Determination of some Engineering Properties of Dika Nut (*Irvingia gabonensis*) at Two Moisture Content Levels as Relevant to Its Processing

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Abstract.

Samples of African bush mango *(Irvingia gabonensis)* were collected from the wild, sun dried for four days to a moisture content of 13.75% (at an average temperature of 38.16^{0}C and relative humidity of 40.60%) and the seeds were carefully split to release the kernels unharmed. The kernels were divided into samples A and B; sample B was sun dried for three days to obtain different moisture content level from sample A. Both samples were then used for the experiments. Some selected physical and mechanical properties of dika nut were determined at two moisture content levels. This study was done under approved standard laboratory conditions using standard engineering methods and instruments. The two moisture content levels of 13.75% and 8.74% were obtained. The result revealed higher values for the physical properties at moisture content level of 13.75% . The following values were obtained for samples A and B respectively: the average length, width, thickness, weight, geometric mean diameter, arithmetic mean diameter, surface area, sphericity, volume and density were 28.97mm, 19.49mm, 11.91mm, 2.23g, 18.77mm, 20.12mm, 1111.81mm^2, 64,95%, 156.17mm^3 and 14.44g/cm^3, and 28.62mm, 18.20mm, 8.24mm, 1.15g, 16.07mm, 18.35mm, 819.02mm^2, 56.46%, 115.61mm^3 and 10.20g/cm^3. The coefficient of static friction was highest on plywood and least on glass for both samples. From the values obtained, it appears the increase in sizes of dika kernel may aid a decrease in coefficient of static friction. The force required to fracture and compress sample A are 25N and 62.5N on axial loading and 12.5N and 45N on longitudinal loading respectively. The force required to fracture and compress sample B was also gotten as 37.5N and 95N on axial loading and 27.5N and 67.5N on longitudinal loading respectively.

Key words: African bush mango, kernel, moisture content, physical properties, mechanical properties

INTRODUCTION

Dika *(Irvingia gabonensis)* is a tree of 15-40m height, with bole slightly buttressed, which occurs in the wild lowland forest with 2 to 3 trees occurring together; in some areas it is found to be gregarious. It is largely distributed in Africa (Leakey, 1999, Leakey and Tchoundjeu, 2001). Dika tree is fully utilized by native African tribes who make use of the bark, leaves, stems, fruits and seed kernels. Also, the wood is a strong and durable material for construction (Festus and Nwala, 2012). Dika tree is a commercially and socially important fruit tree of the West and Central Africa. It is also referred to as African mango, bush mango or wild mango, and the tree has been identified as one of the most important fruit trees for domestication in the region, because of its relative importance to the food industry (Ogunsina *et al.,* 2008; Adebayo-Tayo *et al.*, 2006; Leakey *et al*., 2005). It ranks highly among non-timber forest products in its use.

Dika fruit is a drupe with a thin epicarp, a soft fleshy thick mesocarp and a hard stony endocarp encasing a soft dicotyledonous kernel. The extracts from *Irvingia gabonensis* seed has a large amount of soluble fibre and it is commonly used in Western cultures as a weight loss supplement (http://www.africanmangotreatment.com). Dika kernels are widely used in West Africa, especially for their food thickening properties. The economic importance of the kernel is further strengthened by its use as a pharmaceutical binder and a base material in the manufacture of soap, cosmetics, confectionary and edible fats (Ogunsina *et al*., 2007; Agbor, 1994; Okafor, 1978).

Furthermore, due to the ever increasing importance of agricultural products together with the complexity of modern technology for their production, processing and storage, a better knowledge of the engineering properties of these products is necessary. However, it is essential to understand the physical laws guiding the response of these agricultural products so that machines, processes and handling operations can be designed for maximum efficiency and the highest quality of the final product (Mohsenin, 1986). Information on physical and mechanical properties of agricultural products as a function of moisture content, is needed in design and adjustment of machines used during harvesting, separating, cleaning, handling and storing of agricultural materials and processing them into food, feed and fodder.

The properties which are useful during design must be known and these properties must be determined at laboratory conditions (Gürsoy and Güzel, 2010). Agricultural products especially those of plant origin are now frequently used for a wide range of activities and the economic importance of food materials greatly increasing with the complexity of new technology for storage, production, handling and preservation. Evaluation in quality, distribution and marketing and their various uses depends on, and demands the knowledge of the engineering properties of these materials.

