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Physical properties of guna fruits relevant in bulk handling and mechanical processing

N.A. Aviara, S.K. Shittu, and M.A. Haque*

Department of Agricultural and Environmental Resources Engineering, University of Maiduguri, Maiduguri, Nigeria

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A b s t r a c t. The physical properties of guna fruits, relevant in bulk handling and mechanical processing, were determined and the effect of variety, post harvest history and moisture content investigated. Two varieties of the crop, namely *Citrullus colocynthis* and *Citrullus lanatus,* three post harvest storage durations of eight weeks, four weeks and fresh state that gave three moisture levels in the ranges of 87.21-92.45% (w.b.) and 85.07-89.74% (w.b.) for the *Citrullus colocynthis* and *Citrullus lanatus* fruits, respectively, were used. Fruit moisture content was found to decrease with increase in storage period. In the above moisture ranges, the major and minor semi-axial dimensions varied from 5.27 to 5.71 cm and 5.18 to 5.61 cm, respectively, for the *Colocynthis* variety and from 4.53 to 4.96 cm and 4.25 to 4.66 cm, respectively, for the *lanatus*. The thickness of the epicarp and mesocarp and fruit volume, the fruit, pod and pulp masses, as well as the pod-fruit and pulp-fruit mass ratios increased with increase in moisture content for each fruit variety, while the average seed mass remained virtually constant and the seed-fruit mass ratio decreased with increase in moisture.

The true and bulk densities of the fruits also increased with increase in moisture content and ranged from 0.767 to 0.803 g cm^{-3} and 0.664 to 0.698 g cm^{-3}, respectively, for the *colocynthis* fruit, and from 0.637 to 0.765 g cm^{-3} and 0.554 to 0.665 g cm^{-3}, respectively, for the *lanatus*. Regression equations that could be used to adequately express the relationship existing between the above properties and fruit moisture were established.

The impact strength, bioyield, yield and rupture points and the bioyield, compressive and rupture strengths, as well as the modulus of stiffness and modulus of elasticity of the fruits were higher at the longitudinal loading orientation than at the lateral. At a similar storage condition, all the properties investigated were higher for the *Citrullus colocynthis* fruits than those of *Citrullus lanatus*.

K e y w o r d s: guna fruits, physical properties, impact strength, seed extraction

INTRODUCTION

Guna is the Hausa name for the drought tolerant crop that belongs to the curcubitaceae family of flowering plants shown in Fig. 1a. Two varieties of the crop, namely *Citrullus lanatus*, (Dalziel, 1937; Adamu and Dunham, 1994) and *Citrullus colocynthis* (Gwandzang, 1994), respectively presented in Figs 1b and c, are mainly cultivated in the arid and semi-arid regions of North Eastern Nigeria. The plant leaves and fruit pods are used for medicinal purposes and as livestock feeds, but the crop is important mainly for its seeds (Fig. 2) which have average protein and oil contents of 27.13 and 50%, respectively (Norton, 1993). The seeds, therefore, serve as very good source of vegetable oil for human and livestock consumption.

Aviara and Haque (2002) carried out a survey of the processing and storage practices of guna crop in the North East Arid Region of Nigeria and found that traditional technologies that involve rigorous and time consuming procedures are employed.

Seed extraction from matured guna fruits was reported to be carried out either by crushing with pestle or allowing the fruits to decay in a pit, followed by washing of the mixture of seeds, mucilage and pods several times to retrieve the seeds. These techniques are not only laborious and time consuming, but also wasteful. As a result, seed extraction from guna fruits has posed a bottle neck to guna crop production and processing.

Little information appears to be available on the existence of a mechanical device used for the extraction of guna seeds. There is, therefore, the need to develop an equipment

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

a

b

c

Fig. 1. Guna plant and fruit in the field (a), varieties of guna fruit: *Citrullus lanatus* (b), and *Citrullus colocynthis (c).*

that would be capable of handling and extracting the seeds of guna fruits with minimum damage and losses. The design and development of such a machine require the knowledge of such engineering properties of the fruits as physical and mechanical properties.

