ISSN 2229-5518

Some Physical Properties of *Neem* Seeds & Kernels (Azandirachta indica) as a Function of moisture Content

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Abstract— *This study was carried out to determine the effect of moisture content on some physical properties of neem seeds (Azadirachta indica). Neem fruits were collected from a plantation. Ripe fruits were sorted and neem seeds were obtained by manually depulping the ripe fruits, washed and sundried to about 5.10 % (wb) moisture content. Moisture content adjustment by rewetting was carried out to obtain three levels of 9.95, 14.17 and 18.69 % (wb). Physical properties (length, width, thickness, geometric mean diameter, sphericity, aspect ratio, volume, surface area, 1000-seed mass, true density, bulk density, density ratio and percentage porosity) of the dried seeds and the embedded kernels were determined. Data obtained were statistically analyzed to obtain the descriptive and inferential statistics. Results showed that the seed ranges in values for length (14.15 to 14.51 mm), volume (4.55 to 4.57 mm^3), surface area (238.2 to 240.1 mm^2), 1000-unit mass (216.2 to 326.9 kg), true density (555.8 to 594.3 kg/m^3), bulk density (354.19 to 375.12 kg/m^3), density ratio (156.95 to 158.40), while the width reduced from 6.97 to 6.94 mm, thickness 6.7 to 6.6 mm, aspect ratio 49.4 to 47.9, percentage porosity 36.15 to 36.04. Similarly, for the kernel, the length ranged from 11.02 to 11.27 mm, 1000-unit mass 336.0 to 347.4 kg, true density 797.1 to 954.3 kg/m^3, density ratio 139.70 to 182.18, percentage porosity 28.29 to 45.02. Likewise, the width decreased from 4.49 to 4.42 mm, thickness 4.2 to 3.9 mm, geometric mean diameter 5.9 to 5.8 mm, sphericity 0.54 to 0.52, aspect ratio 40.9 to 39.4, volume 3.08 to 3.03 mm^3, surface area 109.2 to 105.4 mm^2 and bulk density 571.4 to 523.6 kg/m^3 as moisture increased. However, seed geometric mean diameter (8.7mm) and sphericity (0.6) remained constant. For many of the properties considered, moisture content significance at ($p<0.05$) but was not uniform on both seeds and kernel.*

Keywords— *Neem* seed, kernel, wet basis, Moisture content, Physical properties

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1 Introduction

Neem tree (*Azadirachta indica*) is a member of the mahogany family "*Meliaceae*". It is one species in the genus "*Azadirachta*" and is native to Indian Subcontinent, growing in tropical and semi-tropical regions. Other vernacular names include *Neem*, (in some Nigerian languages) *Dongoyaro*. In East Africa it is also known as *Muarubaini* (Swahili), which means *the tree of the 40*, as it is said to treat 40 different diseases, and in Somalia it is known as "*Geed Hindi*" which means "*the Indian tree*" (Rajeev, 2009). *Neem* is considered a weed in many areas, including some parts of the Middle East, and most of Sub-Saharan Africa including West Africa. A typical *neem* tree is shown in Plate 1.1

Plate 1.1: Neem Tree

Neem oil is a vegetable oil pressed from the fruits and seeds of the *neem*. While sharing many properties with tea tree oil, *neem* oil has the added advantage of a high fatty acid and low *terpene* content. *Neem* oil has been found to be an effective mosquito repellent.

Developing countries such as Nigeria needs to prioritize self-reliance in energy for overall economic development. The need to search for alternative sources of renewable energy that will be safe and environmentally friendly should be in top priority bearing in mind that fossil fuels are finite.

Processing operations such as depulping and decortication to obtain the kernel are still carried out manually. Designs of machines that can handle these processing operations require engineering properties of the seed.

Despite the economic importance of *neem* seed in many countries, only little information is known about the engineering properties of the seed. Using manual method in processing (depulping and decorticating) *neem* seed is not only laborious and time consuming but also yields low quality product. The knowledge of physical properties of this seed will enhance the development of appropriate machines and equipment relevant to bulk-handling, during harvesting, sorting, dehusking, drying, storage, aeration, grinding, and extraction of oil from the seed. *Neem* seed which is available in abundance in Nigeria contains about 40% non-edible oil which can be used as biodiesel; this is an untapped and researched potential resource [24]. This study intends to provide physical properties parameters that will be useful for the design and construction of a decorticator and an expeller to extract the *neem* seed oil as a biodiesel. In Nigeria presently there is no recognized commercial production and no known industrial utilization of the seed, hence the necessity for this research work.

Of the various alternate fuels under consideration, biodiesel, derived from esterified vegetable oils, appears to be the most promising alternative fuel to diesel due to the following reasons[2].

i. Biodiesel can be used in the existing engines without any modifications.

ii. Biodiesel obtained from vegetable sources does not contain any sulphur, aromatic hydrocarbons, metals or crude residues. Biodiesel is an oxygenated fuel hence emissions of carbon monoxide and soot is drastically reduced.

iii. Unlike fossil fuels, use of biodiesel does not contribute to global warming as the CO_2 so produced is absorbed by the plants. Thus in nature CO_2 is balanced.

iv. The occupational safety and health administration classify biodiesel as a non-flammable liquid. The use of biodiesel can extend the life span of diesel engine because it is more lubricating than petroleum diesel fuel.

v. Biodiesel is mostly obtained from renewable vegetable oils/animal fats and hence it may improve the fuel or energy security and thus leading to economy independence.

