Effect of moisture content and loading orientation on mechanical properties of bush mango (*irvingia gabonensis*) nut

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Abstract: The use of inappropriate equipment to crack bush mango (*Irvingia gabonensis*) nut to obtain the kernel has adversely affected the processing and utilization of the crop. The manual method of cracking the nut with stone, cutlass or pestle and mortar, is not only slow and risky, but also wasteful. Knowledge of the nut mechanical properties is important in the development of its processing equipment. This study was undertaken to determine some strength or mechanical properties of the nut at different moisture contents under lateral and longitudinal loading orientations, using the Universal Testing Machine (UTM). In the moisture range of 7.52%-20.6% (d.b) under the above loading orientations, results of tests showed that all the strength properties decreased with increase in moisture content. Only the rupture strength increased from 0.0507 to 0.0723 N mm^{-2} as moisture content increased in the above range, under lateral loading orientation. Loading along the longitudinal axis had higher strength property values than lateral loading. This implies that the nut will be easier to crack when loaded on the lateral axis. These findings will be useful in the development of a cracking equipment for bush mango (*Irvingia gabonensis*) nut.

Keywords: mechanical properties, bush mango nut, moisture content, loading orientation, Universal Testing Machine (UTM)

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1 Introduction

Irvingia gabonensis is a genus of African and South Western Asia trees in the family of I*rvingiaceae*. It is also known by some common names as Wild mango, African mango, Bush mango, Bread tree, Dika nut, Odika, Kaka and Etima nut (Burkill, 1994). Traditionally the fruits are harvested by plucking them from the tree or hitting them down with a pole. They are then piled up in heaps and left to ferment before the nuts are extracted by washing off the pulpy materials covering them (Ejiofor, 1994). Also, the fruits may be split open with a cutlass to expose the hard nut inside (Ladipo et al., 1996; Ayuk et al., 1999). The nut is dried on a flat surface under the sun, and then cracked either by hitting with a stone, pounding in a mortar using pestle or cutting through with cutlass. The bush mango nuts and kernels are presented in Figures 1 and 2, respectively. The kernels are dried and ground into flour or paste and used as thickening agent in soup and stew. Kernel constituent can be used as binding agent in pharmaceutical products and as base material in the manufacture of soap, cosmetics, confectionary and edible fats (Agbor, 1994; Okafor, 1973; Joseph, 1995). The kernel meal and derivable edible oil are also used in medicine for curing and controlling body weight, blood glucose, metabolic disorder, obesity and over-nutrition (Olaniyan, 2012). They can also be made into cake called 'dika bread' for all year round preservation and ease of use (Alonge et al., 2015).

Cracking of the nut has been a major bottle neck to the processing and utilization of bush mango (*Irvingia gabonensis).* In order to appropriate the full economic potentials of the crop, there is the need to develop a

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cracking machine and equipment for the nut that will be efficient in terms of energy consumption, ease of use and time consumption. The development of such machine and equipment requires knowledge of mechanical properties of the nut.

Figure 1 Bush mango nuts

Figure 2 Bush mango kernels

Mamman et al. (2005) investigated the variation of mechanical properties of *Balanites aegyptiaca* nuts with moisture contents and loading orientations. Nut moisture content and loading orientation were found to have significant effects on the properties. Similar findings were reported on cumin seed (Singh and Goswami, 1998), sheanut (Olaniyan and Oje, 2002), walnut cultivars (Altuntas and Ozkan, 2008; Aviara and Ajikashile, 2011), barley grains (Tavakoli et al., 2009), jatropha seeds and kernels (Karaj and Muller, 2010), shea kernel (Manuwa and Muhammad, 2011) and *Mucuna flagellipes* nut (Aviara et al., 2012). Khazaei and Mann (2004) noted that the rupture force and modulus of elasticity of sea buckthorn berries respectively decreased with the increase in temperature. Burubai et al. (2007a, b) reported that the compressive force needed to initiate seed coat rupture of African nutmeg, decreased with increase in both pre-heating temperature and moisture content and noted that the cracking of nut was energy demanding and time consuming. However, they observed that the unit operation of cracking the nut to extract the kernel, can be positively manipulated by varying the loading rate and pre-heating time used to condition the nut for mechanical cracking. Dobrzanski and Szot (1997) earlier investigated the resistance of pea seed coat to tension when the seed was dried at different temperatures. Gates and Talja (2004) studied the effects of temperature and moisture content on the mechanical properties of oat and observed that the stiffness of the seed decreased with increase in temperature and increased with increase in moisture content. Information on the variation of mechanical properties of bush mango (*Irvingia gabonensis*) nut with moisture content and loading orientation appears to be scarce.

