with the increase in moisture from 4.6 to 25.8% d.b. [27]. Densities increased substantially in fruits and nuts as the increase of mass is more compared to the increase in volume [28]. These data are useful in the design and development of gmelina fruit and nut cleaning and separation equipment.

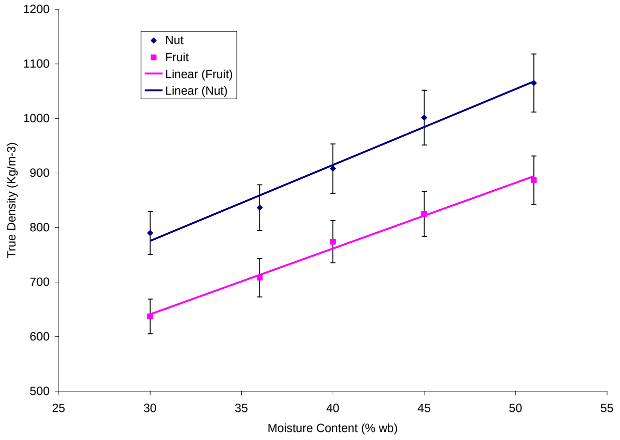

Figure 4: Effect of moisture content on the true density of gmelina fruit and nut.

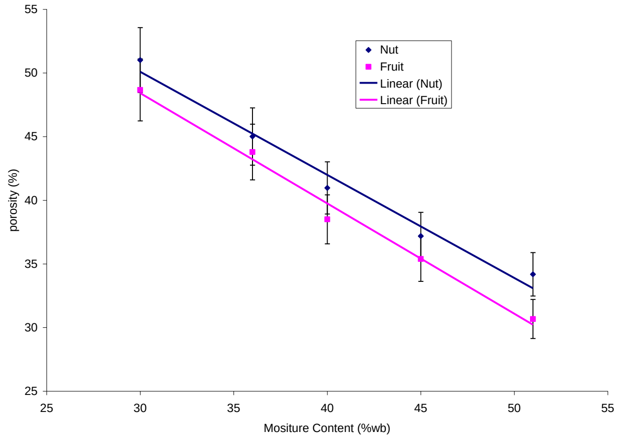

Figure 5: Effect of moisture content on the porosity of gmelina fruit and nut.

3.2.3 Porosity

The porosity of gmelina fruit and nut increased significantly at the 5% level of probability with the increase in moisture content from 30% to 51 % w.b. (Figure 4). From Figure 4, the nut porosity was higher as compared with the porosity of the fruit at each moisture content evaluated. The magnitude of decrease in porosity may be attributed to the change in true and bulk density with the increase in moisture content [28].

Increase in porosity with moisture content shown in Figure 5 was also reported for safflower [15] and traditional black hull sunflower [26]. However, [29] and [30] reported porosity decreased with an increase in the moisture content for soybean and pumpkin seeds respectively. Porosity is a vital parameter necessary to design the aeration systems in containerization. The higher the porosity, the better is the aeration and water vapour diffusion during deep-bed drying [31]. Canavalia seeds showed higher porosity (40.1-44.6%) than the seeds of C. ensiformis (32.6%) [18]. The regression relationship between the porosity and moisture content for the fruit and nut can be represented the equations in Table 2.

3.3 Frictional properties

3.3.1 Static Coefficient of Friction

From the ANOVA table (Table 1), moisture content had significant effect ($P \leq 0.05$) on the coefficient of static friction of both the gmelina fruit and nut. Gmelina nuts showed highest static coefficient of friction against plywood, while it was least on stainless Formica (Figure 5). Figure 5 shows the behaviour of the static coefficient of friction for gmelina fruit and nut determined against four different structural surfaces, namely; plywood, rubber, formica and galvanized iron. The static coefficient of friction of the gmelina nut generally increased with increase in moisture content (from 30 to 51% w.b.) for all the surfaces used. This could be attributed to the increased in adhesion between the nut and the surface at higher moisture content. Plywood had the highest static coefficient of friction, followed by rubber, then galvanized iron, and lastly formica surface. Similar results have been reported by other researchers [32]; [33]; and [34].

But in contrary, the gmelina fruit value of static coefficient of friction decreases with increased by moisture content (Figure 6), which can be attributed to the change in the fruit epicarp mature leading to more adhesion force between the surface and the fruit. At higher moisture content, the fruit was more rigid and having higher sphericity value, making it easily to roll along all the axis. Smooth surface nature of the fruits at higher moisture content resulted in the easy movement on test surfaces at high moisture content, while smooth nature of the fruit at higher moisture content resulted in lower resistance to easy movement on test surfaces. From the results, the coefficient of static friction on all surfaces was higher for nuts than fruits of the gmelina, corroborating the earlier reports on Jatropha seeds and kernels [35]. The least static angle of friction of the formica surface may be owing to the smoother and more polished surface than the other materials used. Likewise, plywood offered the maximum friction for tef seed [36] and almond [37], but the galvanized surface had higher coefficient of friction than plywood for Roselle [38] and lentil seeds [14]. Static angle of friction is important for designing the storage bins, hoppers, pneumatic conveying system, screw conveyors, forage harvesters, threshers, etc. [39]. The regression relationships between static coefficients of friction and moisture content of the fruit on all test surfaces can be represented by the equations presented in Table 2.

