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Effects of Moisture Content Variation on Some Engineering Properties of Almond Seed (*Terminalia Catappa*)

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Abstract- ***The physical and mechanical properties of Almond seed at different moisture content levels of 6.78%, 12.39%, 17.11% and 21.97% were investigated in this study. The physical properties include geometric mean diameter, bulk density and angle of repose; they were determined using standard procedures. The length, width and thickness obtained for the 100 samples of the almond seeds were in the range of 25.42-28.63mm, 23.69-26.63mm, and 7.51-9.18mm respectively. The result shows a high uniformity on the seed sizes and significant variations between the length, width and thickness. The calculated values of the geometric mean diameter and sphericity ranged from 16.48-19.07mm and 64.66- 66.63% respectively. The results of the surface area varied from 853.6-1143.04mm^2. The result also indicated a high variation in the surface area of the seeds with respect to the different moisture content levels. The mechanical properties which include rupture force, compressive strength and tensile strength were determined on the seeds. The mechanical properties show that the fracture force and compressive strength decreased from 2689N to 2499N, 410N/mm^2 to 398 N/mm^{2}respectivelywith an increase in moisture content (6.78%-21.9%). The tensile strength obtained for moisture levels of 6.78%, 12.39%, 16.11% and 21.9% were 3.20Mpa, 3.90Mpa, 4.20Mpa and 4.60Mpa respectively.***

Keywords- physical properties, mechanical properties, moisture content, almond seed

I. Introduction

The generic name of almond comes from the Latin word "*terminalis"* which is derived from the distinctive bunched spirals of leaves at the twig end. It is a native of Southeast Asia, and was believed to have originated from Malaysia and scattered all over the old tropics and tropical America [1]. Almond (*Terminalia catappa*) is a large tropical tree in the lead wood tree family of *cambretaceae* that grows mainly in the tropical regions of Asia, Africa, and Australia. The crop is one of the lesser known legumes in the tropics and in the ecosystem of Nigeria [2].

The seed forms an important source of balanced food because it is rich in protein 14.1-24.7%, fat 21.8-23.8%, ash content 3.5-4.1%, fiber 6.4-14.0%,carbohydrate 29.5-39.2%,calcium 20.7-29.8mg/100g, phosphorus 16.0-17.2mg/100g, iron 0.7-1.4mg/100g, zinc 0.8-1.2mg/100g, tannin 0.3-0.4mg/100g, phytate 0.1-0.3mg/100g [2]. It produces fruits whose flesh is fibrous, sweet and edible when ripe and is widely eaten by children as forage food. The seed has an important place in the human diet and it can be used fresh, when dried or in processed form [3]. According to [2], the seed is greatly cherished by children and used by many rural dwellers in the Southern part of Nigeria to support the local complimentary foods which are low in protein. It also forms part of the local feedstock for tropical aquarium fishes in Nigeria [4]. The major countries growing this plant include; Italy, Spain, Morocco, France, Greece and Iran [3].

Almond seed has wide range of uses and importance. The development of adequate harvesting, storage and processing systems and machine are influenced by the physical and mechanical properties of almond seed. Most of the machines and systems used today are generally designed without taking into consideration some of these engineering properties of the seed. Thus, resulting in inadequate applications, reduction in labor efficiency and increased losses in production.

II. Material and Methods

A. Material and Equipment

The following materials were employed in the study; vernier caliper, cylindrical flask, beaker, oven and digital weighing balance. The almond fruits samples used for this study were obtained from trees around the Federal University of Technology, Minna, Niger state. The outer flesh of the fruits were manually removed with a knife and were oven dried to a moisture content of 6.57% to enable easy removal of the seeds from the nuts with least percentage of cracking.

B. Methods

Variation of Moisture Content

The moisture content of almond seed was determined using the method reported by [5] for Shea nut. The samples were transferred to separate polythene bags and reconditioned to desired moisture content levels of 6.78%, 12.39%, 17.11% and 100 almond seeds were randomly selected for

each of the moisture content levels for the measurement of length (L), With (W) and Thickness (T) with the use of a vernier caliper with resolution of 0.01mm. The arithmetic and geometric average diameters of almond seed were calculated using the following relationships as reported by [7].

