Int. Agrophysics, 2008, 22, 249-253

INTERNATIONAL
Agrophysics
www.international-agrophysics.org

Deformation and fracture of dika nut (*Irvingia gabonensis*) under uni-axial compressive loading

B.S. Ogunsina[1], O.A. Koya[2], and O.O. Adeosun[1]*

[1]Department of Agricultural Engineering, [2]Department of Mechanical Engineering,
Obafemi Awolowo University, Ile-Ife 22005, Nigeria

Received December 10, 2007; accepted January 16, 2008

Abstract. Fracture behaviour of dika nut under quasi-static loading along the longitudinal axis and the transverse axis was investigated. The fracture resistance of the nut was measured in terms of average force, deformation and toughness at nutshell fracture, and nut stiffness. Physical dimensions and shape of the nut, to provide for complementary input in design of handling equipment, were also determined. The force required to crack the nut increased with nut diameter but was not significantly different in both loading orientations. The mean cracking force was in the range of 2.06 to 3.67 kN. The compression of the nut exhibited a pronounced linearity between load and deflection. Dika nuts loaded along the transverse axis required less energy for nutshell fracture than those loaded along the longitudinal axis. Minimum toughness occurred with the small size nuts loaded along the transverse axis, thus providing base-line data in future design of an appropriate nutcracker.

Keywords: fracture behaviour, dika nut, quasi-static loading, nut cracker

INTRODUCTION

The wild mango (*Irvingia spp.*), also called dika tree, is classified in the *Irvingiacea* family of plants and is a commercially and socially important fruit tree of the West and Central Africa. 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 (Adebayo-Tayo *et al*., 2006; Leakey *et al*., 2005; White and Abernethy, 1996).

Dika fruit is a drupe with a thin epicarp, a soft fleshy thick mesocarp and a hard stony endocarp encasing a soft dicotyledonous kernel (Fig. 1). The kernel, with about 62.8% lipids, 19.7% carbohydrates, 8.9% protein, 5.3% dietary fibre and 3.2% ash (Ejiofor, 1994; Osagie and Odutuga, 1986) has been incorporated in human nutrition for controlling dietary lipids and weight gain (Leakey *et al*., 2005; Ngodi *et al*., 2005). Dika kernels are widely marketed locally, nationally and between countries 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 (Agbor, 1994; Ayuk *et al*., 1999; Ndoye *et al*., 1997; 1995; Okafor, 1978).

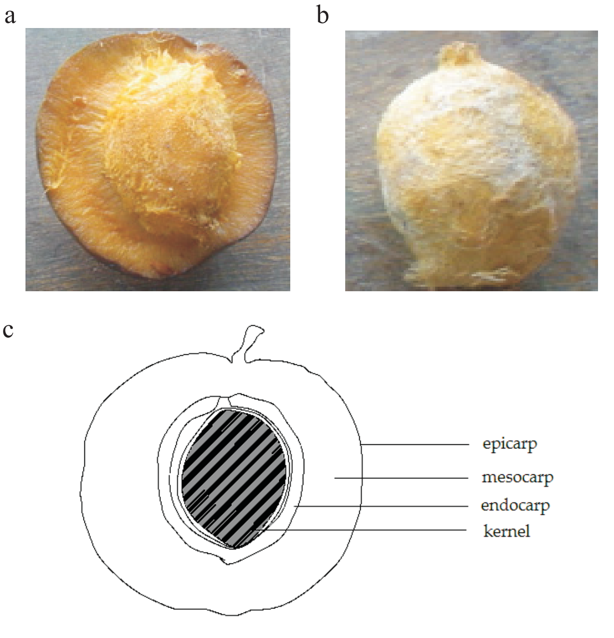

Fig. 1. Pictures of dika fruit, the nut and a cross-section: a – Nigerian grown dika fruit, partly peeled to show the mesocarp and the nut, b – Dika nut, c – schematic drawing of a longitudinally sectioned dika fruit.