Therefore, the objective of this study, was to determine the mechanical properties of bush mango (*Irvingia gabonensis*) nut and investigate their variation with moisture content and loading orientation, using the Universal Testing Machine (UTM). The mechanical properties include bioyield point, yield point, rupture point, bioyield strength, compressive strength, rupture strength, modulus of elasticity, modulus of resilience and modulus of toughness.

2 Materials and methods

Bulk fresh fruits of bush mango (*Irvingia gabonensis*) was bought from Iware market near Fiditi in Afijio Local Government Council of Oyo State, Nigeria. The fresh fruits were kept inside sacks to enable them to decay and make the removal of nuts easy. Thereafter, the nuts were removed manually and washed several times in clean water and sun dried to low moisture level. The bush mango (*Irvingia gabonensis*) nuts were divided into four portions labelled A, B, C and D. The portions which formed the nut samples, were prepared for tests by soaking in clean water at room temperature for different time durations to obtain lots that have different moisture contents. Sample A was left at lowest moisture content, while samples B, C and D were soaked for 30, 60 and 90 min respectively, in order to obtain nuts at four different moisture levels. The nuts were removed from water and spread in thin layer under shade to eliminate free water from the surface after soaking. They were sealed separately in labelled polyethylene bags and kept at ambient condition for 24 h to ensure uniform moisture distribution.

Moisture content of each sample was determined using the method described by ASAE (1983), Ajibola et al. (1990), Oje (1993), and Aviara et al. (2005). The method involved oven drying of nut samples at 105°C with weight loss monitored on hourly basis to give an idea of the time at which the weight began to remain constant. The weight of samples were found to remain constant after oven drying for a period of about 6 h. After oven drying, the nuts were weighed using an electronic balance with accuracy of 0.001 g to determine the final weight. The moisture content was determined using the formula.

$$M_{wb} = \frac{W_i - W_f}{W_i} \times 100 \qquad (1)$$

where, M_{wb} = wet basis moisture content, %; W_i = initial mass of sample (g); W_f = final mass of dry sample (g).

It was converted to the dry basis moisture content using the formula.

$$M_{db} = \frac{M_{wb}}{1 - M_{wb}} \times 100 \qquad (2)$$

where, M_{db} = dry basis moisture content (%).

The experiment was repeated three times for each sample and the average values of moisture contents were determined.

Mechanical properties are those characteristics with which the behaviour of a material under an applied force can be expressed (Mohsenin, 1986). The machine used in carrying compression tests on bush mango (*Irvingia gabonensis*) nuts was the Testometric Universal Testing Machine (UTM) controlled by a micro-computer at National Centre for Agricultural Mechanization (NCAM), Ilorin, Nigeria. Nuts at specified moisture content were compressed at cross head speed of 10 mm min^{-1} (Mamman et al., 2005) under either lateral or longitudinal orientation. As the compression began and progressed, a force-deformation curve was plotted automatically by the machine in relation to the response of the nut. The force - deformation curves obtained at each loading orientation were analyzed for bioyield point, yield point, rupture point, bioyield strength, compressive strength, rupture strength, modulus of elasticity, modulus of resilience and modulus of toughness.

