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Moisture Content and Compression Axis Effects on Mechanical Properties of Shea Kernel

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Abstract: Some mechanical properties of Shea kernel were investigated in this study. The kernels were divided into two categories sizes namely, Small Size Kernel (SSK) and Large Size Kernel (LSK) and the properties investigated were rupture force, deformation at rupture and energy consumed at rupture. The tests were carried out at a deformation rate of 50 mm min^{-1} and four moisture content levels of 25.9, 11.60, 6.88 and 4.98% (db) for SSK and 11.19, 6.21, 5.78 and 2.77% (db) for LSK. The variations in these properties were observed considering the effects of moisture content and compression axes on them as the kernels were air-dried. Sample kernels were compressed along the orthogonal axes corresponding to major diameter (length), intermediate diameter (width) and minor diameter (thickness) of Shea kernel. Some physical characteristics of Shea kernel such as dimensions, geometric mean diameter and mass were also evaluated.

Key words: Moisture content, compression axis, Shea Kernel, mechanical properties, Nigeria

INTRODUCTION

Shea butter tree (*Vitellaria paradoxa*) is a medium sized deciduous tree belonging of to the family sapotacea. It is believed that it is native to the West-African Savannas and Central Africa (Purseglove, 1974). The shea tree has a rough an corky bark which is deeply cracked. It is usually characterized by milky latex in the stems and branches. The shea tree produce a fruits green-yellow in colour called shear fruit which is of great economic importance. As highlighted by Purseglove (1974). In Nigeria, it grows widely in the North, some parts of West and East of Nigeria.

One of the most important characteristics of biological materials is their moisture content. According to Sitkei (1986), the moisture content of agricultural materials affects their physical and mechanical properties. Moisture content also affects the storability, handling and processing of biomaterials.

Some researchers have reported the physical and mechanical properties of biomaterials (Ogunjimi *et al*., 2002; Olaniyan and Oje, 2002; Aviara *et al*., 2005; Ozturk and Esen, 2008; Oluwole *et al*., 2007; Tabatabaeefar, 2003; Razavi *et al*., 2007; Davies, 2010; Dash *et al*., 2008).

The physical properties of biomaterials are essential is in the design and development of specific equipment and structures for transporting, handling, processing and storage and also for assessing the behavior of product quality (Kashaninejad *et al*., 2005). Physical properties of shea kernel are essential in the design of items of equipment for decortications, drying, cleaning, grading, storage and oil extraction. Moisture content relationship is useful information in the dry process. The dimensions and shape are important in designing separating, harvesting, sizing and size reduction machines (Dash *et al*., 2008).

The aim of this study was to investigate the effects of moisture content and compression axes on the mechanical properties of shea kernel. The parameters studied include rupture force, deformation at rupture, energy consumed at rupture. The dimensional properties of the kernel were also observed with moisture loss.

MATERIALS AND METHODS

Fresh Sheabuiter fruits were procured from the local market in Ilorin, Nigeria. The pulps were removed by hand to release the nuts. These were left on the open floor for some days to dry for easy detachment of the kernels from the nuts. The kernels were released from the nuts manually using stones. Thereafter the kernels were graded into two size categories Large Size Kernel (LSK) and Small Size Kernel (SSK). Grading was done manually. Experiments were carried out to determine the mechanical properties as the kernels dried in free air at five moisture levels.

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Moisture content determination: The moisture content of Shea kernels was determined for the two size categories LSK and SSK. Five replicates were used for each size at four moisture levels. The moisture content was determined by oven drying representative samples of the kernel at 130°C for 6 h as reported Oje (1994).

Some physical properties: Size of Shea kernels was determined by randomly selecting 100 seeds separately for each of LSK and SSK from the bulk sample. The three principal dimensions of major (length), intermediate (width) and minor (thickness) diameters (MJD, ITD and MND), respectively were measured using a vernier calipers having accuracy of 0.01 cm.

Geometric mean diameter: The Geometeirc mean diameter Dp of Shea kernel was determined using standard formula by Mohsenin (1970).

$$Dp = (abc)^{1/3}$$

Where:

Dp = Geometric mean diameter (mm)
a = Major diameter (mm)
b = Intermediate diameter (mm)
c = Minor diameter (mm)

This was carried out for groups, LSK and SSK using, 100 replicates each at four moisture levels.

Mass: The mass of kernel for both groups, LSK and SSK were determined using a sensitive electrical weighing machine with accuracy of 0.0I g. About 100 replicates each were used for each group.