---

*Corresponding author's e-mail: bsogunsina@yahoo.com

© 2008 Institute of Agrophysics, Polish Academy of Sciences

The kernel extraction process is largely non-mechanized; the fruits are piled in heaps and are left to ferment, to facilitate the extraction of the nuts. The nuts are then cracked in the wet state or after sun drying. The wet nut is slit open by placing it on a stone and slitting with a machete along the natural line of cleavage of the nut. The process is arduous and risky and a large percentage of the kernels are broken. The dried nuts are broken, one at a time, between two stones, the magnitude of the applied force being judged by experience. However, dika nuts are irregular in shape and must be carefully positioned to break the nut along its natural seam. The dried kernel-in-shell is brittle and a large percentage is crushed during the process, thereby reducing the market value of the kernels. In order to crack the nuts more efficiently while protecting the kernels from being crushed, an adequate knowledge of the mechanical behaviour and failure criteria of the nut is essential. Previous researches using other crops, such as cashew nut (Oloso and Clarke, 1993), soy-bean (Pulsen, 1978), Macadamia nuts (Wang and Mai, 1995), palm nuts (Koya and Faborode, 2005), corncob (Anazodo, 1983), and cocoa pod (Maduako and Faborode, 1994) indicate that significant information on the facture of a biomaterial may be obtained by subjecting it to quasi-static compressive loading.

The focus of this paper, therefore, was to determine the average compressive force, deformation and toughness at nutshell fracture of dika nut under quasi-static loading as a function of the nut size and loading orientation. It is expected that the results will provide impetus for the mechanization of dika nut cracking and whole kernel recovery.

METHODOLOGY

A total of 250 fresh dika fruits were selected from a large stock obtained from Oje fruit market in Ibadan, Nigeria. The fleshy mesocarp of the fruits was removed to obtain the nuts. The nuts were dried under ambient conditions for several days, following the prevailing cultural practices by the local farmers and processors of dika nuts. The actual moisture content of the nuts at the time of experimentation was determined, drying the sample at 130°C for 6 h as specified for oil bearing seeds and as had been used for cashew nuts and palm nuts (ASAE, 2002; Koya and Faborode, 2005; Oloso and Clarke, 1993). The nuts were sorted into three grades: small, medium and large, based on the visual physical assessment of their sizes. The three principal axial dimensions of 50 nuts from each grade were measured using a vernier caliper. Measurement along the longitudinal axis, from the point of attachment to the base, was taken as the major diameter. The two mutually perpendicular dimensions in the transverse axes were taken as the intermediate and minor diameters. The sphericity γ of the nut was computed from these dimensions (Mohsenin, 1986), as:

$$\gamma = \left[\frac{bc}{a^2}\right]^{1/3}, \qquad (1)$$

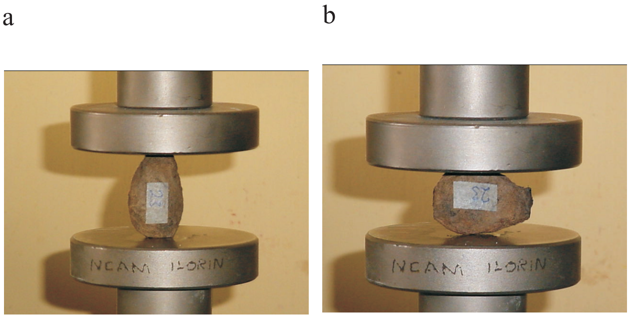

Fig. 2. Compressive loading of dika nut between two parallel plates on the Instron Universal Testing Machine: a – longitudinal loading, b – transverse loading.

where: a is the major diameter in m; b is the intermediate diameter in m; and c is the minor diameter in m. Ten nuts from each grade were randomly selected and cracked in order to measure the shell thickness. Shell thickness was measured near the point of attachment, the distal end and the mid-section of the nut.

