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A COMPARATIVE STUDY OF SELECTED ENGINEERING PROPERTIES OF CASHEW KERNELS GROWN IN NIGERIA

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ABSTRACT

Engineering properties aid in the design and construction of equipment for post processing of cashew kernels. In this study, the engineering properties of cashew kernels from different locations were evaluated. The physical, mechanical and thermal properties of the kernels at a moisture content of 5% (wet basis) were investigated. The samples used for the study were randomly selected from four different plantation locations across two basic agro-ecological zones of Nigeria. The experiments were carried out in three replicates for each of the properties examined in any location in order to get average values. The physical properties considered were length, width, sphericity, bulk density, true density and specific gravity while the mechanical properties evaluated were porosity, angle of repose, terminal velocity, coefficient of friction, compression force, stress and deformation. The thermal properties examined were specific heat capacity and thermal conductivity. The results showed no significant difference ($p < 0.05$) in the physical and thermal properties. Similarly, there was no significant difference ($p < 0.05$) on porosity, angle of repose and deformation while terminal velocity, coefficient of friction, compressive force and stress were significantly different ($p < 0.05$). It can be concluded that a processing system developed using the property values of a particular variety of cashew kernel can be conveniently used with any other variety of the kernel. It is, however, recommended that varying force applications are to be used depending on variety of kernel. This is because there were significant differences ($p<0.05$) in the values of the mechanical properties examined and the end-product of the processing operation will be the same due to the fact that deformation in all cases was significantly the same. Equally, the thermal response of the cashew kernel from different plantation locations will be the same since the thermal properties of the cashew kernels were significantly the same.

Key words: Cashew, processing, mechanical, physical, thermal, properties, agro-ecological, engineering, zones

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INTRODUCTION

Cashew kernel is part of the nut of the fruit of the tree (*Anarcardium Occidentale L.*) (Figure 1). The fruit of the tropical tree resembles kidney in shape is basically made up of the cashew nut (seed) and cashew apple [1]. African countries like Tanzania, Mozambique, Kenya, Nigeria, Senegal, Côte d'Ivoire, Malawi and Angola among others top the list of cashew nut producing countries in the world [2]. In fact in 2014, Côte d'Ivoire was the highest exporter of cashew nut in Africa even though dehumanizing and un-conducive working conditions led to industrial disharmony in the cashew nut industry. The global demand for cashew kernel has been on the increase [3].In 2015, global production of cashew kernel was 738,861 tonnes, led by India and Côte d'Ivoire with both countries producing a total of 46% of the world total yield [3].

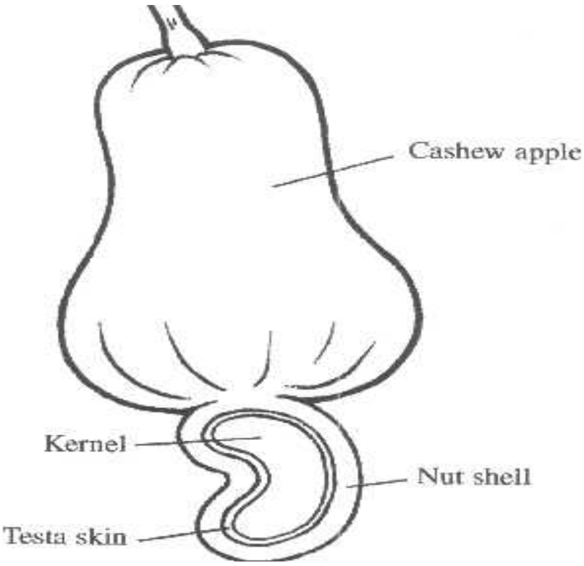

Figure 1: A Cashew fruit [1]

The composition of the kernel for protein, fat and carbohydrates are 21%, 46% and 25%, respectively [4] while the values for magnesium, phosphorus, zinc, iron, potassium, vitamin C vitamin E and folic acid are 43.9mg, 129mg, 1.24mg, 0.85mg, 58.5mg, 35.5mg, 1.77mg and 36.5µg in content, respectively [5]. The kernels' phytochemical compositions are the total phytosterol(2.48mg), phenol (1.65mg), phytate (1.54mg), tannin (1.84mg), alkaloid (2.77mg), flavonoid (3.47mg) and carotenoid (8.74µg). These compositions make the kernel useful in the reduction of mortality rate, cardiovascular disease, metabolic syndrome, diabetes and cancers, and good for weight loss [6 – 11].