The aim of this study was to determine the relevant engineering properties of guna fruits as affected by variety, post harvest history and moisture content. The properties include major and minor semi-axial dimensions, thickness of the epicarp and mesocarp, fruit volume and mass, pod, pulp and seed masses, pod-fruit, pulp-fruit and seed-fruit mass ratios, fruit true and bulk densities, impact strength, bioyield point, yield point and rupture point. Others are bioyield strength, compressive strength, and rupture strength, modulus of stiffness and modulus of elasticity.

MATERIALS AND METHODS

Bulk quantities of freshly harvested fruits of the two varieties of guna crop, namely *Citrullus colocynthis* and *Citrullus lanatus*, were purchased from farmers at Ngamdu in Kaga Local Government Area of Borno State, Nigeria.

The fruits were sorted and the damaged ones discarded. The undamaged ones were cleaned and divided into three lots from each variety. The first set of lots was composed of freshly harvested fruits, and because the on-farm storage of products as practiced in the locality does not normally exceed eight weeks, the second and third sets of lots were stored on 'zanah' grass spread on the floor of sheds constructed with 'zanah' mats for a duration of four and eight weeks respectively. The roof of the sheds was made of 'zanah' mat. The moisture contents of the fresh fruits were determined by randomly selecting samples from each variety, reducing the size of the samples and oven drying at 130°C with weight loss monitored until constant weights were attained. This was replicated thrice for each variety and the average moisture contents were determined. The same procedure was followed

Fig. 2. Matured guna fruit and seeds.

in determining the moisture contents of the fruits stored for four and eight weeks, respectively. The above experiments yielded the three levels of moisture content which were used to determine the effect of moisture content and post harvest history on the parameters being investigated.

Using one hundred randomly selected samples of fruit from each variety at each of the three moisture contents, the mass of fruit, mass of pod, mass of pulp and mass of seeds in each fruit were determined using an electronic balance reading to 0.001 g, and their average values were recorded. The major and minor semi-axial dimensions of the fruit and the thickness of their epicarp and mesocarp (Fig. 3) were determined using a vernier caliper reading to 0.005 cm and a micrometer screw gauge reading to 0.001 cm, respectively. The pod-fruit, pulp-fruit and seed-fruit mass ratios were then determined. The average values of these parameters were recorded.

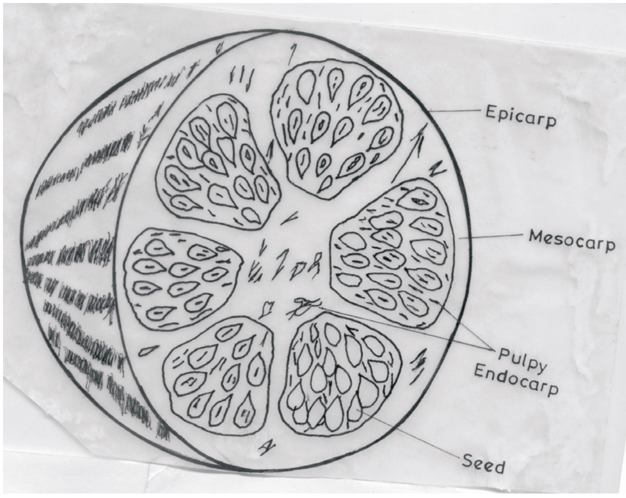

Fig 3. Cross section of guna fruit showing the seed arrangement.

The fruit volume and true density were determined at each moisture level using the water displacement method (Mohsenin, 1986; Aviara *et al.*, 1999; 2005a). The bulk density of fruits was determined using the AOAC (1980) method. The impact strength was determined by subjecting samples of guna fruits to impact from a hammer on a specially constructed impact test apparatus shown in Fig. 4. The mass of the hammer and the height of fall were used to determine the impact energy. The height of fall was varied until the impact energy produced was able to give a 100% breakage of thirty randomly selected fruits from each variety and moisture level, loaded on the apparatus either in the lateral or longitudinal orientation. The impact strength of the fruits was determined as the impact energy that gives 100% fruit breakage at a specified moisture content and loading orientation. The experiment was replicated thrice and the averages of the percentage of fruit broken with impact energy for each variety at various moisture contents and loading orientations were recorded. A similar apparatus was used by Oluwole (2004) in investigating the impact energies of sheanut. Compression tests were conducted on only the freshly harvested fruits of the two varieties using a TESTOMETRIC Universal Testing Machine (UTM) controlled by a microcomputer. The fruit was placed between two parallel plates on the machine and compressed till failure occurred.