Biodiesel is better than the conventional fossil fuel as it does not emit harmful fumes and is a cheaper source for generating fuels. Using bio fuels is the only way to lessen the environmental pollution and lessen the usage of conventional fuels (www.genetix.com).Table 1.0 illustrates properties of vegetable oils as compared with diesel (ASTM D975). Esterified *neem* oil as a biodiesel satisfied the important fuel properties as per ASTM D975 [2].

Table 1.0: Properties of vegetable oils as compared with diesel (ASTM D975)

Before blend			
Properties	Diesel	Mustard	Neem
Cetane number (CN)	45-55	37	31
Viscosity (20^{0}C) mm^2/sec	4.7	24.67	37.42
Specific gravity	0.83	0.953	0.968
Calorific value (MJ/kg)	42	32.43	29.97
Carbon (%)	86	74.45	78.92
Hydrogen (%)	14	10.63	13.41
After blending (20% by volume with diesel)			
Cetane number (CN)	45-55	54	48
Viscosity (20^{0}C) mm^2/sec	4.7	5.65	6.3
Specific gravity	0.83	0.914	0.934
Calorific value (MJ/kg)	42	34.562	31.142
Carbon (%)	86	76	83
Hydrogen (%)	14	11.3	15

Source: [2]

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The knowledge of physical properties of agricultural materials is important in many problems associated with the design of specific machines or in storage, handling, planting, harvesting, threshing, cleaning, sorting, sizing, grading, and drying. Quality knowledge of physical parameters, such as shape and size (axial dimension), sphericity, density (true and bulk), porosity, weight, and volume is very important in this regards [24].

[4] Reported that guna fruits major and minor semi-axial dimensions varied from 5.27 to 5.71cm and 5.18 to 5.61cm for moisture ranges of 87.21-92-45% (wb.) and 85.07-89.74% (wb.) respectively. The mean of major diameter, intermediate diameter, minor diameter and geometric mean diameter of acorn kernel were found to be 31.27, 18.20, 16.64, and 21.89 mm, respectively [20]. [1] Noted that shape and sphericity of fruit, nut and kernel of oil palm studied was not dependent on treatment.

[27] Reported that the mean values for sphericity and aspect ratio of two varieties of fresh oil palm fruit (Dura and Tenera) which were 70.67 and 64.23; 67.78 and 56.77 respectively. Surface area, true and bulk density of chestnut seeds increased with increase in moisture content [39]. Bulk density of borage seeds followed a parabolic relationship with moisture content [38]. As the moisture content of soybean grains (*Glycine max* L.) increased from 6.92 to 21.19 % db., the bulk density and true density were found to decrease from 650.95 to 625.36 kg/m^3 and from 1147.86 to 1126.43 kg/m,^{3} respectively, while the porosity was found to increase from 43.29 to 44.48 % [36].

2 Materials and Methods

2.1. Sample preparation

This study was conducted at the Department of Agricultural and Environmental Engineering in Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria during the period of June–October 2012. *Neem* fruits (*Azadirachta indica*) of about 200 kg were collected from a plantation in *Dawaki, Kanke* Local Government Area of Plateau State. Ripe fruits (yellowish in colour) and unripe fruits (greenish in colour) were collected from the tree by shaking branches of the tree. These seeds were allowed to fall freely on poly bags spread under the tree. Sorting of matured fruits from immature ones was carried out manually in order to get good quality seeds, [32]. *Neem* seeds were obtained by manually depulping ripe fruits. The sorted matured seeds were later sundried to safe moisture content of about 5.10% (wb).

Moisture content (5.10%) of the safe sun dried ripe sample was later adjusted to three other different moisture content levels of 10.0, 14.17 and 18.69% (wb). In order to obtained different moisture content of the seed, the standard procedures stated for ungrounded grain and seed in the ASAE S352.2 FEB 03 was adopted. Electric oven (the Gallenkamp oven 300plus series), moisture content cans, desiccators containing desiccants and Electronic balance (METTLER TOLEDO) with accuracy of ±0.001g were used to determine moisture content of the *neem* seeds. The initial average moisture content was determined using oven method. Three samples of 10.0g were heated for twenty-four hours at 105±2^{o}C in Gallenkamp 300 plus series oven until constant weight was reached [20], [33]. The experiment was replicated three times and average weight was recorded. The moisture content was calculated using equation 3.1:

$$M.C\ (w.b) = (M_b - M_a)/\ (M_b - M_c) \times 100\% \qquad (3.1)$$

where;

M.C (w.b) = moisture content (wet basis)
M_b = the weight of can plus sample weight before heating (kg)
M_a = the weight of can plus sample weight after heating (kg)
M_c = weight of can (kg)

The mean value and standard deviation of the three samples was calculated.

