STRENGTH PROPERTIES OF SHEA-BUTTER NUTS UNDER COMPRESSIVE LOADING

*Olaniyan, A.M. and Oje, K.
Department of Agricultural Engineering
Faculty of Engineering,
University of llorin
PMB 1515, Ilorin - 240003,
Kwara State, Nigeria.
E-mail: amolan@unilorin.edu.ng

ABSTRACT
Compression tests were performed on heat-treated Shea-butter nuts to study the effects of temperature and loading position on rupture force, deformation, toughness and firmness of the nuts. The factors examined had significant effects on the measured parameters (rupture force, deformation, toughness and firmness) at 95% confidence level. Rupture force, deformation and toughness decreased while firmness increased with increases in temperature in both axial and lateral loading positions. Higher values of firmness but lower values of rupture force, deformation and toughness were obtained when Shea-butter nuts were compressed in lateral loading position compared with axial loading position under the same conditions.

Keywords: Strength properties, Shea-butter nut, compressive loading.

1. INTRODUCTION

Shea-butter nut (vitellaria paradoxa) belongs to the family of Sapatacea. The Hausa, Igbo and Yoruba people of Nigeria know it as Kandayi, Osisi and emi respectively. Its shape is ellipsoidal with white scar at one side. The mean size of the nut is about 35mm long x 25mm wide x 23mm thick. It has a kernel inside which fits properly into the shell and of about 32mm long x 23mm wide x 21 mm thick in size. The shell is fairly uniform and it is about 1mm thick. Edible oil (shea-butter oil) is extracted from the kernel and the cake from which the oil is extracted is used in livestock production (Purseglove [1]).

According to Purseglove [1], Nigeria, Ghana, Burkinafaso, Senegal, Mali and Benin Republic are the principal exporters of shea-burter nuts. Formerly, Belgium and the Netherland used to be the major importers but recently, Denmark, Japan and the United Kingdom import majority of the produce. For the exporting countries, the sale of Shea-butter nut contribute considerably to foreign exchange earnings.

Food and Agriculture Organisation [2] revealed that, for most West African Countries like Burkina Faso, Ghana and Benin Republic, Shea-butter oil serves as the only source of vegetable oil. It was also discovered by Momodu [3] that the oil is used for curing headache, leprosy and also used to aid childbirth. The oil is used in Europe for soap making, cosmetics and for making various types of cream [1].

Olaoye [4] stated that the most important stages in the oil extraction process are cooking of harvested fruit to produce clean Shea-butter nuts, drying of the nut, cracking of the nut, washing and crushing of the kernel, cooking of the milled product and clarification. However, an improved processing procedure and equipment is essential for full exploitation of the product.

Shelling is one of the major problems in processing Shea-butter nut and, unfortunately, this process has not been mechanized thus far. The manual method currently being employed is tedious and labourious. Even at the Shea-butter nut processing centre at Kureoja, Kwara State, Nigeria, the manual tools and manually operated devices being used are performing below expectation. Also in villages throughout the production zones in Nigeria, the manual method is prevalent. It involves crushing the nuts with mortar and pestle anutfus results in a lot of kernel breakage. It is therefore necessary to develop cracking machinery for efficient cracking of shea nuts. This can only be done after a thorough study of the response of the nut to applied load under different loading conditions.

Strength properties of cashew nuts was studied by Oloso and Clarke [5] taking into consideration the effects of moisture content, directions of loading and pre-damaged type on rupture force, deformation at rupture and energy absorbed at rupture. They discovered that deformation at rupture and energy absorbed increased with increase in moisture content while rupture force decreased with increase in moisture content.

Predamage to the shell led to decrease in all the measured parameters in most cases. Okoli [6] studied physical properties of shea-butter kernels. No information was available on strength properties of Shea-butter nut.

The aim of this research was therefore to study the effects of temperature and loading position on rupusre force, deiormotion, loughness and firmness of Shea-butter nuts.