Investigation into the fracture resistance and failure of the nut was carried out subjecting one nut at a time to quasi-static axial compression between two parallel plates as shown in Fig. 2. The load was applied along the longitudinal axis and transverse axis at a constant rate of 2 mm min^{-1} until the nut cracked. The compression testing machine was equipped with an X–Y plotter, and the resulting force-deformation curves were analysed to determine the stiffness modulus and the toughness of the nut for each size grade. Three replicates were made for each experimental run. Toughness was defined as the energy absorbed per unit of nut volume prior to nutshell fracture. Energy absorbed was determined from the integration of the force-deformation curve, from the origin to the bio-yield point.

RESULTS AND DISCUSSION

Physical characteristics

The physical dimensions of the nuts at 6.6% moisture content (wet basis) at the time of the experiment are shown in Table 1. The average geometric mean diameters of the nuts are 28.7, 31.4 and 34 mm for the small, medium and large size grades respectively. The nuts are fairly spherical with an overall average sphericity of 0.71 for the different size grades. Although the dika nut is bigger in size, its sphericity is almost identical with that of the palm nut (Koya and Faborode, 2005). The embedded kernel is approximately an ellipsoid, and there is no significant difference between the sizes of kernels from the different nut sizes. This further confirms the independence of the fruit and kernel mass as reported by Leakey *et al*., (2000).

Table 1. Some physical and mechanical properties of dika nuts (6.6% – moisture content, wet basis) used in the experiment

Properties	Size grade		
	Small	Medium	Large
	Axial dimensions (mm)		
Major diameter (a)	39.92 (1.51)*	43.55 (1.21)	46.43 (2.81)
Intermediate diameter (b)	28.51 (1.37)	31.83(0.69)	31.53 (1.92)
Minor diameter (c)	20.71 (1.97)	22.35 (1.55)	23.28 (1.85)
Geometric mean diameter	28.65 (1.38)	31.39 (0.64)	34.04 (3.24)
Sphericity	0.72 (0.02)	0.72 (0.03)	0.70 (0.06)
	Average cracking force (kN)		
Along transverse axis	2.06 (0.43)	3.61 (0.15)	3.47 (0.17)
Along longitudinal axis	2.48 (0.56)	3.63 (0.63)	3.67 (0.14)
	Stiffness (kN m^{-1})		
Along transverse axis	250.25	259.63	480.33
Along longitudinal axis	299.80	595.21	448.99
	Toughness (kJ)		
Along transverse axis	8.70	9.76	14.11
Along longitudinal axis	10.81	10.30	12.06
	Shell thickness (mm)		
At point of attachment	5.18 (1.15)	5.77 (1.45)	6.06 (2.24)
At distal end	2.98 (0.52)	3.67 (0.44)	3.84 (0.72)
At mid-section	3.03(0.45)	3.88 (1.12)	4.52 (2.35)
	Embedded kernel		
Major diameter (d)	30.16 (1.20)	31.00 (1.33)	33.83 (2.70)
Minor diameter (e)	15.81 (1.21)	18.25 (1.96)	18.25 (1.40)

*Numbers in parentheses are the standard deviations.

The shell is thinnest at the distal end, indicating higher chances of nutshell crack initiation at the distal end in random impact cracking of the nuts. Hence, fracture resistance of the distal end would provide the basis in predicting the minimal force required in cracking the nut.

Uni-axial compression test

The results of compression tests of the nuts when loaded between two parallel plates at a constant loading rate are shown in Figs 3 and 4. The general nature of these curves is similar to those reported for Macadamia nuts (Wang and Mai, 1994) and palm nuts (Koya and Faborode, 2005) which are hard-to-crack nuts. Each curve consists of a short initial non-linear and non-elastic portion, followed by a more pronounced apparently elastic portion which terminates abruptly. The apparent linear elastic portion of the curve represents the primary resistance of the nutshell to facture, while the upper limit marks the onset of bio-yield, or nutshell fracture. The nutshell fails catastrophically, splitting into pieces to release the brittle kernel.