Bioyield point was taken as the point on the force-deformation curve at which the compressed nut shell weakened and failed internally without cracking outwardly. At that point, increase in deformation resulted from either a decrease or no change in force (Mohsenin, 1986), and the nut could be said to have failed in its internal cellular structure (Anazodo, 1982). Yield point was the point on the force deformation curve at which visible failure of the nut shell just occurred and it began to tear (Aviara et al., 2007). The rupture point was defined as the the point at which the nut shell gets completely broken and torn with the kernel exposed (Mohsenin, 1986). Compressive (yield) strength was the stress at which visible failure of the nut shell was initiated so that it began to tear, while the rupture strength was the stress at which the nut shell got completely broken. Modulus of elasticity was defined as the ratio of the stress to the strain up to bioyield and modulus of resilience was the area under the force-deformation curve up to bioyield. Modulus of toughness was the area under the force-deformation curve up to failure (Aviara et al., 2012). It was determined using the method that was followed by Haque et al. (2001). Figure 3 (a, b) shows the Universal Testing Machine (UTM) with the nut loaded longitudinally and laterally, respectively.

(a) Longitudinal orientation

(b) Lateral orientation

Figure 3 Universal Testing Machine (UTM) showing loading of bush mango nut on different orientations

3 Results and discussion

The average moisture contents of the four bush mango (Irvingia gabonensis) nut samples A, B, C and D were found to be 7.52%, 10.6%, 15.62% and 20.60% (db) respectively.

The variation of bioyield, yield and rupture points of the nut with moisture at both lateral and longitudinal loading orientations is presented in Figures 4, 5 and 6 respectively. These Figures show that under both lateral and longitudinal loading, the bioyield, yield and rupture points decreased from 443.333-218.333 N and 1053.333-862.15 N (bioyield), 3078-999 N and 2725-1562.333 N (yield) and 6.62-4.673 N and 8.318-5.466 N (rupture) as moisture content increased in the above range, with the values on the longitudinal axis being higher than that of lateral loading. This could be attributed to loss of turgor pressure and chemical changes in the cell wall (Van Buren, 1979) due to cell separation (Shomer, 1995) or rupture (Reeve, 1977; Ramana et al., 1992). The variation of bioyield, compressive (yield) and rupture strengths of the nut with moisture content under lateral and longitudinal loading orientations is shown in Figures 7, 8 and 9, respectively. From these Figures, it can be seen that the bioyield strength of the nut decreased from 3.893 to 2.365 N mm^{-2} and 11.835 to 5.953 N mm^{-2}, compressive (yield) strength from 23.556 to 10.82 N mm^{-2} and 30.618 to 19.763 N mm^{-2}, respectively, while rupture strength increased from 0.0507 to 0.0723 N mm^{-2} for lateral loading and decreased from 0.0935 to 0.0377 N mm^{-2} for longitudinal loading with increase in moisture content. This may be due to resistance to deformation that must have built up prior to disruption of the nut cellular structure.

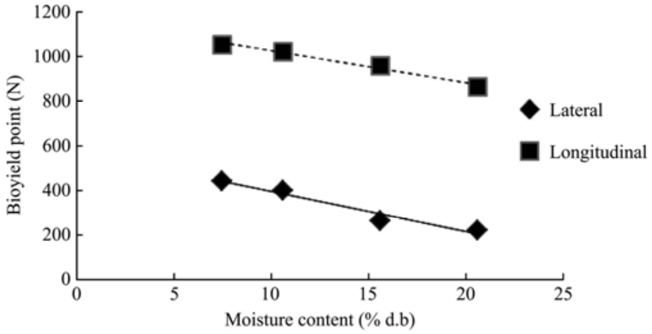

Figure 4 Effect of moisture content on bioyield point of bush mango (*Irvingia gabonensis*) nut