The moisture content of the sample was adjusted to three levels, 9.95, 14.17 and 18.69% [26], [25]. Each sample weighing 300.0 g was sealed in a separate polythene bags with the calculated amount of distilled water that will change the moisture content to the desired level. The quantity of distilled water that was added in order to adjust the moisture was calculated using equation 3.2 given below [9];

$$M=W_s\,((M_2 - M_1)/\,(100-M_2)) \qquad (3.2)$$

where;
W_s = weight of sample (kg)
M = weight of distilled water that was added (kg)
M_1 = initial moisture content (%)
M_2 = final moisture content (%)

After addition of the required distilled water (10% of the calculated distilled water was added to cater for losses), the samples were kept in refrigerator at a temperature of about 5°C for one week to enable the moisture to equilibrate. After one week, three replicates of the samples were randomly taken from each batch weighed in order to know the initial moisture content before they were oven dried for twenty-four hours at 105 ± 2°C. When constant weight was attained, the samples were weighed again to know the final weight. Equation 3.1 was used to determine the moisture content of the samples. The moisture content determination was replicated thrice with the mean and standard deviation values calculated.

2.2. Determination of physical properties

The physical properties determined include size (in terms of axial dimensions), geometric mean, sphericity, volume, surface area, and aspect ratio, 1000-unit mass, true density, bulk density, density ratio and percentage porosity. These properties were determined for the seed and kernel. The measurements were taken at an average room temperature of 36^0 C.

Neem seed and kernel sizes (geometric mean diameter) were determined by measuring the dimension of the principal diameter on three axes-major (L), intermediate (W) and minor (T) - for 100 seeds and 100 kernels that were randomly selected from each moisture level. Digital Vernier calliper with accuracy of ±0.01mm was used to determine these dimensions. The geometric mean diameter (D_g) was calculated using equation 3.3 [29]:

$$D_g= (LWT)^{1/3} \qquad (3.3)$$

This measurement was replicated three times; the mean and standard deviation values were calculated.

The sphericity of the samples were determined by using equation 3.4, as contained in [21] and used by [13], [19] and many other researchers thus;

$$\varphi=D_g/L \qquad (3.4)$$

where:
φ = sphericity

Source: [34].

The aspect ratio of the 100 seeds from each moisture level was determined as recommended by [27] using equation 3.5 below:

$$R_a=W/L\times 100. \qquad (3.5)$$

The volume and surface area of the sample was determined using the equations 3.6 and 3.7, respectively, in accordance with [35]:

$$V=\pi\,(LWT)^3\,/6 = \pi\, D_g^3/6 \qquad (3.6)$$

$$S=\pi D_g^2 \qquad (3.7)$$

where:
V = volume (mm³)
$S = surface\ area$ (mm²)
Other parameters as defined earlier.

To evaluate the 1000 unit mass, 100 seeds and kernels were randomly selected from each sample and their weights were determined using the electronic weighing balance. Each weight was multiplied by 10; the mean and standard deviation values of five replicates was calculated and recorded, [9].

The true density (ρ_T) of the *neem* seed and kernels were determined by toluene displacement method in order to avoid water absorption by the sample [34], [29]. Ten randomly selected *neem* seeds and 20 kernels were weighed separately and each was dropped into graduated measuring cylinder containing 30.0 ml of toluene. The net volumetric toluene displacement by seed and kernel were noted and recorded. The procedure was repeated three times. The true density ρ_T was then calculated using the equation 3.8:

$$\rho_T=m/V \qquad (3.8)$$

where;
$\rho_T = true\ density\,(kg/m^3)$
$m = mass\ of\ the\ sample, kg$
V = volume (m³)

The bulk density of the seed and kernel was determined by filling a cylinder of known volume (400 cm³) with each sample. The initial weight of the cylinder was determined using the electronic balance (M_1). The top of the container was gently leveled after filling it with no additional manual compaction was done, the cylinder and the sample was weighed. The bulk weight (M_2) was recorded. This was replicated ten times. Equation 3.9 gives the bulk density of the material:

$$\rho_B= (M_2 - M_1)/V \qquad (3.9)$$

where:
M_2 = mass of cylinder plus seeds (kg)
M_1 = mass of empty cylinder (kg)
V = volume of the cylinder (m³)

The density ratio $\in$ is the ratio of the true density of the seed or kernel to the bulk density and it was determined as a percentage in equation 3.10 [27]:

The percentage porosity (P) was computed from the values of the true density (ρ_T) and the bulk density (ρ_B) of the seed and kernel, by using expression given by [9] in Eq. (3.11) below:

$$P= (1-(\rho_B/\rho_T))\,x100 \qquad (3.11)$$

3 Results and Discussion

3.1. Size

3.1.1 Length of *neem* seed and kernel

The length of the *neem* seed and kernel was observed to increase from 14.15 to 14.51 mm for seed and from 11.02 to 11.27 mm for kernel as the moisture was increased from 5.10 to 18.69 % w.b. This amounts to 2.5 % increase for seed and 2.3 % increase for the kernel. Fig. 3.1 shows the effect of moisture on the length of neem seed and kernel.