After harvesting the cashew fruit at maturity, the cashew apple is usually consumed raw or processed into cashew juice drink, preservatives and jams. On the other hand, the nuts which are of the colour greyish to brown, could either be exported raw to industries where the basic interest is in the processing of the nuts' shells or be thermally processed to kernels. The kernels can then be transformed into other purposes by frying, roasting, milling to flours or to different confectioneries [12]. In the Asian region, the nuts are the most important product of the fruit because of the kernels' extraction [13].

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The knowledge of engineering properties of biological materials is useful in its treatment. However, these properties are not constant because of material variety (Figure 2). These non-constant property values make study and characterization of these materials a hectic task.

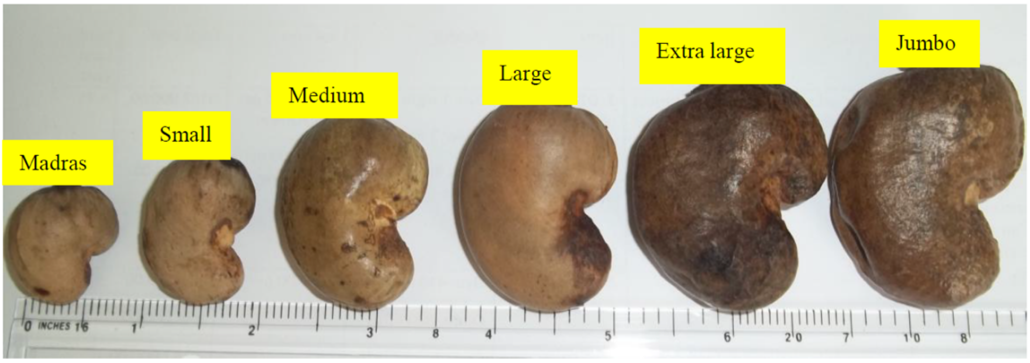

Figure1:Different sizes of Cashew nuts [14]

Physical properties (characteristics of the materials that could be observed or measured like size, mass and volume among others) of food and agricultural materials are useful in process designs of transportation and preservation of food and agricultural materials [15]. Different forms of cleaning, sorting and transporting equipment and storage structures are developed based on the physical and mechanical properties [16]. How food materials behave under thermal process is affected by the thermal properties of the material, while mechanical properties determine how the materials react to the application of force [2]. Thermal properties include characteristics such as thermal conductivity and specific capacity among others while the mechanical properties include characteristics such as porosity, angle of repose, terminal velocity, coefficient of friction, compression force, stress and deformation among others.

In other to develop machines and equipment for processing and handling of the kernels, there is then the need to study the properties of cashew kernels especially the physical, mechanical and thermal properties. Several studies have been done on the evaluation of properties of cashew kernel [2, 17]. However, the values of these properties differ from study to study. There seems to be lack of agreements among the authors on this matter. Hence, there is a need to comparatively study the properties of cashew kernels from different locations.

Nigeria (Latitudes 4^0-14^0N and Longitude 2^0-14^0E) is basically made up of two agro-ecological zones- the forest and savanna with the yearly rainfall ranging from 500mm from extreme savanna in the north of the country to 3000mm in the coastal southern part [18].

The objective of the study is to compare the engineering properties of Cashew kernel from various cashew plantations across the two basic agro-ecological regions of Nigeria. The engineering properties considered were limited to only the physical, mechanical and thermal properties. Data on engineering properties of a biomaterial are dependent on a

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number of factors such as variety and the climatic environment where it is cultivated [19].

MATERIALS AND METHODS

Materials

Cashew nut samples were procured from cashew plantations from four cashew producing states (Kogi, Enugu, Abia and Ogun) in Nigeria in April, 2018. The states cut across the two main ecological/ agricultural zones of the country, which are rain forest (comprising of Ogun and Abia states) and savanna (comprising of Kogi and Enugu) zones.

The cashew kernels were processed through roasting using hot oil process at temperature of 185^{0}C for 90 secas described by Azam-Ali and Judge [20]. Five kilograms of cashew nuts collected from each of the cashew plantations were roasted before shelling to get the kernels as described by Azam-Ali and Judge [20]. The kernels' moisture content was adjusted to 5% using a standard oven method at 103±2ºC [21], the moisture content recommended for proper storage of cashew kernel [22].