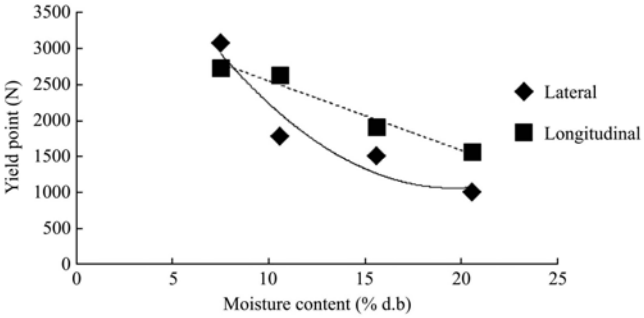

Figure 5 Effect of moisture content on yield point of bush mango (*Irvingia gabonensis*) nut

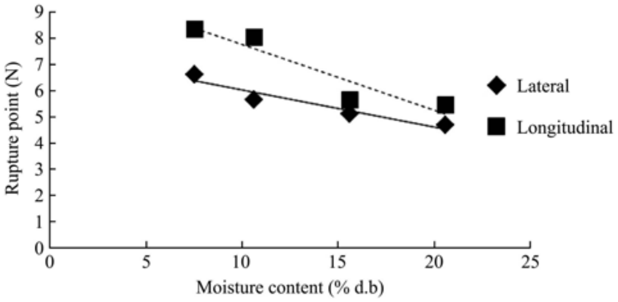

Figure 6 Effect of moisture content on rupture point of bush mango (*Irvingia gabonensis*) nut

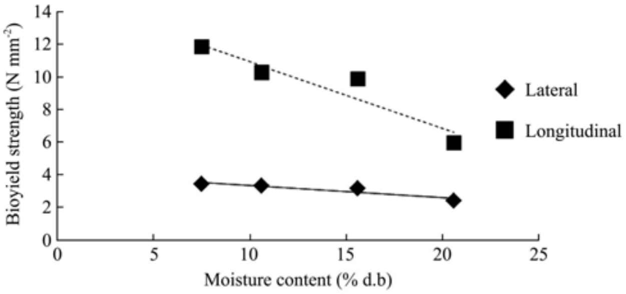

Figure 7 Effect of moisture content on bioyield strength of bush mango (*Irvingia gabonensis*) nut

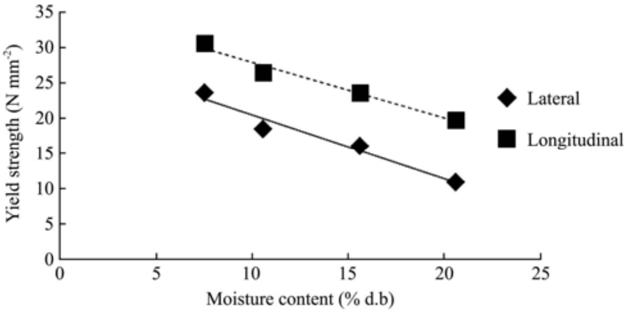

Figure 8 Effect of moisture content on compressive (yield) strength of bush mango (*Irvingia gabonensis*) nut

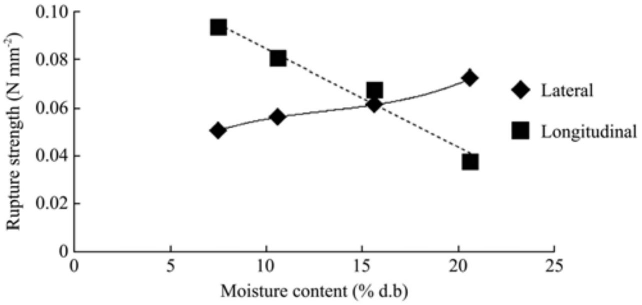

Figure 9 Effect of moisture content on rupture strength of bush mango (*Irvingia gabonensis*) nut

The moduli of elasticity, resilience and toughness of bush mango nut at different moisture contents under lateral and longitudinal loading orientations are presented in Figures 10, 11 and 12 respectively. Modulus of elasticity decreased from 3.71 to 0.775 N mm^{-2} and 1.966 to 1.282 N mm^{-2}, modulus of resilience from 9461.333 to 5026.73 J and 11930.33 to 9862.42 J and modulus of toughness from 6141.58 to 3011.53 J and 11092.09 to 9647.8 J, with increase in moisture content for each loading orientation, in agreement with the findings of Khazaei and Mann (2004). This could be attributed to loss of turgor pressure and chemical changes in the cell wall (Van Buren, 1979) due to cell separation (Shomer, 1995) or rupture (Reeve, 1977; Ramana et al., 1992).