Mechanical properties: The mechanical properties of rupture force, deformation at rupture and the amount of energy to cause the deformation were investigated. The samples used for the experiment were collected from the bulk of the purchased kernels that were already cleaned. Moisture content of each category was also determined using the standard procedure. Tests were carried out for the two size categories (SSK and LSK) at three loading position and four moisture levels. Twenty replicates were used for each size, loading position and moisture content. The mechanical tests were carried out in the Strength of Material section at the Technical and Scientific Workshop of the National Centre for Agricultural Mechanization (NCAM), llorin, Nigeria. The average room temperature throughout the test was 30°C. The Testometric Universal Testing Machine (UTM), manufactured by the Testometric Co. Ltd. U. K. was used to perform the tests. The tests were carried out as the kernels were air-dried. Before carrying out the tests, the kernels were observed for cracks and any other form of damage to ensure that the best kernels were used for the test.

Experimental procedure: The faces of the compression plates of the UTM were cleaned of dust. The machine was then switched on. Each kernel was placed in between the compression plates and the Personal Computer (PC) was switched on to respond to the behaviour of the kernel under loading. The height of the kernel as indicated on the UTM was input into the PC. Other information like the name of the test, type of material, test speed, size, moisture content, loading position and so on were also fed into the PC. For this test, a speed of 3 mm min was used. The parameters needed from the test like rupture force (load peak) deformation at rupture (deformation at peak) and amount of energy required to cause the deformation (Energy at peak) were also input into the PC.

The start bottom was then pressed to commence the test. As the test proceeded, the graph of the force-deformation (load-deflection) (not reproduced for this report) was plotted automatically and displayed by the PC as the kernel responds to compression. When the specimen cracked, the test stopped automatically. This was the point of rupture and was observed as a sharp or continuous decrease of the load on the graph of the load-deflection. The rupture force and deformation were easily read on the graph. Then the machine was stopped to end the test. The crosshead was then raised up to remove the crushed kernel. This procedure was followed unit all the kernels that were tested. The UTM gave the actual values of rupture force, deformation and energy at rupture including their units. All these were displayed on the PC.

RESULTS AND DISCUSSION

The dimensional properties and mass of the shea kernels in the two groups are shown in Table 1 and 2. As shown in the Table 1 and 2 the major diameter (length), intermediate diameter (width) and minor diameter (thickness) all had decreasing trend with decrease in

Table 1: Dimensions and mass of Shea kernel (SSK)+ at different moisture contents

Moisture (%, db)	6.58	20.82	38.46
Major DIA[a] (mm)	23.32 (1.74)	26.93 (2.36)	27.14 (1.55)
Intermediate DIA[b] (mm)	15.76 (1.70)	17.75 (1.79)	18.09 (1.23)
Minor DIA[c] (mm)	13.36 (1.19)	14.70 (2.15)	15.25 (1.22)
Geometric mean DIA	19.96 (1.10)	19.09 (1.61)	19.54 (1.09)
Mass (M), g	3.14 (0.42)	4.32 (0.95)	4.62 (0.80)

*Standard deviation values in parenthesis; +small size kernel

Table 2: Dimensions and mass of Shea kernel (LSK)++ at different moisture contents

Moisture (%, db)	7.47	18.18	28.01
Major DIA[a] (mm)	29.42 (2.12)	30.01 (1.44)	30.98 (1.77)
Intermediate DIA[b] (mm)	19.28 (1.53)	19.57 (1.30)	20.45 (1.74)
Minor DIA[c] (mm)	15.67 (1.88)	16.98 (1.15)	18.00 (1.72)
Geometric mean DI A	20.66 (1.23)	21.53 (0.94)	22.46 (1.19)
Mass (M), g	5.25 (0.78)	5.94 (0.55)	6.59 (0.81)

*Standard deviation values in parenthesis; ++large size kernel; DIA = diameter

Table 3: Effect of moisture content and compression axis on rupture force, deformation and energy at rupture of SSK Shea kernel