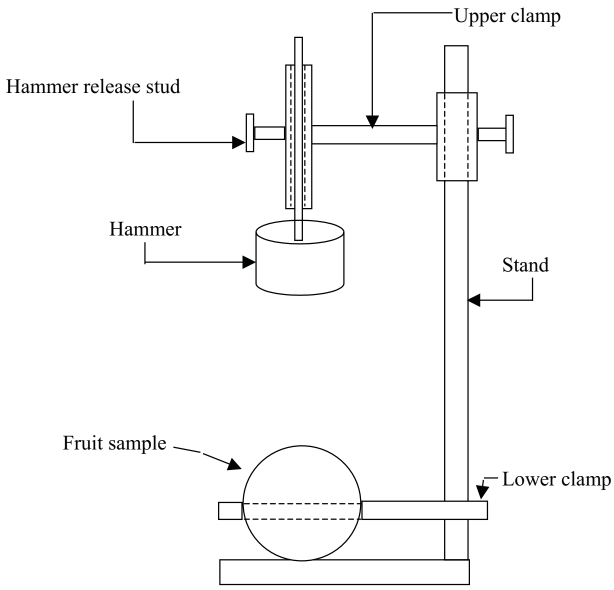

Fig. 4. Schematic diagram of the Impact Test Apparatus.

Two loading orientations were used and thirty randomly selected fruits from each variety were each compressed laterally or longitudinally by the UTM (Fig. 5). The compression rate was 5 mm min^{-1}. Test results, statistics and

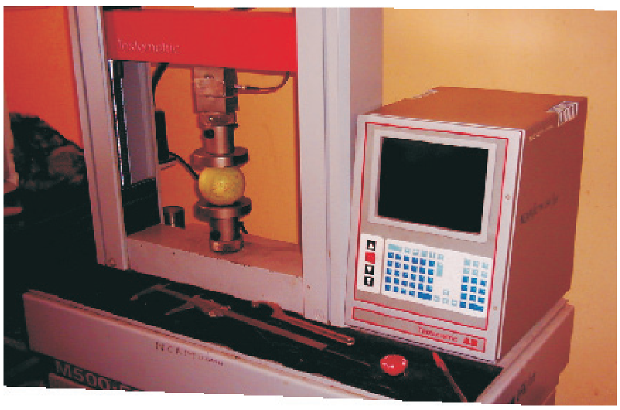

Fig. 5. Compressive test using the TESTOMETRIC Universal Testing Machine (lateral and longitudinal loading).

graphs were automatically generated. 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 Figs 6a and 6b. The force-deformation curves were analysed for bioyield. This is the point on the force-deformation curve at which the liquid from compressed fruit just oozed without the tearing of the epicarp. At this point, an increase in deformation results from either a decrease or no change in force (Mohsenin, 1986), and the material is said to have failed in internal cellular structure (Anazodo, 1982). Others are yield and rupture points. The yield point is the point on the force-deformation curve at which the fruit epicarp begins to tear, while rupture point is the point at which the epicarp breaks completely and the liquid content flows freely (Anazodo, 1982; Mohsenin, 1986). The properties that were automatically generated include bioyield strength, compressive strength, rupture strength and modulus of elasticity. The modulus of stiffness, which is the ratio of the average maximum force to the average maximum deformation at failure (Dinrifo and Faborode, 1993), was calculated from the data obtained. A similar procedure was followed by Mamman *et al.* (2005) in studying the mechanical properties of *Balanites Aegyptiaca* nuts. Comparison of means tests and regression analysis were conducted on the properties for the two varieties of guna fruit.