Kachru *et al*. (1994) reported that it is essential to determine the physical properties of oilseeds for proper design of equipment for handling, conveying, separation, hulling, drying, aeration and mechanical expression of oil from these seeds. Desphande *et al*. (1993); Singh and Goswani, (1996) established that moisture content affects the physical properties of seeds appreciably. The determination of engineering properties of agricultural products under static and dynamic loading is aimed at textural measurement of unprocessed and processed food materials; the reduction of mechanical damage to agricultural produce during postharvest handling, processing and storage; and the determination of design parameters for harvesting and postharvest systems (Anazodo, 1983). Thus, the knowledge of the engineering properties of the products is important in the design of agricultural machinery, equipment and facilities.

MATERIALS AND METHODS

The dika fruits were harvested from different trees in Amako-Nanka village, Anambra State of Eastern Nigeria. The fruits were peeled with knife to reveal the seed. The seeds were sun dried for four days to a moisture content of 13.75% (at an average temperature of 38.16^{0}C and relative humidity of 40.60 %) to remove the pulp and release the kernels for easy cracking and to avoid breakage of the kernels. The cracking was done manually with stone and hammer, after which only the unharmed ones were selected.

Sample Preparation

The unharmed kernels were divided into two samples (A and B). Sample A was stored in a polythelene film under room temperature to maintain its moisture content level of 13.75%, while sample B was sun dried for three days to obtain a different moisture content level of 8.74%, just before the kernels start splitting. All properties within the scope of this study was determined using the two samples at the two moisture content levels of 13.75 and 8.74%.

Moisture Content Determination

The moisture content of the samples was determined by oven drying method at 130°C for 19hours, and all weight loss was considered to be moisture, according to the standardized procedure for moisture content determination by ASABE standard S352.2 (2007). The moisture content was then calculated using the formula (Mohsenin, 1970).

$$\text{Moisture content (Mc)} = \frac{W_2 - W_3}{W_3 - W_1} \times 100$$

W_1 = Weight of container, g
W_2 = Weight of wet sample + container, g
W_3 = Weight of dry sample + container, g

Determination of the Physical Properties

Shape Determination

The shape was determined by tracing the longitudinal and lateral cross section of the kernel on a cardboard and compared with the shapes listed on the charted standard, then descriptive terms was used to define the shape (Mohsenin, 1970). This was done for four replicates.

Size Determination

Twenty (20) kernels were selected at random from both samples. The three principle diameters (axial dimension); major diameter (a), intermediate diameter (b) and minor diameter (c) were measured using venier caliper and the average was taken.

Geometric Mean Diameter

The geometric mean diameter was determined from the major (a), intermediate (b) and minor (c) diameter using the formula;

$$\text{Geometric mean diameter (Dg)} = (a.b.c)^{1/3}$$

Arithmetic Mean Diameter

The arithmetic mean diameter of the kernel was determined from the three principle diameter using the relationship by Mohsenin (1970):

$$Da = \frac{(a+b+c)}{3}$$

Weight Determination

The weight of the kernel was determined by using digital electric weighing balance. Results were obtained for twenty replicates and the average was recorded.

Surface Area Determination

The surface area was determined by using the following equation as cited by Sacilik *et al*., (2003), Tunde-Akintunde and Akintunde (2004) and Altuntas *et al*., (2005):

$$Sa = \pi GMD^2$$

Where; Sa = surface area (mm^2)
GMD = geometric mean diameter (mm)

Sphericity Determination

The sphericity of the kernel was calculated by using the following relationship (Mohsenin, 1970)

$$\text{Sphericity } (\boldsymbol{\Phi}) = \frac{Dg}{a} \times 100, (\%)$$

Where, Dg = Geometric mean diameter (mm)
a = major diameter

Volume Determination

The volume of the kernel was determined by using the following formula

$$\text{Volume} = \frac{\pi BL^2}{6(2L-B)}, \ mm^3$$

Where; B = $(WT)^{1/2}$
L = Major diameter, mm
W = Minor diameter, mm
T = Intermediate diameter, mm

Density Determination

The density of the kernel was determined using the ratio of weight to the volume (Mohsenin, 1970)

$$\text{Density } (\rho) = \frac{\text{Weight (g)}}{\text{Volume (cm}^3)}, \ g/cm^3$$

Coefficient of Static Friction

The static coefficient of friction for the kernel was determined for three grades at the two different moisture content levels with respect to three materials: wood with grain parallel to the direction of flow, galvanized steel and glass. A topless and bottomless box was used to determine the coefficient of static friction. The surface was raised gradually until the filled cube just start to slide down, the angle at this point was recorded and the coefficient of static friction was calculated using the formula bellow. Three different readings were taken for each sample.

$$\mu = \tan\theta$$

Selected Mechanical Properties

The mechanical properties are those having to do with the behaviour of a material under applied forces. The machine used in determining some of the mechanical properties of dika kernel is the Universal Material Testing Machine (ENERPAC) of 100KN capacity, which was used for determining the fracture and compressive force of the biomaterial.