The kernels were then taken to different laboratories at the University of Nigeria Nsukka, Nigeria for analysis of physical, thermal and mechanical properties. All tests were conducted in triplicates. The statistical method adopted was the completely randomized design (CRD).

Determination of physical properties

The physical properties considered were length, width, sphericity, bulk density, true density and specific gravity. The size and the sphericity index of the kernels were evaluated by the method of Mohsenin [23]. In evaluating the average size of the kernels, 20 kernel samples were selected randomly. Vernier callipers of 0.01 mm accuracy was used to measure the axis (comprising of Length as x, Width as y, and Thickness as z) of the kernels individually. Then, the kernels geometric mean diameter, Geo_m was given as

$$Geo_m = (xyz)^{1/3} \qquad (1)$$

Equation 2 was used to calculate the kernels Sphericity index (S_i). The equation is given as

$$S_i = \frac{(xyz)^{1/3}}{a} \qquad (2)$$

In determining the shape of the cashew kernel, the method outlined in Kachru *et al.* [24] was used; the true and bulk densities were evaluated using the method of Mohsenin [25]. The true density, D_T is the ratio of the sample mass to its kernel volume, given as shown in equation three.

$$D_T = \text{(mass of kernel) / (Volume of kernel)} \qquad (3)$$

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For the bulk density calculation, a known mass of the cashew kernels was poured into a container that is cylindrical in shape whose volume is known. In doing this, care was taken to ensure that the samples were just at the brim of the cylinder without pile or overflow of the cashew kernels at the top of the cylinder while excess ones above the cylinder were carefully removed. This was done without forced compaction. Then the bulk density was obtained by dividing the mass of the samples by the volume of the cylinder. The Specific Gravity was determined by the method of Ogungbenle [26].

Determination of mechanical Properties

The porosity, P_R, was evaluated using the method described by Mustafa [27]. It is the void space in the bulk sample that is not covered by the kernels. It is calculated by using the relationship between true and bulk densities as shown in equation four:

$$P_R = \frac{D_{\mathrm{T}} - D_B \times 100}{D_{\mathrm{T}}} \quad (4)$$

Where D_T and D_B are the true and bulk densities respectively. The 'emptying method' was adopted in determining the kernels' angle of repose (θ). In 'emptying method', kernels were poured in to a cylinder kept on top of a plain area surface. To form a natural slope, the cylinder was gradually and carefully raised to allow the samples flow gradually down. Considering the height and diameter of the pile formed, the dynamic angle of repose was then given as shown in equation five,

$$\theta = \tan^{-1}\frac{2l}{d} \quad (5)$$

Where, l is the pile height (m) and d is the pile diameter (m).

The method of Kachru *et al.* [24] was used to evaluate the coefficient of static friction (μ). The Compressive force, Stress and Deformation were analyzed using a Hounsfield Monsanto Tensometer [2]. During the tests, the kernels were loaded with the position of the intermediate (width) diameter as the load bearing axis. Each kernel was compressed with a motion probe at a constant speed until the specimen fractured. The compressive force and deformation values were recorded from the data chart of the Tensometer. The compressive stress δs was calculated using the formula in equation six:

$$\delta s = Fn/A_{sF} \quad (6)$$

Where,

Fn = compressive force, N

A_{sF} = surface area, mm^2

δs = stress, N/mm^2

The terminal velocity was determined by measuring the fluid velocity required to suspend the sample in a vertical fluid stream in a calibrated cylinder. The samples were dropped into a cylinder filled with glycerine. As the sample moved down, the resistance force is said to be zero and the initial acceleration as '*g*'. As its speed increased, the resisting force increased until it was equal in magnitude to the sample's weight. Using Newton's second law: $\sum F_y$ = mg-kv = ma = 0, the acceleration became zero and there was no further increase in speed. The terminal velocity V_t, was then calculated as:

$$V_t = mg/k = (\sqrt{2mg})/(A_p\rho C_D) \qquad (7)$$

Where,
m = mass of sample, kg
g = acceleration due to gravity, m/s^2
k = proportionality constant, N.s/m
A_p= projected area of sample, m^2
C_D = drag coefficient
ρ = density of liquid, kg/m^3