2. MATERIALS AND METHODS

The Shea-butter nuts used in this study were purchased from Igbeti area of Oyo State where the crop is relatively cheap and abundant All experiments were carried out in the processing and storage laboratory of the Department of Agricultural Engineering, University of Ilorin. The nuts were compressed using Monsnato Tensoma Universal Testing Machine. The average room temperature in the laboratory was 30°C through the period of experimentation. The initial moisture content of all nuts used was found to be 6.81 percent (dry basis).

2.1 Experimental Design

A 5 x 2 factorial experiment in a completely, Randomized Design (CRD) was employed to study the effects of temperature and loading positions on rupture force, deformation, toughness and firmness of S Shea-butter nuts under compressive loading Five temperature levels and two loading positions were considered and each experiment was replicated twenty times. The range of temperatures were selected based on literature review and preliminary laboratory tests. A total of 160 nuts were individually measured and tested.

2.2 Experimental Procedure

The experiments involved heat treatment, size measurement, and compression tests. For each nut, the three principal dimensions (major, intermediate and minor diameters) were measured with the aid of vernier callipers (Figure 1). These dimensions were used for the calculation of volume of individual nut. For the purpose of this study, the nuts were graced into large, medium and small sizes based on major diameters. The medium size nuts (33 - 39mm long) which formed the majority of the whole nut population were used for all compression tests.

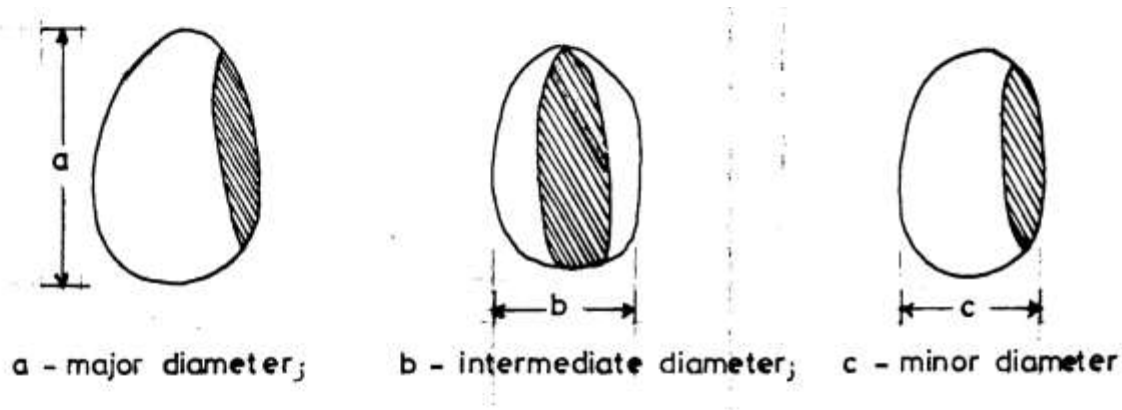

Fig. 1: Shea Butter Nut Showing the three Principal Dimensions.

The nuts were heated by putting them in the oven at known temperatures. A standard thermometer was used to calibrate the oven temperatures. Nuts were heated in the oven at different temperatures for 15 minutes. The values of temperature used were 30, 50, 70, 90 and 110^{o}C one. These values were chosen based on literature review [5] and preliminary laboratory studies.

Two loading positions were used in the experiments and these were based on the orientation of the nut. As shown in Figure 2, in the axial loading position, the direction of loading was perpendicular to the planes of the longitudinal axis, while in the lateral loading position, the direction of loading was perpendicular to the planes of the intermediate axis

.