RESULTS AND DISCUSSION

Fruit moisture content

The fresh fruit moisture contents of the two varieties of guna crop investigated, namely *Citrullus colocynthis* and *Citrullus lanatus*, were found to average 92.45 and 89.74% (w.b.), respectively. The variation of the moisture content of the fruits with storage duration in a 'zanah' shed is presented in Table 1. The moisture content of *Citrullus colocynthis* fruits decreased from 92.45 to 87.21% (w.b.) as the storage duration increased from fresh state to eight weeks of storage, while that of *Citrullus lanatus* decreased from 89.74 to 85.07% (w.b.). The results of comparison of mean tests

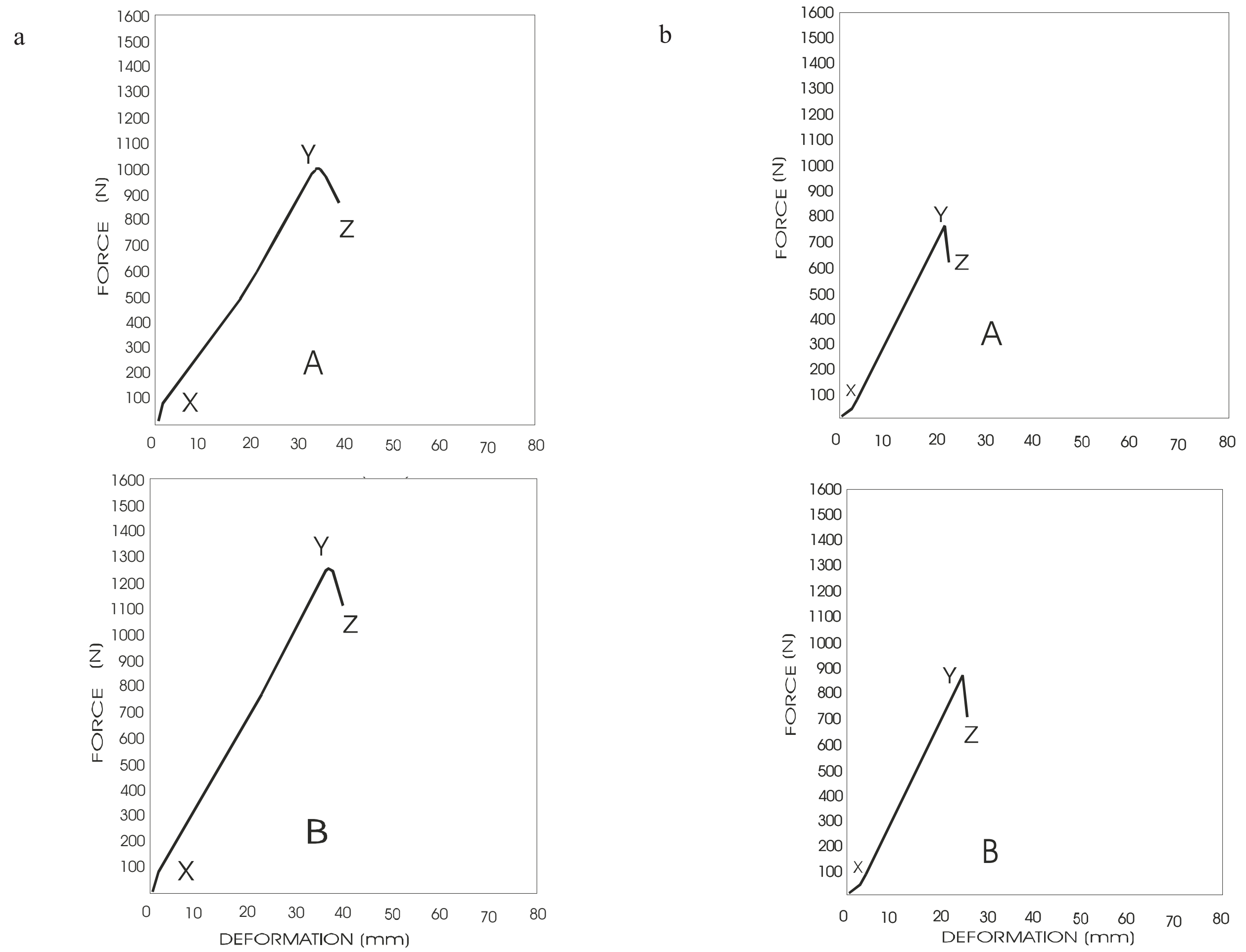

Fig. 6. Typical force-deformation curves of: *Citrullus colocynthis* (a) and *Citrullus lanatus* (b) fruit under compression; A – lateral loading, B – longitudinal loading. X – bioyield point, Y – failure point, Z – rupture point.

T a b l e 1. Some physical properties of guna fruits

Parameters	Variety					
	Citrullus colocynthis			*Citrullus lanatus*		
Post harvest history	Fresh	4 weeks of storage	8 weeks of storage	Fresh	4 weeks of storage	8 weeks of storage
Moisture content (%) w.b.	92.45 (0.15)	90.10 (0.25)	87.21 (0.95)	89.74 (0.45)	87.58 (0.97)	85.07 (0.75)
Major semi-axial dimension (cm)	5.71 (2.73)	5.69 (1.02)	5.27 (1.11)	4.96 (0.80)	4.94 (0.79)	4.53 (0.72)
