Fracture resistance of kola nut (*Cola nitida*)

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Abstract: In order to design appropriate processing machineries, the knowledge of the force and deformation curve of agricultural materials is very important. In this research, fracture resistance of kola nut (*cola nitida*) was measured in terms of the rupture force, compressive stress, modulus of elasticity and energy absorbed. Kola nuts were quasi-statically loaded in horizontal and vertical orientations with moisture content at four levels (47.59%-61.41%) and loading rate of 5 mm min^{-1}. The result showed that the compressive load decreased from 458.95 to 334.41 N and 605.46 to 228.10 N, compressive stress decreased from 0.40 to 0.289 MPa and 0.52 to 0.20 MPa and energy absorbed decreased from 3.46 to 1.81 J and 2.79 to 0.52 J, for vertical and horizontal orientations, respectively. These findings will be useful in the development of processing equipment for kola nuts

Keywords: kola nut, moisture-content, loading- orientation, fracture-resistance

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1 Introduction

The genus *Cola* of the family *Sterculiaceae* is indigenous to tropical Africa and has its centre of greatest diversity in West Africa. In the forest areas of West Africa, kola is perhaps second only to palm oil in importance in the list of indigenous cash crops. About 40 *Cola* species have been described in West Africa. However, in Nigeria, the *Cola* species of real importance are *C. acuminata* and *C. nitida* (Lovejoy, 1980), *C. nitida* is available in commercial quantities and it is more traded than the *C. acuminata* variety. Kola is used in jam and jelly production because of its high pectin content. Furthermore, due to the high potassium content of the kola nut testa, it has been suggested as a possible ingredient for making fertilizers (Ayodele, 1988; Olubamiwa et al., 2002). The kola pod husk has also been utilized for the production of liquid soap. The most recent and remarkable advancement in kola by-product utilization is the use of kola pod husk in the replacement of up to 60% of the maize used in poultry feed formulations (Yahaya et al., 2001; Hamzat et al., 2000; Hamzat and Babatunde, 2001; Hamzat and Longe, 2002;; Hamzat et al., 2002a; Olubamiwa et al., 2002). It is also used locally for cloth dying, traditional medicine to reduce labour pains and treatment of swellings and fresh wounds.

Knowledge of fracture resistance of agricultural products have been found to be very important in the design of dehulling systems and grinding system (Baümler et al., 2006; Saiedirad et al., 2008). Many researchers have studied the effect of moisture content on fracture resistance of agricultural products viz Gupta and Das (2000) for sunflower seed and kernel, Vursavuz and Özgüven (2004) for apricot pit, Baümler et al. (2006) on safflower seed Altuntaz and Yildix (2007) on Faba beans, Saiedirad et al. (2008) on cumin seed and Singh et al. (2010) on banyard millet among others. Generally rupture force was observed to decrease with increase in moisture content, however, the rupture force for the kernel of safflower exhibit a reverse trend (Gupta and Das, 2000). Also the materials were observed to have lower rupture force in horizontal than those loaded in the vertical direction implying flexibility in the horizontal direction except for safflower seed (Gupta and Das, 2000). Deformation for apricot pit was observed to decrease with increase in moisture content (Vursavus and Özgüven,

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2004) while the deformation of barnyard millet grain and kernel was reported to increase with increase in moisture content (Singh et al., 2010).

Rupture energy was observed to increase with increase in moisture content for safflower (Baümler et al., 2006) cumin seed (Saiedirad et al., 2008), safflower seed and kernel (Gupta and Das, 2000), barnyard millet grain and kernel (Singh et al., 2010) and faba bean (Altuntaz and Yildiz, 2007). Minimal energy was required for seed loaded in vertical direction than for horizontal direction.

Little information appears to be available on the existence of a mechanical device used for the peeling of kola nut. Kola nut requires soaking (moisture conditioning) before it can be peeled. The design and development of a kola nut peeling machine require the knowledge of such engineering properties of the nuts as mechanical properties like fracture resistance at different moisture content (soaking time). There is, therefore, the need to determine the fracture resistance of kola nut at different moisture content and loading orientations.

The aim of this study was to determine the relevant engineering properties of kola nut as affected by moisture content and loading orientation. The properties include compressive load, compressive stress, modulus of elasticity and energy absorbed.