Determination of thermal properties

The method outlined in Aviara and Haque [28] was used to evaluate the Specific heat capacity (C_{shp}), using the mixtures method where samples of given mass and temperature were put in a calorimeter made of copper material and was properly insulated to avoid heat loss. The calorimeter filled with water was stirred continuously until an equilibrium temperature was reached [28]. C_{shp} was then calculated as:

$$C_{shp} = \frac{(M_{oc}C_{oc} + M_{wa}C_{wa})(T_{fl} - T_{wa})}{M_{ks}(T_{ks} - T_e)} \qquad (8)$$

Where,
C_{shp} = specific heat of sample, J/kg °C
C_{oc} = specific heat of calorimeter, J / k g °C
C_{wa} = specific heat of water, J / k g °C
M_{wa} = mass of water, kg
M_{oc} = mass of calorimeter, kg
M_{ks} = mass of sample, kg
T_{ks} = initial temperature of sample, K
T_{fl} = equilibrium (final) temperature, K
T_{wa} = initial temperature of water, K
T_e = equilibrium temperature, K

The principle outlined in Sweat and Haugh [29] was used to evaluate the thermal conductivity (*Kco*) of the cashew kernels. A cylinder made of plastic and fixed with two thermocouples at the central point was filled with the kernel samples. The thermocouples were for temperature measurement. Other details of the set up are as discussed in [29]. Then *Kco* is given as:

$$kco = \frac{Q \ln {}^{t2}/_{t1}}{4\pi\,(T_{t2} - T_{t1})} \qquad (9)$$

Where,
Q = heat input, W/m

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t_1 = initial time, s
t_2 = final time, s
T_{t1} = initial temperature, ºC
T_{t2} = final temperature, ºC

Data analysis

In analyzing the data generated in this study, the analysis of variance (ANOVA) for completely randomized design (CRD)was done using excels programming software as outlined by Eze and Ojike [30]. The cashew kernels from different states served as the treatment. Fisher's Least Significant Difference (F-LSD) test was used to compare differences between means when significant ($p < 0.05$).

RESULTS AND DISCUSSION

Physical properties

The values of the physical properties for the four varieties considered is as shown in Table 1 where the superscripts represent the level of significance at 5% probability level. All the properties considered had varying values for different cashew kernels. This is in agreement with literature with varying values for a particular engineering property depending on the location and variety [2, 17].The mean length, width, sphericity, true and bulk densities for guinea savannah were 25.5mm, 10.9mm, 53.5%, 1091 kg/m^3 and 646.5 kg/m^{3}while for rain forest the values were 24.0mm, 9.4mm, 52.3%, 1223 kg/m^3 and 618.6 kg/m^{3,} respectively. Apart from the true density, kernels from guinea savannah had higher values than those from rain forest. Hence, the vegetative and climatic conditions in guinea savannah are more favourable than those of rain forest in terms of physical characteristics of cashew kernels. The implication of the statistical results of Table 1 is that the cashew kernels can be handled and processed using the same machine/mill irrespective of the variety and agro-ecological zone where the kernels were produced.

Mechanical properties

The mechanical properties of the cashew kernels are showed in Table 2. The mean porosity, angle of repose, deformation, terminal velocity, coefficient of friction, compressive force and stress for guinea savannah were 40.2%, 35.8^0, 6.04mm, 2.89m/s, 0.49, 725N and 1.28N/mm^2 while for rain forest the values were 49.3%, 36.1^0 8.05mm, 3.68m/s, 0.33, 658N and 1.32N/mm^2,respectively. With the exception of coefficient of friction and compressive force, kernels from guinea savannah unlike the physical properties had lower values than those from rain forest. Hence, the vegetative and climatic conditions in guinea savannah are more favourable than those of rain forest in terms of mechanical properties of cashew kernels. Equally, from Table 2 it could be observed that terminal velocity, coefficient of friction, compressive force and stress were significantly different. The implication of this is that the energy requirement in the processing of the kernels is affected by the variety and agro-ecological zone of the cashew. However, the same level of result, that is, deformation and porosity will be actualized irrespective of the variety and agro-ecological zone of the cashew. This is because there was no significant difference ($P<0.05$) in the porosity, angle of repose and deformation.