*Arithmetic Average Diameter (*Dα) = $\frac{(L+W+T)}{3}$ (1)

Geometric Average Diameter (Dg) = $(LWT)^{0.333}$ (2)

Sphericity (φ)

The sphericity φ (%) was calculated by using the following relationship as reported by [8].

$$\varphi = \frac{(LWT)^{0.333}}{L} \quad (3)$$

Surface Area (S)

The surface area (S) of the seed was obtained by analogy with a sphere of the same geometric mean diameter using the expression reported by [9].

$$S = \pi Dg^2 \quad (4)$$

Bulk Density and True Density

The bulk density of the samples at different moisture content levels was determined by the method reported by [10], while the liquid displacement method was used to determine the true density of the seed samples as described by [11].

Coefficient of Static Friction

The static coefficient of friction was determined with respect to three test surfaces namely: plywood galvanized steel sheet and glass. The static coefficient of friction was calculated based on this equation [12].

$$\mu = \tan \theta \quad (5)$$

Angle of Repose

The angle of repose was calculated by the following expression reported by [13].

$$\Theta s = \tan^{-1}\left[\frac{2d}{h}\right] \quad (6)$$

21.97%. The reconditioning technique to achieve the desired moisture content for the seed was reported by [6].

Seed Weight

The weights of the seeds were determined with respect to the variation of the moisture levels with the use of a digital weighing balance.

Arithmetic and Geometric Average Diameter

Specific Gravity

The specific gravity of the samples at the different moisture content levels was determined using the method reported by [14] while the mechanical properties of the seed which include fracture force, compressive strength and tensile strength were obtained using Testometric Machine (ZDM50-2313/56/18, Germany).

III. Result and Discussion

The result of the effect of moisture content variation on the physical properties of almond seed is presented in Table 1.

TABLE 1: **Effects of moisture content on some physical properties of *terminalia catappa* at different moisture contents.**

PARAMETERS	Variation of Moisture Content 6.78% wb	12.39% wb	17.11% wb	21.97% wb
Length (mm)	25.42±0.47^a	26.70±0.50^b	27.57±0.25^c	28.63±0.18^d
Width (mm)	23.69±0.68^a	25.13±0.22^b	26.27±0.19^c	26.63±0.23^c
Thickness (mm)	7.51±0.43^a	7.71±0.03^a	8.24±0.03^b	9.18±0.07^c
Geometric mean diameter (mm)	16.48±0.05^a	17.26±0.11^b	18.08±0.02^c	19.07±0.06^d
Arithmetic mean diameter (mm)	18.88±0.24^a	19.84±0.18^b	20.69±0.03^c	21.48±0.10^d
Surface area (mm^2)	853.69±6.57^a	936.38±11.32^b	1027.08±1.97^c	1143.04±6.59^d
Weight of seed (g)	7.06±0.03^a	7.59±0.29^a	7.64±0.13^a	8.82±0.70^b
Sphericity (%)	64.66±0.81^a	64.87±1.44^a	65.41±0.57^a	66.63±0.23^b
Bulk density (g/cm^3)	0.58±0.01^a	0.54±0.01^b	0.50±0.01^c	0.48±0.01^d
True density (g/cm^3)	1.27±0.01^a	1.09±0.01^b	1.04±0.01^c	0.98±0.01^d
Angle of repose (^{0})	38.84±1.64^a	46.74±0.85^b	51.54±1.81^c	52.29±2.0^c
Specific gravity	0.79±0.01^a	0.87±0.01^b	0.91±0.01^c	0.95±0.01^d

*values followed by same superscript alphabet are not significantly different at (P<0.05) along the rows. Values are Mean ±Standard deviation.

TABLE 2: The result of the effect of moisture content variation of *terminalia catappa* on coefficient of friction.