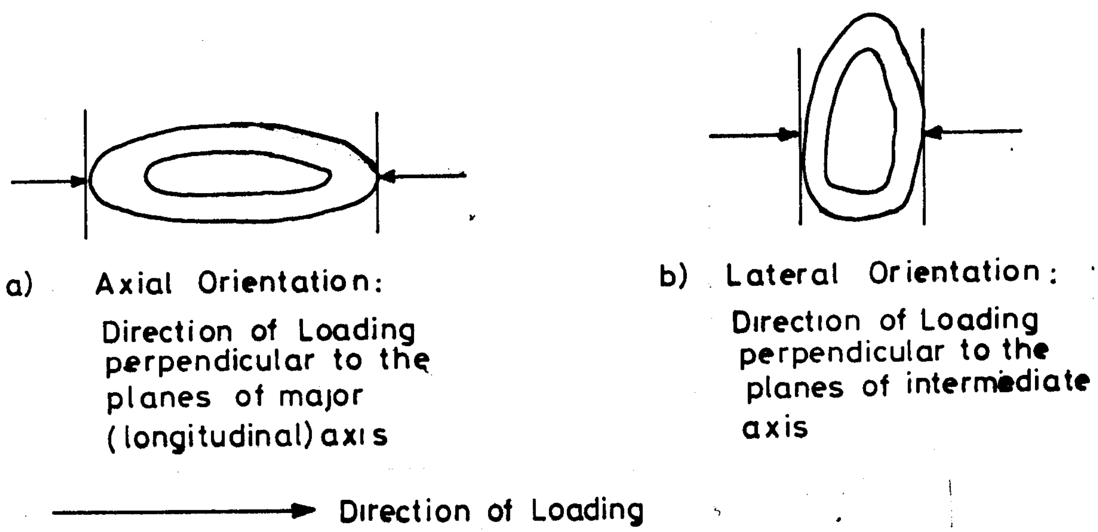

Fig. 2: Orientation of Shea Butter Nut in Relation to the Direction of Loading.

All compression tests were performed in the laboratory using the Monsnato Tensometer Universal Testing Machine. Two factors (temperature and loading positions of the nut) were varied during compression tests. Each nut was loaded between the plates of the compression rig fitted to the machine; the deformation on the nut and the load causing the deformation were monitored. A raid and continuous reduction in the load is an indication that the nut was ruptured and the loading was stopped at this point. This is called the rupture point. For each test sample, the force and the corresponding deformation at rupture point were read off from the force-deformation curve and recorded accordingly. A typical force deformation curve is shown in Figure 3.