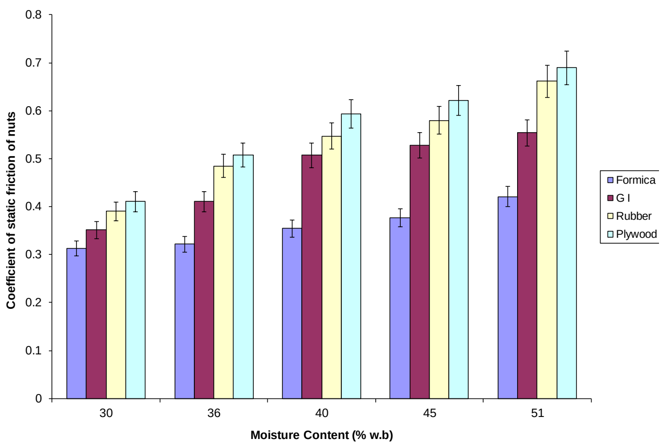

Figure 6: Effect of moisture content on the static friction of gmelina nut

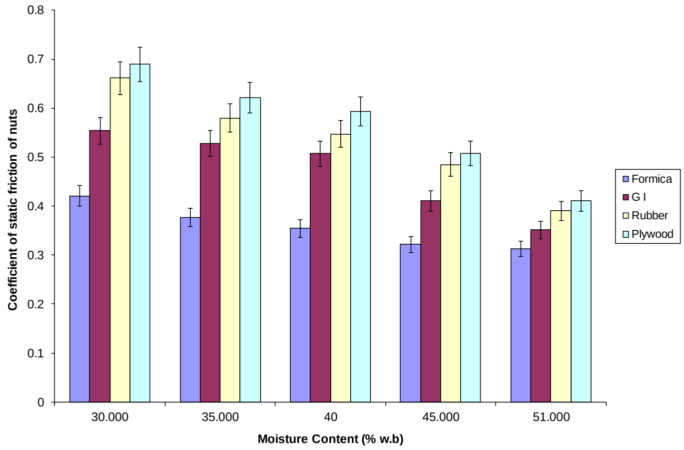

Figure 7: Effect of moisture content on the static friction of gmelina fruit

3.3.2. Angle of repose

The angle of repose is an indicator of the gmelina fruit and nut flow ability. From the ANOVA table (Table 1), the angle of response of both the gmelina fruit and nut were significantly ($p < 0.05$) affected by the moisture content. The result show that angle of repose, which indicates the cohesion among the individual fruit and nut was dependent on the moisture content, is presented in Table 2. The results for the angle of repose of gmelina fruit and nut, with respect to the moisture content, are shown in Figure 7. It is found that the angle of repose increased linearly with the increase in moisture content for the nut and decreased linearly with the increase in moisture content for the fruit. The angle of repose was higher for fruit at lower moisture level, because the gmelina fruit is more cohesive a lower moisture levels, caused by the shrinkage of the fruit's epicarp caused by loss of water. The rise in surface roughness of the gmelina fruit at the lower moisture level is also responsible for the increasing trend of the angle of repose. Similar results were also reported on minor millets [40], and neem nuts [41]. The regression equation as a function of the moisture content with their respective coefficient of determination (R^2) for angle of repose of fruit as well as nut are given in Table 2.

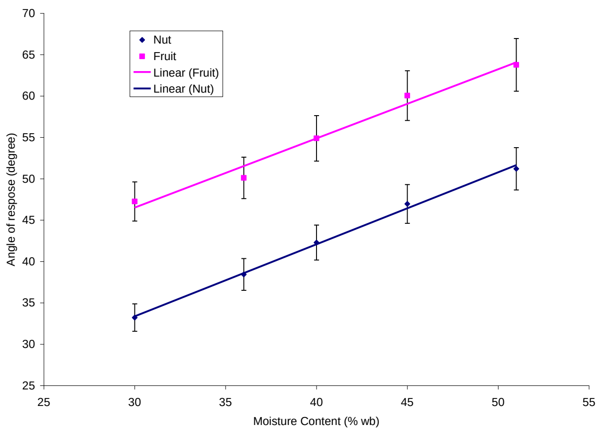

Figure 6: Effect of moisture content on the angle of repose gmelina fruit and nut

IV. CONCLUSION

The investigation of the physical properties of gmelina fruit and nut as a function of moisture content revealed the followings. As moisture content increases from 30 to 51 % (w.b), the length, width, thickness, the geometric mean diameter, sphericity, surface area and volume of the nut increased significantly ($P<0.05$) from 12.99 to 15.47mm, 6.31to 9.19 mm, 5.49 to 7.42 mm, 7.66 to 10.18 mm, 59.07 to 65.92 %, 185.12 to 326.81 mm^2 and 238.09 to 558.49 mm^3 respectively. As moisture content increases from 30% to 51% (w.b), the bulk and true density of the gmelina fruit and nut increased linearly with moisture content. Bulk density increased from 387 to 701 kg/m^3 and 327 to 615 kg/m^3 for the gmelina nut and fruit respectively, while the true density increased from 790 to 1065 kg/m^3 and 637 to 887; whereas, the porosity decreased from 51.01 to 34.18 % and 48.67 to 30.67 % respectively for the nut and fruit. kg/m^3. The static angle of friction was determined on four different contacting materials, plywood, robber, galvanized iron sheet, and formica surfaces. At all moisture contents, the maximum frictions are offered by plywood, followed by the rubber, galvanized iron and formica surfaces. The seed volume and area of seed, which are considered important during bulk handling and processing operation such as heat and mass transfer. The data gotten from this research are useful in the design and development cleaning, separation and processing equipment for gmelina nuts and fruits.

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