The Test Procedure

The strength of the kernel was determined by placing the kernel on the platform provided on the machine and the meter reading set to zero. The kernel was positioned horizontally with the major axis of the kernel being normal to the direction of loading. The value of the corresponding force read directly on the digital meter was taken and recorded as the fracture force. Subsequent computations based on this were reported.

Plate 1: Dika Fruits

Plate 2: Hand Peeling of Dika Fruit

Plate 3: Half Peeled Dika Fruits Revealing the Three Distinct Layers

Plate 4: Fresh Dika Seeds with Pulp

Plate 5: Dried Dika Seeds

Plate 6: Unharmed Dika Kernels

RESULTS AND DISCUSSION

The determined physical and mechanical properties of dika kernel are presented as follows: The shape of the dika kernel was found to be Elliptical (Approaching ellipsoid). The moisture content of the samples were obtained as follows: Sample A = 13.75%, Sample B = 8.74%.

Physical Properties of Dika Nut

The physical properties of dika nut are presented in Tables 1 and 2.

Table 1: Results of the determined physical properties for Sample A.

Properties	No of samples	Maximum	Minimum	Mean	SD	CV
Major dia, (mm)	20	32.00	25.90	28.97	1.63	0.06
Intermediate dia, (mm)	20	23.70	12.20	19.47	3.11	0.16
Minor dia, (mm)	20	16.90	10.1	11.91	1.43	0.12
Weight, (g)	20	2.59	1.81	2.23	0.24	0.11
Geometric mean dia, (mm)	20	20.53	15.77	18.77	1.22	0.06
Arithmetic mean dia (mm)	20	21.63	17.27	20.12	1.23	0.06
Surface area, (mm^2)	20	1324.12	781.29	1111.81	140.71	0.13
Sphericity, (%)	20	74.18	55.92	64.95	4.86	0.07
Volume, (mm^3)	20	186.62	110.05	156.17	19.81	0.13

Density, (g/cm^3)	20	18.45	11.53	14.44	2.13	0.15
Coefficient of static friction (μ)						
Glass	3	0.27	0.24	0.25	0.005	0.02
Plywood	3	0.45	0.41	0.43	0.007	0.02
Galvanized steel	3	0.40	0.38	0.39	0.003	0.01

Table 2: Results of the determined physical properties for Sample B

Properties	**No of samples**	**Maximum**	**Minimum**	**Mean**	**SD**	**CV**
Major dia, (mm)	20	33.5	22.9	28.62	3.11	0.11
Intermediate dia, (mm)	20	25.5	11.1	18.20	3.65	0.20
Minor dia, (mm)	20	12.5	5.3	8.24	1.57	0.19
Weight, (g)	20	1.44	0.79	1.15	0.20	0.17
Geometric mean dia, (mm)	20	19.28	13.56	16.07	1.53	0.10
Arithmetic mean dia, (mm)	20	22.27	15.43	18.35	1.74	0.09
Surface area, (mm^2)	20	1197.79	577.66	819.02	157.86	0.19
Sphericity, (%)	20	67.60	46.66	56.46	4.78	0.08
Volume, (mm^3)	20	164.15	81.01	115.61	21.99	0.19
Density, (g/cm^3)	20	13.72	6.09	10.20	2.29	0.22
Coefficient of static friction (μ)						
Glass	3	0.31	0.29	0.30	0.004	0.01
Plywood	3	0.51	0.47	0.48	0.008	0.02
Galvanized steel	3	0.47	0.40	0.44	0.014	0.03

Mechanical Properties of Dika Nut

The results for the mechanical properties of dika nut are presented in Tables 3 and 4:

Table 3: Results of the determined mechanical properties for Sample A

Properties	**No of samples**	**Maximum**	**Minimum**	**Mean**	**SD**	**CV**
Fracture force on Axial Loading (N)	4	30	20	25	5	0.20
Fracture force on Longitudinal loading. (N)	4	20	10	12.5	4.33	0.35
Compressive force on Axial loading(N)	4	70	50	62.5	8.29	0.13
Compressive force on longitudinal loading (N)	4	50	40	45	5	0.11

Table 4: Results of the determined mechanical properties for Sample B

Properties	**No of samples**	**Maximum**	**Minimum**	**Mean**	**SD**	**CV**
Fracture force on Axial Loading (N)	4	50	30	37.5	8.29	0.22
Fracture force on Longitudinal loading. (N)	4	30	20	27.5	4.33	0.16
Compressive force on Axial loading (N)	4	110	80	95	11.18	0.12
Compressive force on longitudinal loading (N)	4	80	60	67.5	8.29	0.12