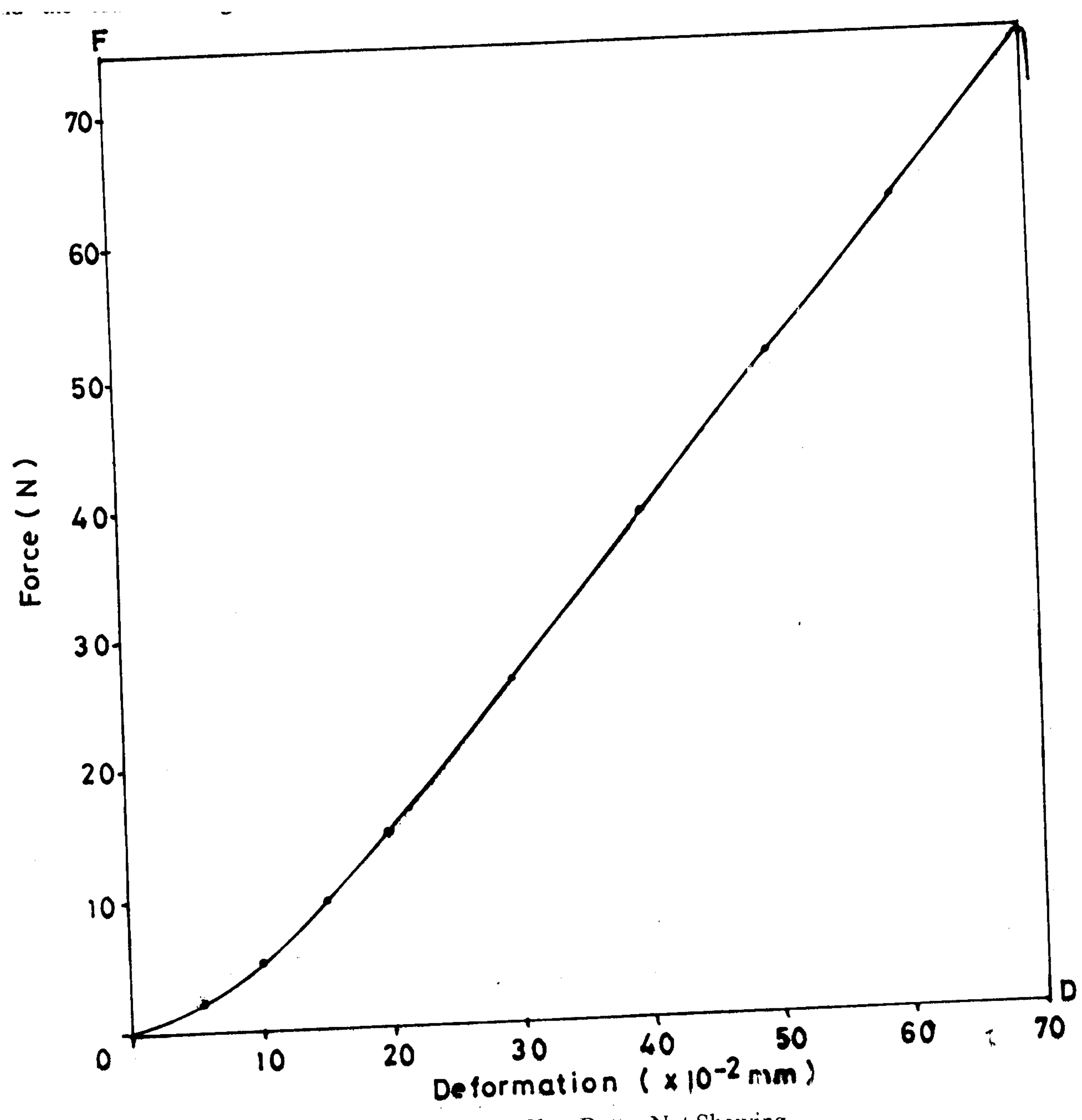

Fig. 3: Force - Deformation Curve for a Shea Butter Nut Showing Rupture Force (F) and Deformation (D).

2.3 Calculations, Records and Analysis

Rupture force and deformation were directly measured from force-deformation curves of the Tensometer chart considering the units of calibration along Y-axis for force and along X-axis for deformation. Rupture force is the point on the force-deformation curve at which visible failure was identified on the nut and this point was detected by a continuous reduction in the load. In this study, deformation is regarded as the distance moved by the compression plates from the first contact with the nut surface to the point of rupture. Toughness, in this study, is regarded as the energy absorbed by Shea-butter nuts up to the rupture point per unit volume. The energy absorbed was estimated as the area under the force-deformation curve up to the point of rupture. In the same development, firmness is regarded as the ratio of force to deformation at the rupture point.

The data obtained were subjected to statistical analysis using the Statistical Analysis System - General Linear Model Procedure (SAS - GLMP) and Duncan's Multiple Range Test (DMRT) was used to compare the mean.

3. RESULT AND DISCUSSION

The data obtained for all compressive tests is as presented in Table 1. Duncan's Multiple Range Test for all data are represented in Tables 2 and 3. From all these illustrations, the effects of temperature and loading positions on Rupture Force, Deformation, Toughness and Firmness were evaluated.

3.1 Effect of Temperature on Rupture Force

Temperature and loading position effects were significant on rupture force but their interaction were not at 95 percent confidence level. This implies that these factors had appreciable effects but their combinations had no effect on rupture force. Rupture, force decreased consistently as temperature was increased from 30 to 90°C but later increased as the temperature was increased further from 90 to 110°C (Tables 1 & 2). The reason as stated by Lehniger [8], is that, heat causes structural damage to carbohydrates, proteins and lipids. Therefore, when materials containing these items are raised to high temperatures, (usually above 90°C in case of shea nut), there is thermoxidation of lipids, denaturation of proteins and depolymerization of carbohydrates. Under this condition, the material (nut in this case) is structurally damaged and there is defect in its structural functions. The force to rupture the nut thus become higher.

3.2 Effect of Loading Position on Rupture Force

As shown in Table 3, rupture force was lower in axial loading position compared with lateral loading position. This implies that nuts loaded in axial position (in a shelling machine) will be cracked by a smaller force compared with those loaded in lateral position. Therefore, it is important to take into consideration, the nuts directions of loading while designing cracking machines.