Moisture content MC (%, db)	Loading position	Rupture force F_R (N)	Deformation at rupture D_R (mm)	Energy at rupture E^R (Nm)
70.34	MJD	204.49 (87.180)*	6.022 (1.2010)	0.4756 (0.2884)
	ITD	357.41 (143.94)	5.397 (1.0530)	0.6085 (0.2894)
	MND	389.60 (109.52)	4.768 (1.0790)	0.6130 (0.2241)
25.90	MJD	170.23 (64.680)	8.512 (1.6660)	0.5524 (1.3369)
	ITD	367.66 (94.510)	7.622 (1.5240)	1.1220 (0.4686)
	MND	637.05 (15.780)	7.013 (1.6390)	1.6195 (0.1680)
11.60	MJD	344.10 (140.35)	8.822 (1.9550)	1.9999 (1.0695)
	ITD	511.92 (122.05)	5.079 (1.8470)	1.6753 (1.0120)
	MND	596.74 (172.31)	4.399 (1.6450)	1.4856 (0.9303)
6.88	MJD	359.24 (129.89)	3.560 (1.7950)	0.9021 (0.4737)
	ITD	408.38 (119.07)	2.933 (1.8720)	0.9162 (0.7028)
	MND	428.12 (100.20)	2.634 (1.1820)	1.0191 (0.6136)
4.98	MJD	458.35 (97.440)	4.042 (1.1425)	1.3562 (0.9232)
	ITD	456.18 (141.68)	2.679 (1.5060)	0.9440 (0.8470)
	MND	588.55 (203.80)	2.626(1.3820)	1.127 (0.78540)

Each value is a mean of 20 test samples; *Standard deviation in parenthesis; MJD = Major Diameter; ITD = Intermediate Diameter MND = Minor Diameter

Table 4: Effect of moisture content and compression axis on rupture force, deformation and energy at rupture of LSK (Shea kernel)

Moisture content (MC db) %	Loading position	Rupture force F_R (N)	Deformation at rupture D_R (mm)	Energy at rupture E^R (Nm)
66.58	MJD	191.31 (61.360)	10.086 (2.6120)	0.7205 (0.3871)
	ITD	289.44 (96.720)	6.523 (1.4610)	0.8104 (0.33710)
	MND	403.18 (227.36)	7.245 (3.4950)	1.276 (0.964400)
11.19	MTD	439.09 (86.620)	5.643 (2.5760)	1.5613 (0.78380)
	ITD	660.04 (129.01)	7.066 (2.5760)	2.8946 (1.23170)
	MND	940.61 (223.56)	6.544 (2.2810)	2.8424 (1.12180)
6.21	MJD	485.30 (106.90)	4.047 (1.6350)	1.3324 (0.64040)
	ITD	605.87 (127.13)	3.020 (1.8010)	1.0677 (0.59240)
	MND	802.08 (141.21)	3.064 (1.2130)	1.3822 (0.60950)
5.78	MJD	531.21 (168.97)	4.993 (2.1270)	1.9992 (1.40290)
	ITD	544.58 (119.87)	2.470 (1.2000)	0.8874 (0.70840)
	MND	553.58 (136.94)	2.110 (0.8887)	0.8475 (0.62250)
2.77	MJD	504.56 (140.40)	4.097 (1.6610)	1.1928 (0.65570)
	ITD	537.76 (127.69)	4.183 (2.2810)	1.7223 (0.89710)
	MND	559.93 (322.06)	3.4815 (2.525)	1.7680 (1.87120)

Each value is a mean of 20 test samples; Standard deviation in parenthesis; MJD = Major Diameter; ITD = Intermediate Diameter; MND = Minor Diameter

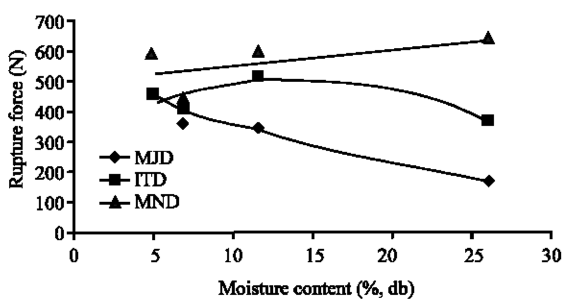

Fig. 1: Effect of moisture content and compression axes on rupture force of SSK Shea kernel

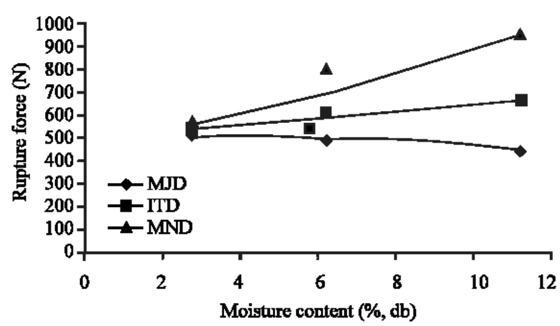

Fig. 2: Effect of moisture content and compression axes on rupture force of LSK Shea kernel

moisture content as the kernels dried. The observed mean values and standard deviation of rupture force, deformation and energy at rupture for both size categories of SSK and LSK are shown in Table 3 and 4.