Minor semi-axial dimension (cm)	5.18 (1.14)	5.59 (1.23)	5.61 (2.91)	4.25 (0.71)	4.64 (0.77)	4.66 (0.73)
Thickness of epicarp (cm)	0.188 (0.035)	0.191 (0.028)	0.21 (0.071)	0.171 (0.019)	0.182 (0.021)	0.192 (0.021)
Thickness of mesocarp (cm)	1.42 (0.75)	1.53 (0.77)	1.60 (0.70)	1.25 (0.59)	1.31 (0.65)	1.42 (0.55)
Volume (cm^3)	635.50 (220.17)	625.97 (222.96)	602.33 (202.42)	534.20 (164.82)	517.77 (197.62)	499.67 (197.49)
Mass of fruit (g)	506.95 (203.79)	499.99 (214.92)	468.17 (199.25)	380.81 (149.71)	377.36 (159.71)	347.41 (145.70)
Mass of pod (g)	174.17 (68.43)	164.97 (66.03)	151.67 (65.42)	109.62 (48.29)	104.42 (48.29)	91.42 (46.70)
Mass of pulp (g)	260.61 (126.33)	249.03 (125.61)	222.23 (110.26)	213.74 (97.00)	192.93 (101.22)	168.99 (88.48)
Mass of seed (g)	71.86 (27.67)	71.96 (30.63)	72.06 (35.97)	51.99 (21.63)	52.19 (24.32)	52.19 (22.94)
Pod-fruit mass ratio	0.3531 (0.05)	0.3367 (0.05)	0.3247 (0.04)	0.2881 (0.05)	0.2743 (0.04)	0.2536 (0.06)
Pulp-fruit mass ratio	0.5034 (0.06)	0.4836 (0.06)	0.4627 (0.07)	0.5578 (0.08)	0.4992 (0.10)	0.4690 (0.09)
Seed-fruit mass ratio	0.1432 (0.04)	0.1457 (0.05)	0.1555 (0.05)	0.1443 (0.06)	0.1463 (0.06)	0.1588 (0.07)
True density ($g\ cm^{-3}$)	0.803 (0.13)	0.781 (0.15)	0.767 (0.11)	0.765 (0.16)	0.724 (0.15)	0.637 (0.20)
Bulk density ($g\ cm^{-3}$)	0.698 (0.08)	0.675 (0.07)	0.644 (0.07)	0.665 (0.06)	0.616 (0.07)	0.554 (0.05)

(Numbers in parentheses are standard deviations).