3.3 Effect of Temperature on Deformation

Table 2 indicates that temperature and loading positions were significant on deformation at 95 percent confidence level. The results of the experiment (as shown in Table 1) clearly show that deformation decreased progressively as temperature was increased from 30°C to 110°C in both axial and lateral loading. This trend of a consistent decrease in deformation with increases in temperature is in agreement with the reports of Waanenen and Okos [7]. The reason for this trend is as discussed in section 3.1 of this study.

Table 1:Effect of Temperature and Leading Positions on Rupture Force, Deformation Toughness and Firmness of Shea-butter

		Strength Properties			
Temperature °C	**Loading Position**	**Rupture Force (N)**	**Deformation (mm)**	**Toughness (mJ/mm^3)**	**Firmness (N/mm)**
	Axial	*100.35	0.92	4.46	116.10
30		(30.31)SD	(0.38)	(2.58)	(33.38)
	Lateral	115.75	1.22	6.36	94.00
		(27.37)	(0.23)	(I. 94)	(5.23)
	Axial	82.80	0.69	2.89	120.94
		(36.14)	(0.35)	(2.20)	(32.49)
50	Lateral	112.30	1.0 1	5.46	110.49
		(30.29)	(0.18)	(2.36)	(19.77)
	Axial	80.00	0.53	2.09	154.56
		(28.45)	(0.15)	(1.21)	(40.27)
70	Lateral	109.20	1.06	5.52	103.05
		(36.78)	(0.23)	(2.52)	(23.82)
	Axial	70.80	0.59	2.35	124.32
		(32.71)	(0.24)	(1.68)	(40.67)
90	Lateral	110.00	1.0 I	5.15	115.11
		(35.97)	(0.33)	(I. 15)	(35.70)
100	Axial	62.80	0.47	1.91	133.30
		(30.61)	(0.23)	(1.32)	(30.45)
	Lateral	122.60	0.97	5.61	129.65
		(34.13)	(0.27)	(1.61)	(28.11)

Each value is the mean of 20 test samples
SD values in parenthesis are standard deviation

Table 2:Effect of Temperature on Strength Properties of Shea-Butter Nut

	Strength Properties			
Tempera ture (°C)	Rupture Force (N)	Deformation (mm)	Toughness (mJ/rnm^3)	Firmness (N/mm)
30	*97.812^a	1.8161^a	8.736^a	62.454^c
50	78.700^b	1.4085^b	5.2 5^b	67.425^c
70	n.7oobc	1.0563^c	3.764^c	77.968^b
90	67.815^c	0.9769^d	3.281^c	75.460^b
110	77.287^b	0.9084^d	3.626^c	93.047^a

*In each column, means with the same letters are not significantly different at P ≤ 0.05 using Duncan's Multiple Range

Table 3: Effect of loading Positions on Strength Properties of Shea-Nuts.

Loading Positon	Strength Properties			
	Future Force (N)	Deformation (mm)	Toughness (m.l/mnr')	Firmness (N/mm)
Axial	*68.647^{b}	1.0622^{b}	3.793^{b}	79.374^{a}
Lateral	89.103^{a}	1.403^{a}	6.084^{a}	71.168^{b}

3.4 Effect of Loading Position on Deformation

Generally, nuts compressed in lateral loading position suffered greater deformation compared with the ones compressed in axial loading position (Tables 1 and 3). The reason for this is that the surface area of the nut in contact with the compression plates is large in lateral loading position compared with axial loading position. Therefore, the nuts absorbed more energy in lateral loading position than in axial loading position before rupture under the same conditions.