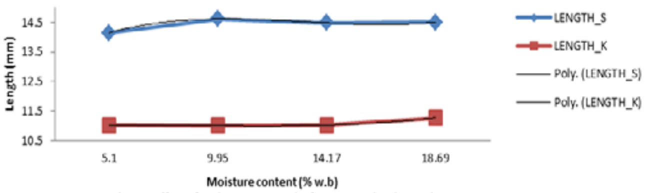

Fig. 3.1: Effect of Moisture on Length of Neem Seed and Kernel

Though increase in moisture content increased the length of neem seed and kernel, the increase in the seed was slightly higher than that of the kernel. The relationship between increase in moisture and increase in length was polynomial in nature. For the kernel the effect of moisture was much more pronounced at the highest moisture level. The increase in length of the seed and kernel with moisture content can be attributed to absorption of water and the consequential expansion by the seed and kernel. Similar results were obtained by [22], [29], [9] and [33] on sorghum, rough rice grain, three varieties of cowpea and neem fruit and seed, respectively.

The mathematical relationships between the length and the moisture using regression analysis are presented as equations 4.1 and 4.2.

L_s (mm) = 0.124mc3 - 1.0386mc2 + 2.7069mc + 12.359 ($R^2 = 1$) (4.1)

L_k (mm) = 0.0316mc 3 - 0.1708mc 2 + 0.2715mc + 10.887 (R^2=1) (4.2)

The effect of moisture content on the length of neem seed and kernel indicated that the effect was significant ($p < 0.05$).

3.1.2 Width of *neem* seed and kernel

The relationship between width and moisture content of neem seed and kernel is shown in Fig. 3.2. The width of the neem seed and kernel was observed to decrease from 6.97 to 6.94 mm for the seed, while that of kernel from 4.49 to 4.42 mm, as the moisture increased from 5.10 to 18.69 % w.b. This amounts to 0.4% and 1.6% decrease for seed and the kernel, respectively. The slight decrease in the width may be attributed to increase in the length which caused shrinkage in the width [5]. The width of seed and kernel decreased having polynomial nature indicating no significant effect on the seed width. The result obtained from the statistical analysis showed that moisture has effect on the width of the kernel but not on the seed. These relationships expressed mathematically are presented in equations 4.3 and 4.4.

W_s (mm) = $0.0128m_c^3 - 0.1246m_c^2 + 0.3434m_c + 6.7422$ ($R^2 = 1$) (4.3)

W_k (mm)= $-0.0489m_c^3 + 0.4768m_c^2 - 1.3774m_c + 5.4354$ ($R^2 = 1$) (4.4)

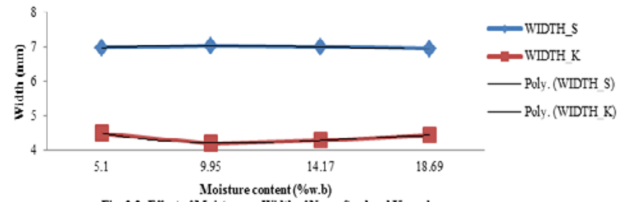

Fig. 3.2: Effect of Moisture on Width of Neem Seed and Kernel

3.1.3 Thickness of *neem* seed and kernel

The variation of neem seed and kernel thickness with increasing moisture content is presented in Fig. 3.3. It could be seen that the thickness of the seed decreased from 6.7 to 6.6 mm, which is 1.5 % decrease while that of kernel decreased from 4.2 to 3.9 mm which is 7.1 % decrease. The higher decrease in the thickness of the kernel compared to the seed may be due to the harder seed coat compare to that of the soft and tender kernel coat.

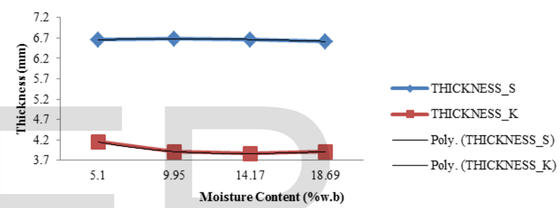

Fig. 3.3: Effect of Moisture Content on Thickness of Neem Seed and Kernel

The mathematical relationships between the seed, kernel and the moisture content are presented below:

T_s (mm) = $0.0009m_c^3 - 0.0241m_c^2 + 0.0882m_c + 6.5922$ ($R^2 = 1$) (4.5)

T_k (mm) = $-0.0156\, m_c^3 + 0.1872\, m_c^2 - 0.691x + 4.6705$ ($R^2 = 1$) (4.6)

The statistical analysis of the effect of moisture content on the thickness of *neem* seed and kernel indicated that the effect was not significant on the on the seed on ($p < 0.05$) but highly significant for the kernel. The effect of moisture on the three dimensions is therefore important. This implies that in the design of processing equipment the effect of moisture content must be carefully considered.

Generally, results obtained for the axial dimension show that the modifications of moisture content of *neem* seed caused a little variation in its size, its kernel being the most affected. Similar observation was observed and reported by [33] on *neem* fruit and seed.