(Table 2) show that at a similar post harvest history, the moisture content of the *Citrullus colocynthis* fruit was significantly higher than that of *Citrullus lanatus* at 1% level. The relationship existing between the moisture content of the fruits and storage duration was found to be expressed by the following regression equations:

$$M_c \approx -0.655\,ST + 92.54, \qquad R^2=0.996 \qquad (1)$$

$$M_l \approx -0.584\,ST + 89.80, \qquad R^2=0.998 \qquad (2)$$

where: M_C and M_l are moisture contents of *Citrullus colocynthis* and *Citrullus lanatus* fruits, respectively, in % (w.b.), *ST* is storage duration (weeks).

At a comparable post harvest condition, the moisture content of guna fruits is higher than that of cocoa pod (Maduako and Faborode, 1990) and African yam bean (Irtwange and Igbeka, 2002).

T a b l e 2. T-ratio of means comparison tests on physical properties of the two guna fruits varieties (var *colocynthis* and var *lanatus*)

Source of variation	Moisture content (%, w.b.)	Semi-axial dimension (cm)		Thickness (cm)		Volume (cm^3)	Mass (g)				Mass ratio			True density	Bulk density
		major	minor	epicarp	mesocarp		fruit	pod	pulp	seed	pod fruit	pulp fruit	seed fruit	($g\ cm^{-3}$)	
Cultivars	14.661*	224.000*	141.500*	5.150**	12.438*	49.310*	78.111*	44.575*	19.088*	160.108*	25.663*	-1.727^{NS}	-2.010^{NS}	2.675^{NS}	3.682^{NS}

Significant at: *1% level, **5% level, ^{NS} no significant difference.

Fruit size and dimensions

The results obtained from the measurements of fruit dimensions and presented in Table 1 show that the fruits which are spheroidal in shape have major and minor semi-axial dimensions, thicknesses of the epicarp and mesocarp and volume that respectively increased with increase in moisture content and decreased with increase in storage duration. The semi-axial dimensions of the *colocynthis* variety were found to be significantly higher than those of the *lanatus* (Table 2) at 1% level of significance when both fruits were stored under the same condition for a particular storage period. The relationships existing between the fruit axial dimensions and moisture content were found to be linear and can be expressed using the equations:

$$a_c \approx 8.629\ 10^{-2} M - 2.202, \quad R^2 = 0.831 \qquad (3)$$

$$a_l \approx 9.399\ 10^{-2} M - 3.410, \quad R^2 = 0.819 \qquad (4)$$

$$b_c \approx 8.432\ 10^{-2} M - 2.121, \quad R^2 = 0.832 \qquad (5)$$

$$b_l \approx 8.961\ 10^{-2} M - 3.321, \quad R^2 = 0.821 \qquad (6)$$

where: a_c and a_l are the major semi-axial dimensions (cm), b_c and b_l are minor semi-axial dimensions (cm) of the *colocynthis* and *lanatus* varieties of guna fruit, respectively, M is the moisture content, % (w.b.). Data on the size of guna fruit are important in the design of the grading and sorting equipment and in the sizing of hoppers.

The axial dimensions of the *colocynthis* variety are higher than those of orange (Haque *et al.*, 2001), balanites aegytiaca nuts (Aviara *et al.*, 2005a) and sea buckthorn berries (Khazaei and Mann, 2004), while those of the *lanatus* are within the same range as the dimensions of orange but higher than those of *Balanites Aegytiaca* nuts and sea buckthorn berries.

Table 2 also shows that the thickness of the epicarp and mesocarp of the *colocynthis* variety was significantly higher than that of the *lanatus* variety, at 5 and 1% levels, respectively, under similar storage conditions. A linear relationship was found to exist between fruit epicarp and mesocarp thickness and moisture content, and this can be expressed using the following equations:

$$T_{ec} \approx 4.079\ 10^{-3} M - 0.17, \quad R^2 = 0.805 \qquad (7)$$

$$T_{el} \approx 4.494\ 10^{-3} M - 0.211, \quad R^2 = 1.000 \qquad (8)$$

$$T_{mc} \approx 3.449\ 10^{-2} M - 0.585, \quad R^2 = 0.995 \qquad (9)$$

$$T_{ml} \approx 3.607\ 10^{-2} M - 1.808, \quad R^2 = 0.956 \qquad (10)$$

where: T_{ec} and T_{el} are the fruit epicarp thicknesses of the *colocynthis* and *lanatus* varieties of guna crop (cm), respectively, while: T_{mc} and T_{ml} are the corresponding thicknesses (cm) of the mesocarp, and M is the moisture content, % (w.b.), respectively.