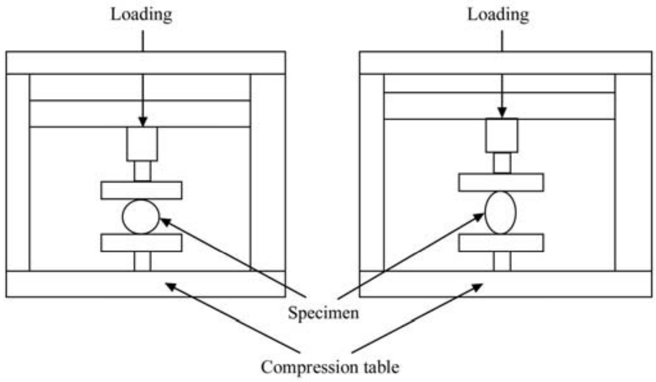
2 Materials and Methods

2.1 Sample preparation

The kola nut (*cola nitida*) used for this research work was obtained from local markets in Garage Olode, Osun State, Nigeria. The pods were immediately split and the kola nut separated from the pods. The kola nut were divided into two samples. The fresh sample was not soaked and reserved for determination of some physical dimensions. The second sample was further subdivided into three sub samples, soaked for 12, 18 and 24 hrs, respectively. At the end of the soaking time the soaked kola nuts were allowed to equilibrate in a desiccator before using them for the determination fracture resistance. Moisture content of samples was determined using standard gravimetric method.

2.2 Compression test procedure

Compression tests were conducted using a Universal Testing Machine (UTM) (Instron Electromechanical Testing System, Model 3369, 60 KN, Istron corporation, USA) controlled by a microcomputer. Two loading orientations were used and twenty randomly selected nuts were compressed laterally and longitudinally by the UTM at a compression rate of 5 mm min^{-1} as shown in Figure 1(a) and (b). Test results, statistics and graphs were automatically generated. As compression progressed, a force-deformation curve was plotted automatically in relation to the response of each kola nut. The properties that were automatically generated include compressive load, compressive stress, energy and modulus of elasticity at yield. A similar procedure was followed by Mamman et al. (2005) and Aviara et al. (2007) in studying the mechanical properties of *Balanites Aegyptiaca* nuts and guna fruits, respectively.



(a) Horizontal orientation (b) Vertical orientation

Figure 1 Orientations of kola nut under compressive loading

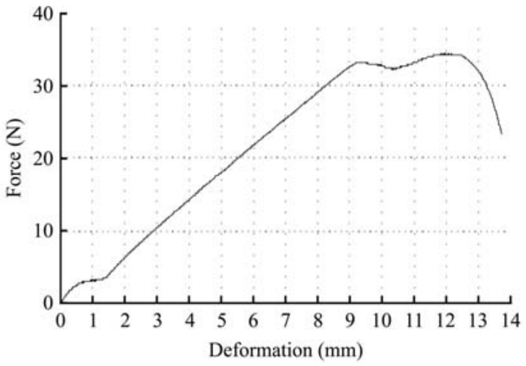
3 Results and discussion

As compression progressed, a force-deformation curve was plotted automatically in relation to the response of each fruit. Typical force-deformation curves obtained during the tests are shown in Figure 2(a) and (b). The properties that were automatically generated include rupture force at yield, compressive stress at yield, energy at yield, and modulus at yield (Table 1).

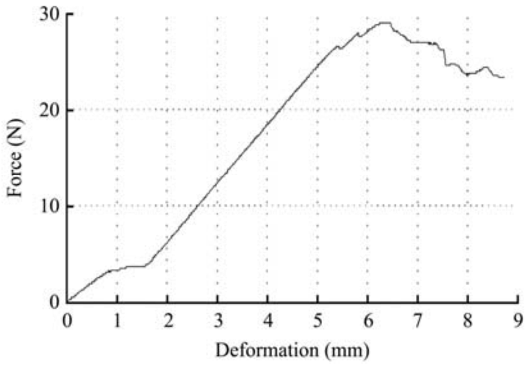
3.1 Rupture force

The result showed that the rupture force decreased from 458.95 to 334.41 N and 605.46 to 228.10 N, for vertical and horizontal orientations, respectively with increase in moisture content. It was observed that the rupture force decreased with increase in moisture content for both orientations. This is similar to what was obtained by Vursavus and Özgüven (2004), Baümler et al.

(2006), Saiedirad et al. (2008), Altuntaz and Yildiz (2007), Burubai et al. (2008) for apricot pit, safflower seed, cumin seed, faba beans and African nutmeg, respectively.