3.1.4 Geometric mean diameter of *neem* seed and kernel

The relationship between the geometric mean diameter and moisture content of *neem* seed and kernel is as shown in Fig. 3.4. The values of the geometrical mean diameter of seed increased linearly but later decrease with increase in moisture content. The geometric mean diameter of the kernel decreased with increase in moisture but later increased with increase in moisture. Geometric mean diameter of seed increased from 8.7 to 8.8 mm but later decreased from 8.8 to 8.7 mm, this account for 1.2% (5.10 to 9.95 % and 14.17 to 18.69 % w.b moisture), while the kernel decreased from 5.9 to 5.7 mm and later increased from 5.7 to 5.8 mm which is about 3.4 and 1.2% de-

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crease and increase, respectively as moisture content increased from 5.1 to 18.7% wb. This result agreed with the earlier report by [11] on faba bean (*Vicia faba* L.) grains.

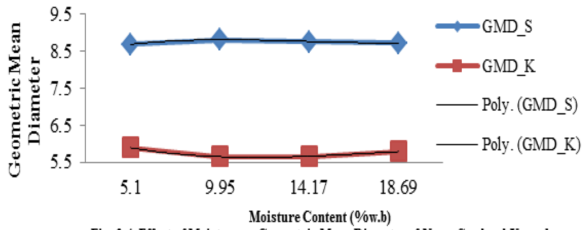

Fig. 3.4: Effect of Moisture on Geometric Mean Diameter of Neem Seed and Kernel

The regression equation for the effect of moisture content on geometric mean is as shown in Equations 4.7 and 4.8.

D_{gs} (mm) = $0.0302m_c^3 - 0.2675m_c^2 + 0.7168m_c + 8.2079$ ($R^2 = 1$) (4.7)

D_{gk} (mm) = $-0.0244m_c^3 + 0.2752m_c^2 - 0.8996m_c + 6.5382$ ($R^2 = 1$) (4.8)

The statistical analysis of the effect of moisture content on the geometrical mean diameter of *neem* seed and kernel indicated that the effect was highly significant on the geometrical mean diameter of the kernel and no effect on the seed on ($p < 0.05$) probability.

3.1.5 Sphericity

The relationship between sphericity and moisture content variation of *neem* seed and kernel is as presented in Fig. 3.5. The sphericity of the seed and kernel was observed to decrease from 0.62 to 0.60 and 0.54 to 0.52 which is about 3.2 and 3.7 % decrease for seed and the kernel, respectively.

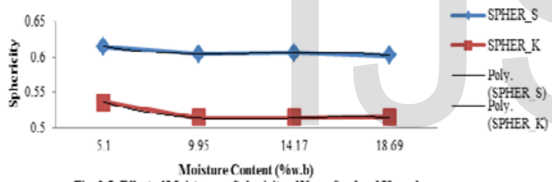

Fig. 3.5: Effect of Moisture on Sphericity of Neem Seed and Kernel

A linear relationship was observed by [18] between the sphericity of sweet corn kernels and moisture content. [17] reported a polynomial relationship between the sphericity of roselle seeds Mexico and China cultivars while Sudan cultivar has a linear relationship.

However, results obtained for *neem* seed and the kernel partly agreed with the report of [17] on roselle seeds and [9] on three varieties of cowpea. The regression equations 4.9 and 4.10 were derived for neem seed and kernel respectively.

$\varphi_s = -0.0029m_c^3 + 0.0232m_c^2 - 0.0597m_c + 0.654$ ($R^2 = 1$) (4.9)

$\varphi_k = -0.0036m_c^3 + 0.0327m_c^2 - 0.095m_c + 0.602$ ($R^2 = 1$) (4.10)

The low value of the sphericity (0.49 % for seed and 0.17 % for kernel) of *neem* is an indication of their inability to roll but slide. This result will be useful in the design of hopper, separating chamber and conveying equipment for seed and kernel.

The statistical analysis of the effect of moisture content on the sphericity of neem seed and kernel showed higher significance on the kernel than the seed on ($p < 0.05$.

3.1.6 Aspect ratio

The relationship between aspect ratio and moisture content variation of *neem* seed and kernel is as presented in Fig. 3.6. The aspect ratio of the seed and kernel decreased from 49.4 to 47.9 which accounts for 3.0% decrease and from 40.9 to 39.4 which accounts for 3.7% decreased, respectively. The low sphericity and aspect ratio is indicative that the seed and the kernel shape have low tendency towards a sphere.

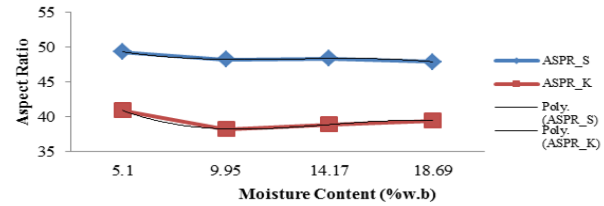

Fig. 3.6: Effect of Moisture on Aspect Ratio of Neem Seed and Kernel

The relationship between moisture content and the aspect ratio for both the seed and the kernel is polynomial. The regression equations 4.11 and 4.12 were derived for neem seed and kernel, respectively.