The thicknesses guna fruit epicarp and mesocarp are higher than those of the orange (Haque *et al*., 2001) and cocoa pod (Maduako and Faborode, 1990).

The fruit volume of the *colocynthis* variety was found to be significantly higher than that of the *lanatus* at 1% level of significance under the same storage conditions (Table 2). The relationship existing between the fruit volume and its moisture content was found to be linear and can be expressed using the following equations:

$$V_c \approx 6.4\,M + 45.175, \qquad R^2 = 0.967 \qquad (11)$$

$$V_l \approx 7.389\,\mathrm{M} - 129.062, \qquad R^2 = 1.000 \qquad (12)$$

where: V_c and V_l are the fruit volumes (cm^3) of the *colocynthis* and *lanatus* varieties, respectively, M is the moisture content, % (w.b.). The volume of guna fruit is lower than that of the hybrid cocoa pod (Maduako and Faborode, 1990) but higher than that of amelonado and trinitario varieties of cocoa pod, African yam bean (Irtwange and Igbeka, 2002), hazel nuts (Aydin, 2002) and almond nut (Aydin, 2003).

Fruit and component mass and mass ratios

The variation of guna fruit mass, that of the pod, pulp and seeds contained in the fruit with moisture content and storage duration is presented in Table 1. Equally presented in Table 1 is the variation of pod-fruit, pulp-fruit and seed-fruit mass ratios with moisture content and period of storage. The fruit, pod and pulp masses of each variety increased with increase in moisture content and decreased with increased storage duration, with their values being significantly higher for the *colocynthis* variety than for the *lanatus* at 1% level of significance (Table 2). The average seed mass remained virtually constant, showing that the moisture content of the fruit did not have any significant effect on the mass of seeds contained in the fruits. However, at similar storage conditions, the average mass of seed in fruit was significantly higher for the *colocynthis* variety than for the *lanatus* at 1% level. The pod-fruit and pulp-fruit mass ratios increased with increase in moisture content and decreased with increase in storage duration, while the average seed-fruit mass ratio decreased with increase in moisture content and increased with increase in storage duration. At specified storage conditions, the pod-fruit mass ratio of the *Citrullus colocynthis* was significantly higher than that of *Citrullus lanatus* at 1% level, while their pulp-fruit and seed-fruit mass ratios showed no significant differences. The relationship existing between the fruit component masses and mass ratios and moisture content can be represented by the equations:

$$Q_{fc} \approx 7.537\,M - 186.029, \qquad R^2 = 0.915 \qquad (13)$$

$$Q_{fl} \approx 7.208\,M - 268.221, \qquad R^2 = 0.858 \qquad (14)$$

$$Q_{pc} \approx 4.306\,M - 223.550, \qquad R^2 = 0.998 \qquad (15)$$

$$Q_{pl} \approx 3.932\,M - 242.049, \qquad R^2 = 0.961 \qquad (16)$$

$$Q_{uc} \approx 7.398\,M - 421.273, \qquad R^2 = 0.973 \qquad (17)$$

$$Q_{ul} \approx 9.581\,M - 646.121, \qquad R^2 = 1.000 \qquad (18)$$

$$Q_{sc} \approx -\,4.16\;10^{-2}\,M + 75.607, \quad R^2 = 0.837 \qquad (19)$$

$$Q_{sl} \approx -\,4.17\;10\text{-}2\;\mathrm{M} + 55.769, \quad R^2 = 0.880 \qquad (20)$$

where: Q_{fc} and Q_{ft} are the masses (g) of guna fruit varieties of *colocynthis* and *lanatus,* respectively, Q_{pc} and Q_{pl} are their corresponding masses (g) of pods, Q_{uc} and Q_{ul} are the corresponding masses (g) of pulps and Q_{sc} and Q_{sl} are the corresponding masses (g) of seeds contained in the fruits, M is moisture content, % (w.b.).