(a) Vertical orientation



(b) Horizontal orientation

Figure 2 Typical force-deformation curve of kola nuts under compression (source: generated data from Instron)

Table 1 Some mechanical properties of kola nuts at different soaking time (moisture content)

Properties	Soaking Time (hrs)											
	0 (47.59% wb)			12(53.02% wb)			18 (57.62% wb)			24 (61.41% wb)		
	Loading Orientation		T-test	Loading Orientation		T-test	Loading Orientation		T-test	Loading Orientation		T-test
	Lateral	longitudinal		Lateral	longitudinal		Lateral	longitudinal		Lateral	longitudinal	
Compressive stress at yield (MPa)	0.524 (0.204)	0.396 (0.218)	0.400	0.420 (0.255)	0.330 (0.125)	0.519	0.255 (0.071)	0.314 (0.063)	0.393	0.197 (0.016)	0.289 (0.096)	0.012
Energy at yield (J)	2.786 (2.090)	3.464 (3.375)	0.723	0.859 (0.199)	2.014 (1.041)	0.111	2.474 (2.541)	1.812 (0.908)	0.651	0.521 (0.174)	1.484 (0.442)	0.006
Rupture at yield (N)	605.456	458.877	0.400	485.462	381.813	0.346	294.904	362.776	0.393	228.113	334.201	0.012
Modulus (MPa)	1.684 (0.380)	2.635 (1.477)	0.291	2.443 (1.235)	3.072 (1.002)	0.403	3.09 (2.505)	2.951 (0.986)	0.912	2.387 (2.380)	2.170 (1.426)	0.866

Note: Numbers in parenthesis are standard deviations.

It was observed that the rupture force was higher for the two initial moisture content of the horizontal orientation but became lower than that of the vertical as the moisture content increased as obtained by Gupta and Das (2000) for safflower kernel.

The regression analysis is shown in Figure 3.

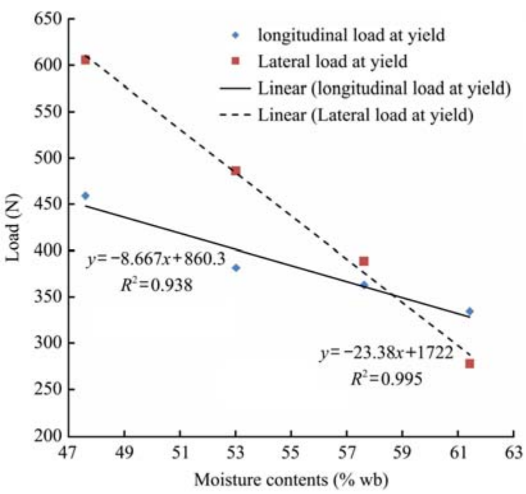


Figure 3 Effect of moisture contents on compressive load at yield of kola nuts for longitudinal and transverse compressive loading

$$y = -23.38x + 1722 \quad R^2 = 0.995 \quad \text{lateral} \qquad (1)$$

$$y = -8.667x + 860.3 \quad R^2 = 0.938 \quad \text{vertical} \qquad (2)$$

where, x is moisture content.

These results indicated that kola nut required more rupture force to dehull when loaded under the horizontal as compared to the vertical orientation. The kola nuts is placed at the suture point when in the vertical direction this made its rupture easier than when it is placed horizontally.

3.2 Compressive stress

Results from the experiment indicated that the compressive stress (Figure 4) decreased from 0.40 to 0.30 MPa and 0.52 to 0.20 MPa for vertical and horizontal orientations, respectively with increase in moisture content. The relationship between moisture content and compressive stress of kola nut compressed along the horizontal and vertical orientation can be expressed mathematically as follows:

$$y = -0.024x + 1.716 \quad R^2 = 0.978 \quad \text{lateral} \qquad (3)$$

$$y = -0.007x + 0.744 \quad R^2 = 0.937 \quad \text{vertical} \qquad (4)$$

where, x is moisture content.

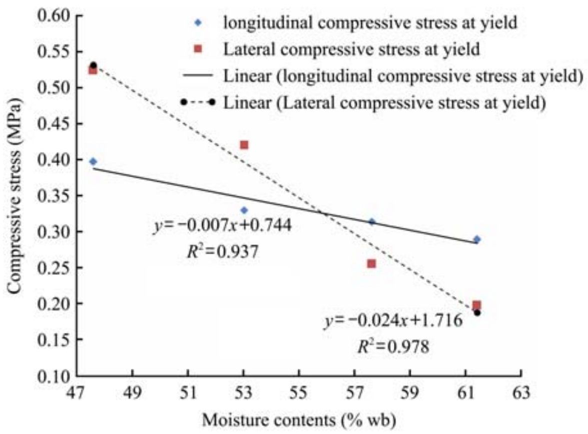


Figure 4 Effect of moisture contents on compressive stress at yield of kola nuts for longitudinal and transverse compressive loading

3.3 Energy absorbed

In both horizontal and vertical loading orientations, the energy absorbed at rupture per unit volume of nut decreased as the moisture content increased. Energy absorbed decreased from 3.46 to 1.81 J and 2.79 to 0.52 J, for vertical and horizontal orientations (Figure 5), respectively with increase in moisture content.