$R_{as} = -0.3006m_c^3 + 2.4062m_c^2 - 6.205m_c + 53.468$ ($R^2 = 1$) (4.11)

$R_{ak} = -0.5614m_c^3 + 5.0144m_c^2 - 13.776m_c + 50.237$ ($R^2 = 1$) (4.12)

The statistical analysis of the effect of moisture content on the aspect ratio of seed and kernel indicated that the effect was significant on the aspect ratio of the seed but more effect on the kernel on ($p < 0.05$) probability.

3.1.7 Volume of *neem* seed and kernel

Fig. 3.7 shows the connection between moisture content and volume of *neem* seed and kernel. The seed volume of *neem* increased from 4.55 to 4.57 mm³ while the kernel volume decreased from 3.08 to 3.03 mm³ which is about 0.44 % increase for the seed and 1.6 % decrease for the kernel as the moisture content increased from 5.10 to 18.69 % w.b. The relationship between the volume of the seed and kernel with respect to moisture content increase is polynomial, which agrees with the results of [18] on coriander seed and [23] on vetia nut which were polynomial.

The result of this study however shows a different trend from the results obtained by [6], [31], [8], [30] on peanut, caper (*Capparis ssp*) fruit, millet and okra seed, respectively which were all linearly related with increase in moisture.

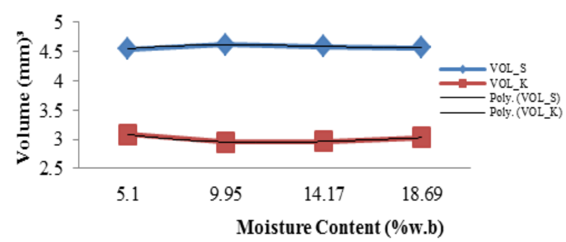

Fig. 3.7: Effect of Moisture on Volume of Neem Seed and Kernel

The difference in the current result may be due to differences in seed composition and the structure. The regression equation for the relationship between the seed and the kernel are as shown in equations 4.13 and 4.14

$V_s = 0.0158mc^3 - 0.14m_c^2 + 0.3753m_c + 4.2977$ ($R^2 = 1$) (4.13)

$V_k = -0.0128m_c^3 + 0.1441m_c^2 - 0.471m_c + 3.4234$ ($R^2 = 1$) (4.14)

From the statistical analysis moisture variation has no significant effect on the volume of the seed but has higher significant effect on the kernel on ($p < 0.05$).

3.1.8 Surface area of *neem* seed and kernel

In Fig. 3.8 the effect of moisture variation on the surface area

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ISSN 2229-5518

of *neem* seed and kernel is clearly shown. The value of the surface area for different moisture levels from 5.10 to 18.69 % w.b. varied from 238.15 to 240.10 mm² (which is 0.8 % increase for seed) and 109.22 to 105.40 mm² for kernel (which is 3.1 % decrease). The result obtained partly agreed with the findings of [9].

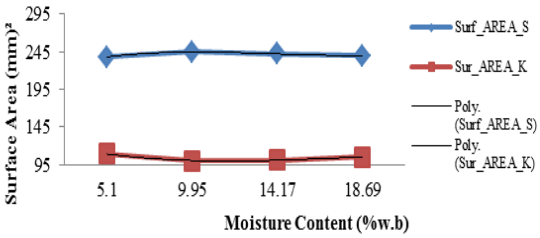

Fig. 3.8: Effect of Moisture on Surface-Area of Neem Seed and Kernel

The regression equations 4.15 and 4.16 represent the relationship between the seed and kernel with moisture content.

$S_s = 1.5907m_c^3 - 14.088m_c^2 + 37.685m_c + 212.96$ (R^2= 1) (4.15)

$S_k = -0.8317m_c^3 + 9.532m_c^2 - 31.468m_c + 131.99$ (R^2= 1) (4.16)

Statistical analysis shows that the effect of moisture content is not significant at 0.05 % level on surface area of the *neem* seed but has higher significance on the kernel.

The increase in surface area with increase in moisture content is as a result of increase in axial dimension with increase in moisture content. This increase is an indicative of its pattern of behaviour in a flowing fluid such as air as well as the ease of separating extraneous materials from the seeds during cleaning by pneumatic means. Another probable reason for some of the variations observed from all the axial dimensions could be that the physical properties are not only affected by moisture content, but by the locality where it was planted.

3.2 1000-unit mass of *neem* seed and kernel

Fig. 3.9 shows the relationship between the moisture content and the 1000-unit mass of the seed and the kernel. The value of the one thousand seed weight increased from 216.2 g to 326.9 g which is 51.2 % increase while the kernel increased from 336.0 to 347.4 g for which is an increase of 3.4 % as the moisture content increased. Similar results were found by [32] for cumin seed, [17], for roselle seed, [16], for cowpea (*vigna sinensis* L.) seed, and [14], for three varieties of sorghum seeds. Equations 4.17 and 4.18 show the relationship between the 1000 seed and kernel mass with moisture content. The relationship for the seed is polynomial while the kernel is linear. Statistical analysis indicates that the effect of moisture content is highly significant at 0.05 levels on mass of the *neem* seed and the kernel.