Rupture force: The kernel rupture was observed at different moisture content levels and along three orthogonal compression directions as shown in Fig. 1 and 2. For SSK category (Fig. 1) rupture decreased more considerably along the minor diameter (thickness) as the moisture content decreased from 25.90-4.98% (db).

In the moisture content range, the rupture force was higher compared to the other two directions of compression. In the LSK Shea kernel category (Fig. 2), the rupture force was also highest when compressed along the minor diameter (thickness) and also decreased with decrease in moisture content. However, when compressed along the length, there seemed to be an increase in rupture force as moisture content decreased. Mathematical correlations were established between moisture content and rupture force of shear kernel compressed along the length, width and thickness.

SSK group Shea kernel:

$$y_{MJD} = 0.221x^2 + -19.28x + 522.34 \quad (R^2 = 0.939) \quad (1)$$

$$y_{ITD} = -0.9098x^2 + 25.34x + 322.84 \quad (R^2 = 0.717) \quad (2)$$

$$y_{MND} = 0.0189x^2 + 5.0884x + 495.68 \quad (R^2 = 0.3415) \quad (3)$$

LSK group Shea kernel

$$y_{MJD} = -1.638x^2 + 14.795x + 477.95 \quad (R^2 = 0.78.68) \quad (4)$$

$$y_{ITD} = 0.455x^2 + 8.546x + 508.32 \quad (R^2 = 0.5453) \quad (5)$$

$$y_{MND} = 1.242x^2 + 29.42x + 459.43 \quad (R^2 = 0.7559) \quad (6)$$

Deformation at rupture: The trend of deformation of Shea kernel with decrease in moisture content is shown in Fig. 3 and 4 for SSK and LSK size categories, respectively. For SSK, deformation decreased with decrease in moisture content for compression in all the three orthogonal directions but was highest for compression along the major axis (length) and least along the minor axis (thickness) in the moisture content range 25.90-4.98% (db).

The correlation between moisture content and deformation of Shea kernel compressed along the three orthogonal axes.

For SSK group are:

$$y_{MJD} = -0.036x^2 + 1.379x-2.829 \quad (R^2 = 0.8738) \quad (7)$$

$$y_{ITD} = -0.009x^2 + 0.525x + 9.0728 \quad (R^2 = 0.9892) \quad (8)$$

$$y_{MND} = - 0.004x^2 + 0.348x + 0.774 \quad (R^2 = 0.9855) \quad (9)$$

The trend of the deformation with decrease in moisture content from 11.19-2.77% (db) for LSK Shea kernels is shown in Fig. 4.

Deformation was highest for compression along the major diameter and decreased at a decreasing rate to attain minimum values at moisture content of about 6% (db).

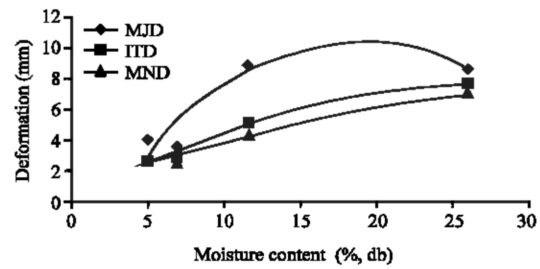

Fig. 3: Effect of moisture content and compression axes on deformation at rupture force of SSK Shea kernel

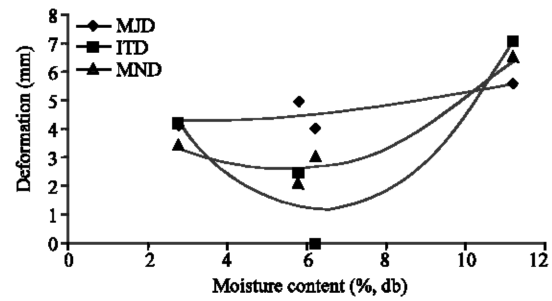

Fig. 4: Effect of moisture content and compression axes on deformation at rupture force of LSK Shea kernel

The trend of deformation with moisture content was similar for both compressions along intermediate and minor diameters. Here, the deformation initially decreased with decrease in moisture content to appoint and subsequently increased in the moisture content further decreased through drying. Mathematical relationship between moisture content and deformation.