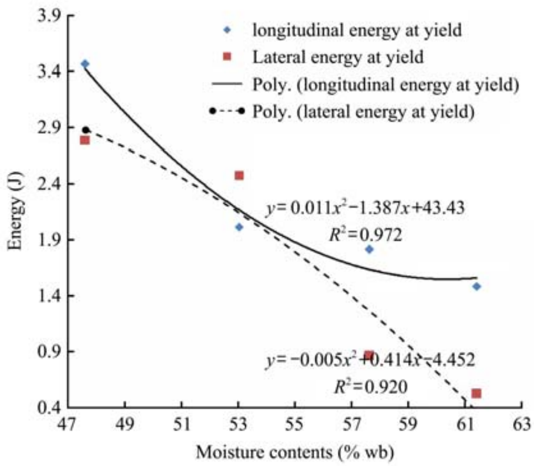


Figure 5 Effect of moisture contents on energy at yield of kola nuts for longitudinal and transverse compressive loading

$$y = -0.005x^2 + 0.414x - 4.452 \quad R^2 = 0.920 \quad \text{lateral} \quad (5)$$

$$y = 0.011x^2 - 1.387x + 43.43 \quad R^2 = 0.972 \quad \text{vertical} \quad (6)$$

where, x is moisture content.

It is also observed that the kola nut absorbed more energy before rupture when compressed in the vertical orientation. This means the chances of dehulling would be greater when there is a higher probability that the kola nut receives an impact or compressive load in the horizontal direction. It is also observed that at the highest moisture contents the kola nut require a lower magnitude of energy for rupture under compressive loading. This is contrary to the result obtained by Gupta and Das (2000), Vursavus and Özgüven (2004), Baümler et al. (2006), Saiedirad et al. (2008), Altuntaz and Yildiz (2007), Burubai et al. (2008) for sunflower seed and kernel, apricot pit, safflower seed, cumin seed, faba beans and African nutmeg, respectively.

3.4 Modulus of elasticity

This is a measure of stiffness and rigidity of the specimen or in other words, a measure of how easily the epicarp of kola nut can be deformed. Young's modulus readings were obtained from the integrator readings of the slope of the linear portion of the force-deformation curve. Experimental results show that Young's modulus of kola nut increased as moisture content increased under compressive loading. This was noticeable in the two loading orientations (Figure 6).

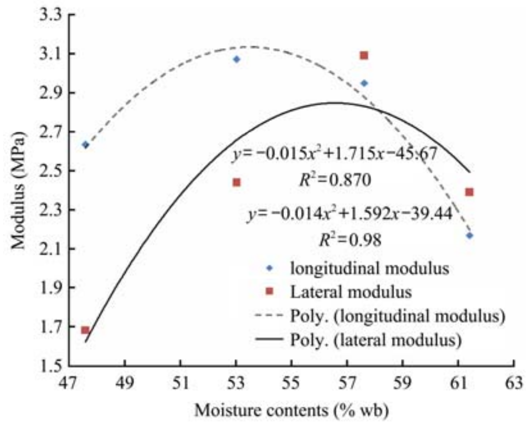


Figure 6 Effect of moisture contents on Modulus of elasticity of kola nuts for longitudinal and transverse compressive loading

$$y = -0.015x^2 + 1.715x - 45.67 \quad R^2 = 0.870 \quad \text{lateral} \quad (7)$$

$$y = -0.014x^2 + 1.592x - 39.44 \quad R^2 = 0.98 \quad \text{vertical} \quad (8)$$

where, x is moisture content.

In the vertical loading position, Young's modulus varies between 2.64 and 3.07 MPa with increase in moisture content, while in the horizontal position, Young's modulus varied from 1.69 to 3.09 MPa with increase in moisture content. Results obtained herein are in contrast with the findings of other researchers like Mamman et al. (2005) and Burubai et al. (2008) for *Balanites Aegyptiaca* nuts and African Nutmeg, respectively.

4 Conclusion

The percentage nut breakage increased with increase in impact energy but decreased with increase in moisture content, with the impact strength of the nut being higher at the longitudinal loading than at the lateral loading. The compressive force needed to initiate rupture of kola nut decreased with an increase in moisture content. The force required to rupture the kola nut is greater in the horizontal than the vertical compressive loading orientation. Energy absorbed per unit volume increases with an increase in moisture content of kola nut. Further, it is greater for the vertical than for the horizontal loading orientation. Assuming that the behaviour for impact loading is the same as in the quasi-static loading used in these experiments, a higher percentage of kola nut will be dehulled, with lower consumption of energy, when the seeds are low in moisture content and are subjected to loading in the transverse (horizontal) direction in appropriate dehulling equipment. The mechanical properties of the fruits evaluated at the fresh state confirmed that more energy would be required in processing the *kola nuts* when it is freshly harvested. The fracture resistance of kola nuts investigated were all moisture dependent. The compressive force decreased linearly with moisture content.

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