3.5 Effect of Temperature on Toughness

As shown in Tables 1 and 2, toughness decreased as temperature was increased from 30 to 110^{o}C when the nut was compressed in lateral loading position. However, in axial loading position, toughness decreased when temperature was increased from 30 to 90^{o}C after which further increase in temperature from 90 to 110^{o}C resulted in an increase in toughness. The reason for this discrepancy is that further heat treatment of viscoelastic material with very high temperature cause depolymerization of the cellulose substance of which the material (nut) is made up and this resulted in structural defects in the nuts [8]. In this study, it appears that these structural defects occurred above 90^{o}C. This implies that temperature above 90°C is not proper for heat- treating sheanuts under any condition

3.6 Effect of Loading Position on Toughness

The average values of toughness obtained in axial loading positions were lower than those obtained with lateral loading position under the same conditions (Tables 1 and 3). This means that more energy was absorbed before rupture when the nut was compressed in lateral loading position as compared with axial loading position. This is because the areas of the nut in contact with the compression plates of the machine were larger in lateral loading than with axial loading position.

3.7 Effect of Temperature on Firmness

Statistical analyses show that temperature, loading position and their interactions were significant on firmness at 95 percent confidence level. There was an increase in firmness as temperature was increased for both axial and lateral loading position (Table 1). This is because as temperature increased, the nut was more susceptible to brittle fracture (fracture with slight or no deformation). The ratio of force to deformation at rupture point (firmness) increased when temperature was increased.

3.8 Effect of Loading Position on Firmness

Table 3 shows that the mean value of firmness was higher in axial loading position compared with lateral loading position under the same condition. This is because, the nut experienced just slight deformation before rupture in axial loading position due to smaller area of contact with the compression plates. Hence the ratio of force to deformation (firmness) was higher in axial loading position than lateral loading position under the same condition.

3.9 Applications to Design

Strength properties should be the basis for the choice of a shelling/cracking principle for Shea- butter nut. It can be observed from this study that the energy to achieve cracking of Shea-butter nut can be greatly reduced, if the nuts were cracked at higher temperatures and in axial loading position. Therefore, these factors can be taken into consideration when forming a cracking principle for Shea-hutter nut. Obviously, there may be slight practical difficulties in any machine design which involves combining temperature, loading position and energy required for cracking but what is important is for cracking to be achieved at the minimum energy and minimum labour of positioning the nuts during cracking.

Compared with the existing methods of using stone to beat the nuts for cracking, there is plenty of scope for improvement. A machine design based on the results of this study can be seen as a means of mechanizing the existing manual method where cracking is by impact or instantaneous compression. The results of this work have shown that if cracking is carried out by slow and progressive compression rather than by impact or instantaneous compression, there will be minimum kernel breakage during the process.

4. CONCLUSION

From the study of strength properties of Shea- butter nuts, the following were concluded.

a. Rupture force, deformation and toughness decrease while firmness increase with increase in temperature of shea nuts in both axial and lateral loading positions

b. Temperature above 90°C is not proper for heat treating shea nuts under any condition as this may cause structural defects in the nuts.

c. Lower values of firmness but higher values of rupture force, deformation and toughness are applicable when shea nuts are compressed in lateral loading position compared with axial loading position under the same condition.

d. The manner of loading of shea nut has a strong influence on strength properties of the nuts under compressive loading.

REFERENCES

1. Purseglove, J.W., *Tropical Crops: dicotyledons*, John Willey and Sons, Inc., New York, 1974.

2. F AO; Forest Trees, *Forest Development Paper*, Vol. 34, pp. 22-28 (Article).

3. Momodu, A .B., *The Prospect of Sea-butter Industries in Nigeria. The Role of Forestry in a Depressed Econony*, FAN Publishing 1987.

4. Olaoye, J.O., Improving Oil Recovery Process from Shea-butter Oilseed through Clarification, University of Ilorin Library,Ilorin, Nigeria, 1994.

5. Oloso, A.O. and Clarke, B., Some Aspects of Strength Properties of Cashew Nuts, *Journal of Agricultural Engineering Research*, Vol. 55, 1993, pp.27-43.

6. Okoli, E.A., Some Physical and Rheological Properties of Shea-butter Kernels, Department of Agricultural Engineering, University of florin, Ilorn, Nigeria, 1997.

7. Waananen, K.M. and Okos, M.R., Failure Properties of Yellow-Dent Com Kernels, *Transactions of ASAE*, Vol. 31, 1988, pp. 1816-1823.

8. Lehninger, A.L. *Principles of Biochemistry*, CBS Publishers and Distributors, India, 1987.