$1000Um_s = 9.0785m_c^3 - 86.14m_c^2 + 276.97m_c + 16.293$ (R^2= 1) (4.17)

$1000Um_k = 3.7647m_c + 332.51$ (R^2= 0.9962) (4.18)

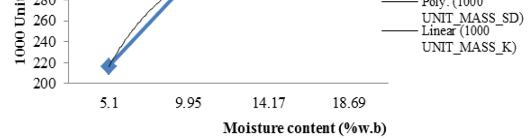

Fig. 3.9: Effect of Moisture on 1000 Unit Mass of Neem Seed and Kernel

3.3 True density of *neem* seed and kernel

The result of the experiment on the effect of variation of moisture content on true density is as presented in Fig. 3.10. The true density of seed increased from 555.8 to 594.3 kg/m³ which account for 6.9 % increase for seed and 797.1 to 954.3 kg/m³ for kernel accounting for 19.7 % for the kernel when the moisture content was varied from 5.10 to 18.69 % w.b. The observed increase in true density which varies with increase in moisture content might be attributed to the relatively lower true volume as compared to the corresponding mass of the seed attained due to water absorption.

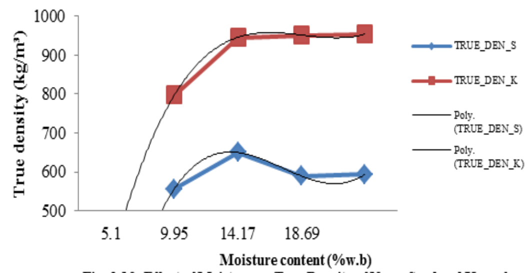

Fig. 3.10: Effect of Moisture on True Density of Neem Seed and Kernel

This agreed with the results of [12] for jatropha seed (*Jatropha curcas* L.), and [7] for Roselle (*Hibiscus sabdariffa* L.) seed. This result was contrary to the result obtained by [33] for *neem* fruit and seed because the true density result obtained in their study decreased with increase in moisture.

The obtained result of true density for both *neem* seed and the kernel indicates that both are lighter than water hence they will partially suspend in water. This is useful information in design of cleaning and separation machines. The statistical analysis of the effect of moisture content on the true density of seed and kernel indicated that the effect was not significant for the seed but highly significant for the kernel at 0.05% probability.

3.4.1 Bulk density of *neem* seed and kernel

The result of the effect of moisture on the bulk density of *neem* seed and kernel is as presented in Fig. 3.11. The values of the bulk density for the range of moisture content studied increased from 354.2 to 375.1 kg/m³ which are 5.9 % increase for the seed while that of kernel varied from 571.4 to 523.6 kg/m3 which is about 8.4 % decrease when the moisture increased from 5.10 to 18.69 % w.b. The relationship between moisture content and the seed is linear while that of kernel is polynomial. The increase in bulk density for the seed indicated increase in mass owing to moisture in the seed while kernel decreased due to low absorption of water. This result agrees with the result of [33] on *neem* fruit and seed, [31] for caper fruit, [10] caper seed.

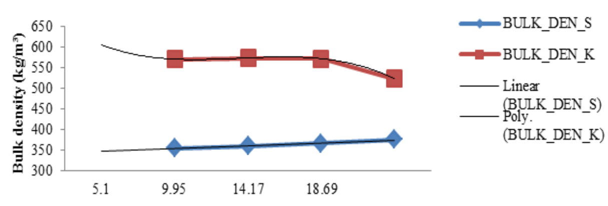

Fig. 3.11: Effect of Moisture Content on Bulk Density of Neem Seed and Kernel

The regression equations for both the seed and the kernel are as shown below.

ρ_{s} = = 6.9459m_c + 339.75 (R^2= 0.9939) (4.19)

ρ_{k} = -7.106m_c^3 + 61.62m_c^2 - 170.12m_c + 721.99 (R^2= 1) (4.20)

The statistical analysis of the effect of moisture content on the bulk density of *neem* seed and kernel indicated that the effect was significant on the bulk density of the kernel but had no effect on the seed ($p < 0.05$) probability.

3.4.2 Density ratio of *neem* seed and kernel

The density ratio for seed and the kernel increased with increase in moisture content (Fig. 3.12) with the result being pronounced in kernel. This result may be attributed to the fact that the kernel becomes softer with increase in moisture at a faster rate than the seed.

The polynomial relationship is as shown below.

ϵ_s = 10.074m_c^3 - 112.17m_c^2 + 392.77m_c - 260.52 (R^2= 1) (4.21)

ϵ_k = 6.3657m_c^3 - 69.135m_c^2 + 249.85m_c - 134.39 (R^2= 1) (4.22)

The result of the statistical analysis of the effect of moisture content on the density ratio as presented in Tables 4.1 and 4.2 indicates that the effects was significant on the density ratio of the kernel only and not on the seed at 0.05 % probability.