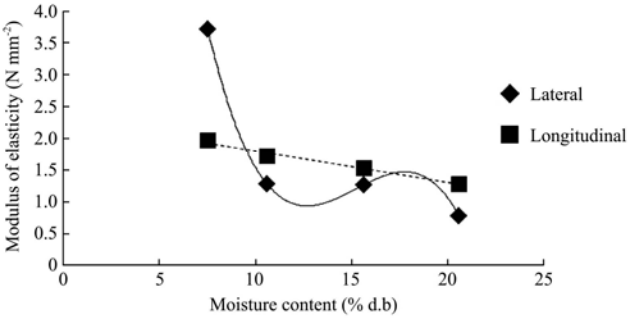

Figure 10 Effect of moisture content on modulus of elasticity of bush mango (*Irvingia gabonensis*) nut

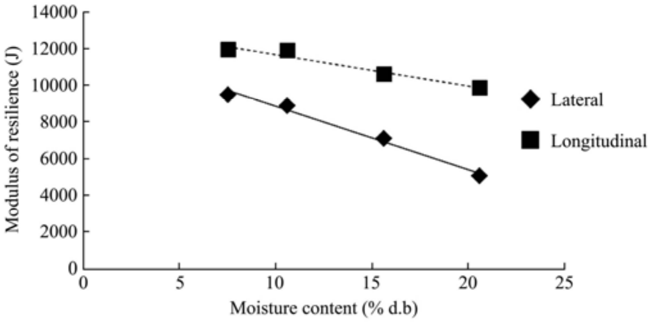

Figure 11 Effect of moisture content on modulus of resilience of bush mango (*Irvingia gabonensis*) nut

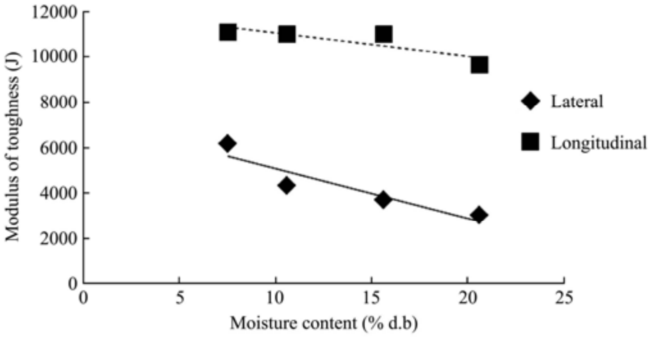

Figure 12 Effect of moisture content on modulus of toughness of bush mango (*Irvingia gabonensis*) nut

4 Conclusion

The investigation of mechanical properties of bush mango (*Irvingia gabonensis*) nuts at different moisture contents and loading orientations revealed the following:

1. Bioyield, yield and rupture points of bush mango (*Irvingia gabonensis*) nut decreased with an increase in moisture content.

2. Bioyield, compressive and rupture strengths of nut decreased with increase in moisture content at lateral loading but on longitudinal loading, the bioyield and compressive strengths decreased while the rupture strength increased with increase in moisture content.

3. Modulus of resilience and modulus of toughness of the nut decreased with increase in moisture content under both lateral and longitudinal loading.

4. Modulus of elasticity varied sinusoidally (rising and falling) with increase in moisture content under lateral loading orientation, but under longitudinal loading, it decreased linearly with increase in moisture content.

5. All the properties had higher values under longitudinal loading than at lateral loading.

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