Coefficient of friction	Variation of Moisture Content 6.78% wb	12.39% wb	17.11% wb	21.97% wb
Wood surface	0.52±0.02^a	0.57±0.03^b	0.59±0.05^b	0.67±0.04^b
Glass surface	0.49±0.01^a	0.51±0.02^a	0.54±0.01^b	0.57±0.02^b
Steel surface	0.52±0.02^a	0.54±0.02^{ab}	0.57±0.02^b	0.62±0.03^c

*values followed by same superscript alphabet are not significantly different at (P<0.05) along the rows. Values are Mean ±Standard deviation.

IV. DISCUSSION

Analysis of the result showed that the different levels of the moisture content have significant difference (p<0.05) on the length, width, thickness, arithmetic and geometric properties of the seed.

Effect of moisture content on length, width and thickness

The mean values of the length, width and thickness of *terminalia catappa* measured at 6.78%, 12.39%, 17.11% and 21.97% moisture content (w.b) are presented in Table 1. Analysis of the result showed that the different levels of the moisture content have significant difference (p<0.05) on the length, width and thickness. There was significant difference in the length at as the moisture content increased from 6.78% to 21.97%; same thing applied to the width at moisture content of 6.78% and 12.39% but no significant difference at 17.11% and 21.97% moisture content. The reverse was the case with the thickness; there was no significant difference at 6.78% to 21.97% but there was significant difference at 17.11% and 21.97% moisture content. The three linear dimensions (length, width and thickness) increased with increase in moisture content due to the increase in microscopic structure of the seed as it absorbs moisture. The length, the width and thickness increased from 25.42 to 28.63mm; 23.69 to 26.63mm and 7.51 to 9.18mm respectively for moisture contents from 6.78% to 21.97% w.b.

Effect of moisture content on geometric and arithmetic mean diameters

The geometric mean and arithmetic mean diameters also presented in Table 1 increased with increase in the moisture content. Analysis of the result showed that the different levels of the moisture content have significant difference ($p<0.05$) on the geometric mean and arithmetic mean diameters. There were significant differences in the geometric mean and arithmetic mean diameters as the moisture content increased from 6.78% to 21.97%; the arithmetic and geometric mean diameters ranged from 18.88 to 21.48mm and 16.48 to 21.48mm respectively.

Effect of moisture content on sphericity

From Table 1, there was no significant difference in the sphericity as the moisture content increased from 6.78% to 17.11% but this changed as the moisture content increased to 21.97%; the sphericity increased as the moisture content increased from 17.11% to 21.97%. These properties are dependent on the linear dimensions which were observed to increase with moisture content. The sphericity increased from 64.66 to 66.63% which is similar to that reported by [15] for barley seeds.

Effect of moisture content on surface area

There was significant difference in the surface area as the moisture content increased from 6.78% to 21.97% ($p<0.05$); it ranged from 853.69mm^2 to 1143.04mm^2. The increase in the values may be attributed to its dependence on the three linear dimensions. Similar results have been reported by [16] for hemp seed, [17] for squash seed, and [18] for cowpea seed.

Effect of moisture content on seed weight and densities

There was no significant difference as the moisture content increased from 6.78 to 17.11% but this changed as the moisture content increased to 21.97%. The 100 weight of the seeds varied from 7.06 to 8.82g with respect to the moisture content. The knowledge is applicable in the design of storage structure for seeds.

Effect of moisture content bulk density

The bulk density varied from 0.58 to 0.48 g/cm^3 respectively and this indicate a decrease in bulk density with increase in moisture content. This was due to the fact that an increase in mass owing to moisture gain in the sample was lower than accompanying volumetric expansion of the bulk [19, 20]. This indicates the significant importance of weight of biomaterials on their bulk density. The negative linear relationship of bulk density with moisture content was reported by [21] for some legumes seeds, [22] for pea seed and [19] for karanja kernel. The relationship between bulk density and moisture content was statistically significant ($p<0.05$).

Effect of moisture content true density

The true density varied from 1.27 to 0.98g/cm^{3}at different moisture contents (Fig 4.5). The effect of moisture content on true density showed a decrease in true density with increasing moisture content. The relationship between true density and moisture content was also statistically significant ($p<0.05$).Similar result has been reported by [16] for hemp seed, [22] for pea seed and [21] for some legumes seeds.