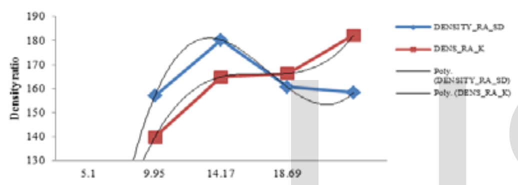

Fig. 3.12: Effect of Moisture Content on Density Ratio of Neem Seed and Kernel

3.4.3 Percentage porosity of *neem* seed and kernel

Figure 3.13 shows the effect of moisture content on percentage porosity of the seed and the kernel. It could be assumed that increase in moisture content does not really affect the porosity of the seed while it increased the porosity of the kernel.

Similar trends were reported by [33] for *neem* fruit and seed. Some researchers reported a polynomial relationship for some crops such as [31] for caper, [15] for sunflower, and [6] for Turkish marhleb.

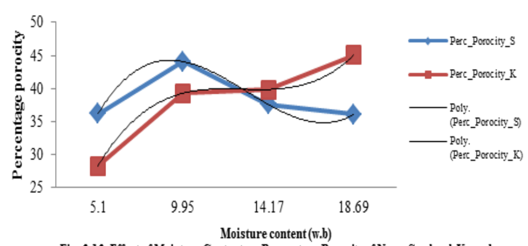

Fig. 3.13: Effect of Moisture Content on Percentage Porocity of Neem Seed and Kernel

The relationship between the moisture content and porosity of *neem* seed and kernel is as presented in Equations 4.23 and 4.24.

P_s = 3.2267 m_c^3 - 26.56 m_c^2 + 65.003 m_c - 5.52 (R^3 = 1) (4.23)

P_K = 2.5033 m_c^3 - 20.225 m_c^2 + 54.132 m_c - 8.12 (R^2= 1) (4.24)

Statistical analysis of the effect of moisture content on the percentage porosity of *neem* seed and kernel indicates that the effect was significant on kernel only ($p < 0.05$). The knowledge of the effect of moisture content on porosity of *neem* seed and kernel is essential in the aeration process during the pneumatic separation of seed, kernel and chaff after shelling of the seed.

4 Conclusion

Research on some selected physical properties of *neem* seed and kernel were determined. The results obtained showed good agreement with some of the general trend and ranges obtained for other similar crops. The following conclusions could be construed from this study.

a) The dimensions of the seed are relatively not uniform hence will make the process of depulping, decortication and separation and cleaning very tedious.

b) *Neem* seed and kernel are a complex mixture of sizes, weight and density, making postharvest processes cumbersome.

c) The seed average length, volume, surface area, true density, bulk density, density ratio, 1000-unit mass increased from 14.15 to 14.51 mm, 4.55 to 4.57 mm^3, 238.2 to 240.1 mm^2, 555.8 to 594.3 kg/m^3, 354.19 to 375.12 kg/m^3, 156.95 to 158.40, 216.2 to 326.9 kg, respectively as the moisture increased from 5.10 to 18.69 % w.b.

d) The kernel, average length, true density, percentage porosity and 1000-unit mass increased from 11.02 to 11.27mm, 797.1 to 954.3 kg/m^3, 28.29 to 45.02 and 336.0 to 347.4 kg, respectively.

e) The following properties of the seed decreased with increase in moisture; width (from 6.97 to 6.94 mm), thickness (from 6.7 to 6.6 mm), aspect ratio (from 49.4 to 47.9), and percentage porosity (from 36.15 to 36.04). Kernel decreased with increase in moisture in the followings; width (from 4.49 to 4.42mm), thickness (from 4.2 to 3.9 mm), geometric mean (from 5.9 to 5.8), sphericity (from 0.54 to 0.52 mm^3), volume (from 3.08 to 3.03 mm^3), surface area (from 109.2 to 105.4 mm^2), aspect ratio (from 40.9 to 39.4) and bulk density (from 571.4 to 523.6 kg/m^3). However moisture had no significant effect on geometric mean and sphericity of the seed.

This information will be very useful in the designing of handling machine and storage equipment for *neem* seed and kernel both in Nigeria and some other countries of the world.

Acknowledgments

I am very grateful to the following people for their contribution, advice and friendship towards the success of this research; Prof. K.O. Adekalu, Prof. (Mrs) K.A. Taiwo, Dr. (Mrs) O.A. Aregbesola, Dr. O.A. Koya, Mr. W.A. Adebayo members of staff of the Department of Agricultural and Environmental Engineering, Obafemi Awolowo University Ile-Ife, Nigeria.

This acknowledgement will be incomplete without mentioning the unconditional love, prayers, great support and consistent understanding my wife Mrs. F.A. Adedeji and our children towards the success of this research. My profound gratitude goes to the entire staff of the Department of Agricultural and Bio-Environmental Engineering Technology of The Federal Polytechnic, Bauchi. Finally, thanks to the TETFUND for the financial support. Now to the only wise God our Sav-

iour, be glory, majesty, dominion and power, both now and forever. Amen.

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