*SD = Standard Deviatoin **CV = Coefficient of Variation

DISCUSSION OF RESULTS

The results of the determined physical properties of dika nut parameters at moisture contents of 13.75% and 8.74% are shown in Tables 1 and 2 respectively. The two moisture content levels were observed to be the range at which dika kernel can be extracted with least percentage of crushing. Further decrease in the moisture content will make the kernel to be brittle, while a higher moisture level will make the kernel to stick to the shell, therefore, resulting to crushing if cracked. The average major, intermediate and minor diameters were found to be 28.97 ± 1.63, 19.49 ± 3.11 and 11.91 ± 1.43 for sample A and 28.62 ± 3.11, 18.20 ± 3.65 and 8.24 ± 1.57 for sample B respectively.

The physical properties of dika nut at the two moisture content levels were found to differ. The dimensions in sample A are higher than those of sample B due to the higher moisture content. The average weight was obtained as 2.23 ± 0.24 and 1.15 ± 0.20 for sample A and B respectively. Transportation of dika nut from location and within the processing plant is therefore advisable at low moisture content. The coefficient of variation (which is an important parameter in determining sieve sizes in dry cleaning operation) for the major, intermediate and minor diameters were found to be 0.06, 0.16 and 0.12 for sample A and 0.11, 0.20 and 0.19 for sample B respectively. The smaller the value of coefficient of variation the better the cleaning operation.

The average value for geometric mean diameter, arithmetic mean diameter, volume and density were obtained as 18.77 ± 1.22, 20.12 ± 1.23, 156.17 ±19.18 and 14.44 ± 2.13, while their corresponding coefficient of variation are 0.06, 0.06, 0.13 and 0.15 for sample A and 16.07 ± 1.53, 18.35 ± 1.74, 115.61 ± 21.99 and 10.20 ± 2.29, while their corresponding coefficient of variation are 0.10, 0.09, 0.19 and 0.22 for sample B. It will be economical to package and store dika nut at low moisture content.

A relatively high value 64.95 ± 4.86 of sphericity was obtained for sample A with higher moisture level, while 56.46 ± 4.78 was obtained for sample B. This property is relevant in the design of grain handling machineries and where ease of rolling is desirable, higher moisture content of dika nut may be relevant. The average surface area obtained for sample A is 1111.81 ± 140.71 and the value for sample B is 819.02 ± 157.86. The surface area increased with increase in moisture content. Olalusi *et al*., (2011), also reported that the surface area of bush mango increased with increase in grain moisture content which agrees with the findings in this research work. The coefficient of static friction is as shown in Tables 1 and 2. There was a decreasing trend in coefficient of static friction as the moisture content increased. The coefficient of friction was highest on plywood and least for glass. Chandrasekar and Viswanathan (1999) and Gupta and Das (1997) reported a similar trend for coffee beans and sunflower seeds, respectively. It appears that the increase in the sizes of bush mango may aid a decrease in coefficient of static friction. These Frictional properties will find useful application in design and construction of hopper for gravity flow.

The result of the determined mechanical properties are given in Table 3 for sample A and Table 4 for sample B. The average force required to fracture dika kernel in sample A for longitudinal loading are 12.5N fracture and 45N compressive with corresponding axial loading of 25N fracture and 62.5N compressive, while the average force obtained for sample B are 27.5N fracture and 67.5N compressive for longitudinal loading and 37.5N fracture and 95N compressive on axial loading. There were significant differences in force required to fracture at both Axial and Longitudinal Loading for both samples of dika kernel with different moisture content level. The force required to crack were higher at axial loading for both samples as the moisture content increased compared with force required to fracture on Longitudinal loading. The force required to fracture dika kernel at higher moisture content level was also less. These parameters are important in the designing of machines for processing biomaterials particularly in the design of a press for extraction of oil from dika kernel. These parameters also gives the energy requirement and consideration governing equipment selection in size reduction operations.

Conclusion

The principal dimensions varied with increase in moisture content, though there was no significant change in the major diameter. This shows that the length of the dika kernel is infinitesimally affected by change in moisture content as the kernel shrank mainly from the minor and intermediate diameter when the moisture content level was reduced. The Results reported in this study showed that moisture content have substantial influence on the physical and mechanical properties of the dika nuts. The values obtained for sphericity indicates the possibility to roll relatively well where necessary. Hoppers and other unloading devices need not be too sloppy because of the relatively low coefficient of static friction of the kernel which decreases with increase in moisture content. The result also revealed that it would be economical to load this kernel longitudinally to reduce energy demand if loaded axially when necessary to fracture or compress the dika kernel.

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