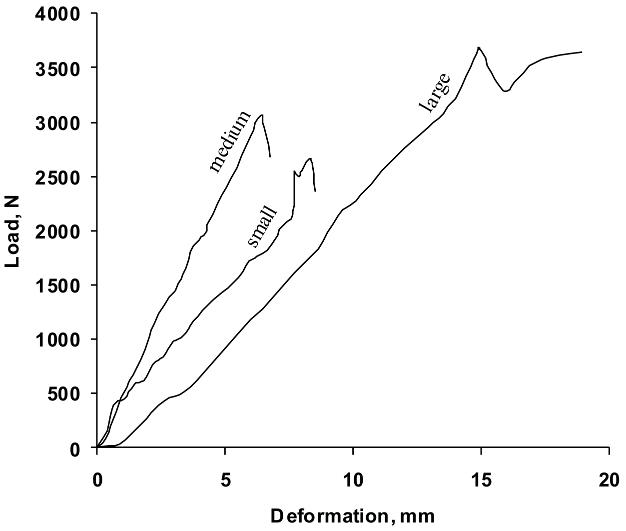

Fig. 3. Force-deformation curves of dika nut of various size grades compressed along the transverse axes at 2 mm min^{-1} loading rate.

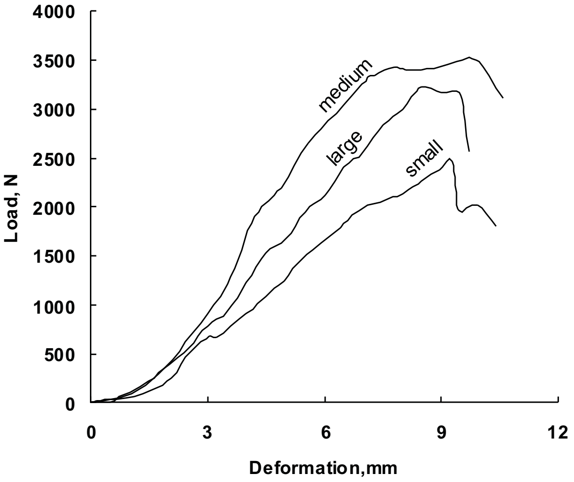

Fig. 4. Force-deformation curves of dika nuts of various size grades compressed along the longitudinal axes at 2 mm min^{-1} loading rate.

The cracking force increases with nut diameter. The fracture load *F* was in the range of: 1.70-3.37, 2.96-4.23, and 3.31-3.82 kN for the small, medium and large size grades, respectively. The mean values are shown in Table 1. However, statistical analysis, using paired t-test (Box *et al.*, 1978), showed that the cracking force along the longitudinal axis is not significantly different from that along the transverse axis.

The gradients of the linear elastic portions of the curves, which indicate material stiffness *S*, are shown in Table 1. Compared with palm nuts (Koya and Faborode, 2005), the stiffness moduli of dika nuts are generally lower than for the thick-shelled *dura* variety (654 kN m^{-1}), but comparable with the thin-shelled *tenera* variety (303 kN m^{-1}). Furthermore, the stiffness is lower and statistically significant ($p \leq 0.01$) with compression along the transverse axis than along the longitudinal axis. This feature, combined with the variation of the shell thickness, causes the nut to be the weakest along the transverse axis, with the highest possibility of crack initiation at the distal end.

Regression analyses relating the force *F* in N to the deformation *D* in mm in the experimental plots up to the bioyield point were best fitted with the linear model. The relationships for the small size nuts, where the cracking force was the least, are $F = 260.93D + 150.17$ for compression along the transverse axis, with a value for the coefficient of determination $R^2=0.993$, and $F = 290.28D - 181.73$ for compression along the longitudinal axis, with $R^2=0.987$.

Estimates of the nuts toughness from the force-deformation curves are shown in Table 1. The stiffness moduli and the toughness of the nuts would provide important base-line data for future design of nutcrackers.

CONCLUSIONS

1. Dika nut is fairly spherical and the embedded kernel is approximately ellipsoidal, but that the nut and kernel sizes are independent.

2. The quasi-static uni-axial compression of the nut is characterised by two regimes of force-deformation behaviour prior to nutshell fracture: a non-linear, non-elastic transient stage and a pronounced elastic portion preceding brittle failure.

3. The average compressive force required to crack the dika nut increases with nut diameter.

4. The cracking force is lower applied to the nut along the transverse axis but not significantly different from that along the longitudinal axis.