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Thermal Properties

The differences between mean values of the thermal properties of the kernels are shown in Table 3.The Specific heat capacity of the kernels ranged from 1554±5.99 to 1635±5.73 J/Kg/K, while the thermal conductivity values were between 0.196±0.19 and 0.239±0.12 W/mK with rain forest zone having higher mean values in all cases than guinea savannah zone. However, there was no significant difference ($p<0.05$) in all cases across the locations. The implication of this statistical result is that the cashew kernels can be handled and processed using the same thermal application and the effect of heat on the kernels would be the same. The values are comparable with those reported by Bart-Plange *et al.* [2]. The mean Specific heat capacity and thermal conductivity for guinea savannah were 1562 J $kg^{-1}K^{-1}$ and 0.20 W/mK, while for rain forest the values were1663J $kg^{-1}K^{-1}$ and 0.22 W/mK, respectively.

CONCLUSION

From this study, it can be concluded that that the physical and thermal properties of cashew kernel are not affected by agro-ecological zone where the cashew tree that produced them was grown. On the other hand, agro-ecological zone affects the terminal velocity, coefficient of friction, stress and compressive force characteristics of cashew kernels. From the conclusion, it is recommended that a cashew kernel processing system/machine designed using the properties of a given cashew kernel as design parameters can equally be used for any other variety of cashew kernel irrespective of the agro-ecological zone where it is gotten from. However, varying force applications are to be used depending on the variety of the cashew kernel.

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Table 1: Mean values of the physical properties of Cashew kernels

	Guinea Savannah		**Rain Forest**	
Properties	**Kogi**	**Enugu**	**Abia**	**Ogun**
Length (mm)	24.7±0.01[a]	26.3±0.11 [a]	24.1±0.57 [a]	23.9±0.08 [a]
Width (mm)	11.3±0.04 [a]	10.4±0.03 [a]	9.5±0.13 [a]	9.3±0.07 [a]
Sphericity(%)	54.2±0.07 [a]	52.8±0.01 [a]	52.6±0.06 [a]	52.0±0.40 [a]
Bulk density (kg/m^3)	653.3±2.33 [a]	639.6±4.62 [a]	612.9±3.89 [a]	624.2±1.74 [a]
True density(kg/m^3)	1000±5.41 [a]	1181±4.86[a]	1220±7.23[a]	1225±6.09[a]
Specific gravity	0.921±0.52 [a]	0.893±0.44 [a]	0.915±0.19 [a]	0.888±0.52[a]

*On the same row mean values with superscript ‘a’ letters are significantly the same at five percent probability($P<0.05$)

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Table 2: Mean values of the mechanical and thermal properties of cashew kernels

	Guinea Savannah		**Rain Forest**	
Mechanical properties	**Kogi**	**Enugu**	**Abia**	**Ogun**
Porosity (%)	34.7±2.02 [a]	45.6±1.87 [a]	49.8±2.26 [a]	48.8±1.68 [a]
Angle of repose (°)	36.3±2.97 [a]	35.3±3.07 [a]	34.1±3.62 [a]	38.1±2.48 [a]
Terminal velocity (m/s)	2.48±0.09[c]	3.29±0.07[b]	3.88±0.49[a]	3.48±0.08[b]
Coefficient of friction	0.406±0.11[b]	0.568±0.04[a]	0.259±0.07[c]	0.41±0.21[b]
Compression force (N)	650±3.96 [b]	800±4.72[a]	842±4.12 [a]	475±6.13[c]
Stress (N/mm^2)	1.17±2.02[c]	1.39±1.38[b]	1.66±1.67 [a]	0.97±0.48[d]
Deformation (mm)	6.33±1.39 [a]	5.75±1.81 [a]	8.1±1.60 [a]	8.0±1.52 [a]

*On the same row, mean values with different superscript (abc) letters differ significantly at five percent probability level($P<0.05$)

Table 3: Mean values of the mechanical and thermal properties of cashew kernels

	Guinea Savannah		**Rain Forest**	
Thermal properties	**Kogi**	**Enugu**	**Abia**	**Ogun**
Specific heat capacity (J/Kg/K)	1571±6.72[a]	1554±5.99[a]	1692±6.38[a]	1635±5.73[a]
Thermal conductivity (W/mK)	0.196±0.19[a]	0.206±0.08[a]	0.239±0.12[a]	0.202±0.09[a]

*On the same row mean, values with superscript 'a' letters are significantly the same at five percent probability ($P<0.05$)

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