Effect of moisture content on angle of repose

The angle of repose increased with increase in moisture content. This may be due to the fact that an increase in moisture content increased the cohesion between the seeds, thus increasing the friction the seed experiences during its movement on the selected surface. The angle of repose is important in the design of hopper openings, storage bin side wall and chutes for bulk transport [23]. There was significant difference between the values obtained at moisture content of 6.78 to 17.11%.

Effect of moisture content on specific gravity

Specific gravity increased with increase in moisture content due to the increase in the weight of the seeds. Specific gravity is an important quality criterion for processing of biomaterials. It is used as an estimate of solid or dry matter content of biomaterials. The higher the dry matter content, the lower the water content and the higher the specific gravity. The relationship between specific gravity and moisture content was statistically significant ($p<0.05$).

Effect of moisture content on coefficient of friction

Coefficient of friction for all samples at the various moisture content levels followed a similar pattern; it increased with an increase in moisture content on all the surfaces used. In Table 2, it was observed that coefficient of friction was highest on wood surface; this is similar to that reported by [24] for rape seed and karinda seeds [25]. While the minimum friction occurred for samples on the glass surface, this is similar to that reported for lentil seeds [26]. This difference could be due to the roughness of the various surfaces.

Effect of Moisture Content on Mechanical Properties of Almond Seed

The result of the effect of moisture content variation on mechanical properties of almond seedis presented in table 3.

TABLE 3: Effect of moisture content on mechanical properties of almond seed

Moisture Content (%)	Fracture Force (N)	Compressive Strength (N/mm^2)	Tensile Strength (Mpa)
6.78%	2689±580	410±40	3.20±1.10
12.39%	2679±580	408±40	3.90±1.80
16.11%	2598±280	402±20	4.20±1.23
21.97%	2499±382	398±19	4.60±1.11

*values followed by same superscript alphabet are not significantly different at ($P<0.05$) along the rows. Values are Mean ±Standard deviation.

From the result presented in table 3, fracture force decreased with increase in moisture content (6.78%w.b to 21.97%w.b) from 2689N to 2499N. The lower the moisture content, the greater the force required to fracture the seeds, thus a higher cost of operation. Also the higher the moisture content, the lesser the force required to fracture the seed; also this indicates a lower cost of operation. This is similar to those reported by [27] on faba seeds and [28] on hazel nut. The compressive strength decreased from 410 to 398N/mm^2 as the moisture content increased from 6.78% to 21.7%w.b and tensile strength 3.20 to 4.60Mpa respectively with increase in moisture content. These parameters give the energy required and consideration governing the selection machines and equipment in size reduction operation [29].

V. CONCLUSION

The physical and mechanical properties of the seed determined as function of moisture content varied with increase in moisture content.The average length, width and thickness, for almond seed ranged from 25.42mm to 28.63mm, 23.69mm to 26.63mm and 7.51mm to 9.18mm respectively as moisture content varied from 6.78% to 21.97% w.b. The sphericity increased marginally from 64.66 to 66.63% as moisture content varied within the range of 6.78% to 21.97% w.b. The surface area of the seed increased from 853.69mm^2 to 1143.04mm^2 with moisture content ranging from 6.78% to 21.97% wb. True and bulk density decreased from 1.27g/cm^3 to 0.98g/cm^{3}and 0.58g/cm^3 to 0.48g/cm^3 respectively as moisture content was increased from 6.78% to 21.97%wb. The weight of 100 seeds and specific gravity increased from 7.06 to 8.82g and 0.79 to 0.95 respectively with increase in moisture content of the seed. The coefficient of static friction for wool, glass and steel varied from 0.52 to 0.67, 0.49 to 0.57 and 0.52 to 0.62 respectively as moisture content ranged from 6.78% to 21.97%wb.

The fracture force of *Terminalia catappa* increased from 2499N at 6.8% wb to 2689N at 21.79% wb. Tensile strength and compressive strength varied from 3.20Mpa to 4.60Mpa and 410N/mm^2 to 398N/mm^2 respectively as moisture content ranged from 6.78% to 21.97% wb.

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