5. The stiffness modulus is significantly lower compressing the nut along the transverse axis than along the longitudinal axis.

6. The least energy of failure (8.7 kJ) was obtained with the small sized nuts with the force applied along the transverse axis.

REFERENCES

Adebayo-Tayo B.C., Onilude A.A., Ogunjobi A.A., Gbolagade J.S., and Oladapo M.O., 2006. Detection of fungi and alfatoxin in shelved bush mango seeds (*Irvingia* spp.) stored for sale in Uyo, Nigeria. African J. Biotech., 5(19), 1729-1732.

Anazodo U.G.N., 1983. Mechanical properties of corncob under quasi-static radial compression. Transactions of the ASAE, 26, 1222-1229.

Agbor L.O.N., 1994. Marketing trends and potentials for *Irvingia gabonensis* products in Nigeria. Proc. ICRAF-IITA Conf. *Irvingia gabonensis*, May 3-5, Ibadan, Nigeria.

ASAE Standards, **2002**. Moisture measurement-unground grain and seeds. S352.2., St. Joseph, MI, USA.

Ayuk E.T., Duguna B., Kengue J., Mollet M., Tiki-Manga T., and Zenkeng P., 1999. Uses, management and economic potential of *Irvingia gabonensis* in the humid lowlands of Cameroon. Forest Ecol. Manag., 113(1), 1-9.

Box G.E.P., Hunter W.G., and Hunter J.S., 1978. Statistics for Experimenters: An Introduction to Design, Data Analysis and Model Building. Wiley Press, London, UK.

Ejiofor M.A.N., 1994. Nutritional values of Ogbono (*Irvingia gabonensis* var. *excelsa*). Proc. ICRAF-IITA Conf. *Irvingia gabonensis*, May 3-5, Ibadan, Nigeria.

Koya O.A. and Faborode M.O., 2005. Mathematical modeling of palm nut cracking based on hertz theory. J. Biosys. Eng., 95(3), 405-412.

Leakey R.R.B., Greenwel P., Hall M. N., Atangana A.R., Usoro C., Anegbeh P.O., Fondoun J.M., and Tchoundjeu Z., 2005. Domestication of *Irvingia gabonensis*: 4. Tree-to-tree variation in food-thickening properties and in fat and protein contents of dika nut. Food Chem., 90, 365-378.

Maduako J.N. and Faborode M.O., 1994. The mechanical breaking behaviour of whole cocoa pods. J. Agric. Eng. Res., 59(2), 89-96.

Mohsenin N.N., 1986. Physical Properties of Plant and Animal Materials. Gordon-Breach Press, London-New York.

Ndoye O., Ruiz-Perez M., and Eyebe A., 1997. The Markets of Non-Timber Forest Products in the Humid Forest Zone of Cameroon. Rural Development Forestry Network. Paper No. 22c, ODI, London, UK.

Ngodi J.L., Oben J.E., and Minka S.R., 2005. The effect of *Irvingia gabonensis* seeds on body weight and blood lipids of obese subjects in Cameroon. Lipids Health Discovery, 4, 12-19.

Okafor J.C., 1978. Development of forest tree crops for food supplies to Nigeria. Forest Ecol. Manag., 17, 1-11.

Oloso A.O. and Clarke B., 1993. Some aspects of strength properties of cashew nut. J. Agric. Eng. Res., 55(1), 27-43.

Osagie A.U. and Odutuga A.A., 1986. Chemical characterisation and edibility of the oil extracted from dika kernel. Nigerian J. Nutr. Sci., 1(1), 33-36.

Pulsen G.R., 1978. Fracture resistance of soybean to compressive loading. Transactions of the ASAE, 21, 1210-1216.

Wang C. and Mai Y., 1995. Deformation and fracture of macadamia nut. Int. J. Fracture, 69, 51-65.

White L. and Abernethy K., 1996. Guide de la végétation de la Réserve de la Lopé, Gabon. ÉCOFAC Press, Dakar, Gabon.