For LSK Shea kernel:

$$y_{MJD} = 0.0117x^2 + 0.0136x + 4.0038 \quad (R^2 = 0.7114) \quad (10)$$

$$y_{ITD} = 0.247x^2 - 3.1228x + 11.032 \quad (R^2 = 0.8907) \quad (11)$$

$$y_{MND} = 0.122x^2 - 1.337x + 6.201 \quad (R^2 = 0.9635) \quad (12)$$

Energy at rupture: The effects of moisture content and compression axes on energy at rupture of shea kernels for SSK and LSK shea are shown in Fig. 5 and 6. For both groups, the variation of energy at rupture with moisture content appeared dissimilar. In the SSK size category, the energy at rupture increased to a maximum for all the directions of loading (to a lesser extent for minor diameter) as the moisture content decreased.

Thereafter, the energy at rupture decreased as the moisture content further decreased to about 4.98% (db).

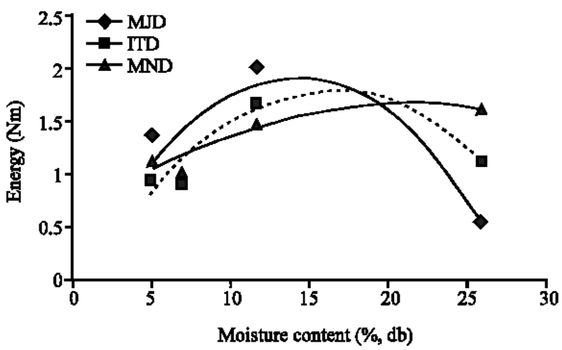

Fig. 5: Effect of moisture content and compression axes on energy at rupture force of SSK Shea kernel

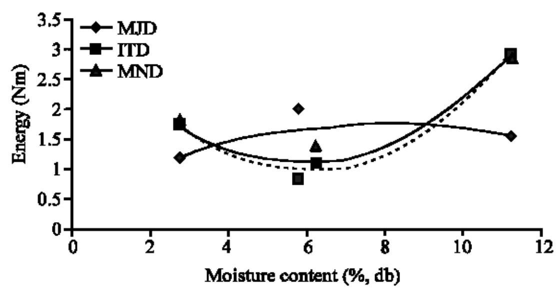

Fig. 6: Effect of moisture content and compression axes on energy at rupture force of LSK Shea kernel

The maximum energy at rupture of about 1.7 N-m was observed at moisture content of about13.5% (db) when loaded along the length. The regression equations that best describe the relationship between moisture content and energy at rupture.

For SSK group:

$$y_{MJD} = -0.009x^2 + 0.277x - 0.0819 \quad (R^2 = 0.7148) \quad (13)$$

$$y_{ITD} = -0.0072x^2 + 0.238x - 0.1871 \quad (R^2 = 0.8441) \quad (14)$$

$$y_{MND} = -0.0022x^2 + 0.097x + 0.6035 \quad (R^2 = 0.8616) \quad (15)$$

In the LSK size category, the energy at rupture decreased to a minimum for compression along intermediate and minor diameters at moisture content of about 6% (db) and thereafter, it increased to a value of about 1.3 N-m at moisture content of about 2.0% (db). The minimum energy at rupture of was about 0.6 and 0.7 N-m for compression along intermediate and minor diameters, respectively.

However, in this size category, the variation of energy at rupture when compressed along the length (MJD) was quite different (Fig. 6). There, the energy at rupture decreased polynomially as the moisture content decreased. The regression equations that best describe the relationship between moisture content and energy at rupture.

For LSK group:

$$y_{MJD} = -0.0185x^2 + 0.2973x + 0.5403 \quad (R^2 = 0.3419) \quad (16)$$

$$y_{ITD} = 0.0711x^2 - 0.8519x + 3.5289 \quad (R^2 = 0.9934) \quad (17)$$

$$y_{MND} = 0.0627x^2 - 0.744x + 3.326 \quad (R^2 = 0.9338) \quad (18)$$

CONCLUSION

Results showed that generally rupture force, deformation and energy at rupture decreased as moisture content decreased. The regression models that best fitted the relationships were polynomial functions of the second order. The highest and lowest force for shea kernel to rupture were those through the minor axis (thickness) and major axis (length), respectively.

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