The relationship existing between the pod, pulp and seed to fruit mass ratios and moisture content can be expressed using the following linear equations:

$$R_{pc} \approx 5.372\;10^{-3}\,M - 0.145, \quad R^2 = 0.978 \qquad (21)$$

$$R_{pl} \approx 7.411\;10^{-3}\,M - 0.376, \quad R^2 = 0.995 \qquad (22)$$

$$R_{uc} \approx 7.747\;10^{-3}\,M - 0.213, \quad R^2 = 0.998 \qquad (23)$$

$$R_{ul} \approx 1.883\;10^{-2}\,M - 1.138, \quad R^2 = 0.950 \qquad (24)$$

$$R_{sc} \approx 2.39\;10^{-3}\,M - 0.363, \quad R^2 = 0.992 \qquad (25)$$

$$R_{sl} \approx 3.16\;10^{-3}\,M - 0.426, \quad R^2 = 0.928 \qquad (26)$$

where: R_{pc} and R_{pl} are the pod-fruit mass ratios of the *colocynthis* and *lanatus* varieties, respectively, R_{uc} and R_{ul} are the corresponding pulp-fruit mass ratios and R_{sc} and R_{sl} are the corresponding seed-fruit mass ratios, M is moisture content, % (w.b.). The above parameters will be necessary in the performance evaluation of a mechanical seed extractor which could be designed for the crop and the operation of its winnowing system.

The pod-fruit and seed-fruit mass ratios of guna fruits are less than those of cocoa pod (Maduako and Faborode, 1990), while the pulp-fruit mass ratio is higher than that of cocoa.

True and bulk densities

The variation of the true and bulk densities of guna fruits with moisture content and storage duration is presented also in Table 1. The true and bulk densities of both varieties increased with increase in moisture content and decreased with increase in storage duration. Table 2 shows that under the same storage conditions the true and bulk densities of the two varieties of guna fruit were not significantly different. The relationship existing between the true and bulk densities and moisture content of the fruits was found to be linear and can be expressed using the following equations:

$$\rho_{tc} \approx 6.794\ 10^{-3}\ M + 0.173, \quad R^2 = 0.965 \qquad (27)$$

$$\rho_{tl} \approx 2.760\ 10^{-2}\ M + 1.706, \quad R^2 = 0.974 \qquad (28)$$

$$\rho_{tl} \approx 1.032\ 10^{-2}\ M + 0.173, \quad R^2 = 0.999 \qquad (29)$$

$$\rho_{bl} \approx 2.379\ 10^{-2}\ M - 1.469, \quad R^2 = 0.999 \qquad (30)$$

where: ρ_{tc} and ρ_{tl} are the true densities (g cm^{-3}) of the *colocynthis* and *lanatus* varieties, respectively, ρ_{bc} and ρ_{bl} are corresponding bulk densities (g cm^{-3}), M is moisture content, % (w.b.).

True density would be necessary in the determination of the equivalent sphere effective diameter of the fruits (Aviara et *al*., 1999, Aviara *et al*., 2005b), while the bulk density could be used in the estimation of the seed extractor material throughput. The true density of guna fruits is higher than that of sheanut (Aviara *et al*., 2005b), but lower than that of balanites aegyptiaca nuts (Aviara *et al*., 2005a), cocoa pod (Maduako and Faborode, 1990), orange fruit (Haque *et al*., 2001) and African yam bean (Irtwange and Igbeka, 2002). The bulk density of guna fruits is higher than that of cocoa pod, balanites aegytiaca nuts, sheanut and almond nut, but lower than that of African yam bean.

Impact strength

The variation of percentage fruit breakage with impact energy at different moisture contents and loading orientation is presented in Fig. 7a for *Citrullus colocynthis* and Fig. 7b for *Citrullus lanatus*. From these figures, it can be observed that the percentage fruit breakage increased with increase in impact energy but decreased with increase in moisture content at both lateral and longitudinal orientation. The impact strength of the fruits at longitudinal loading was higher than

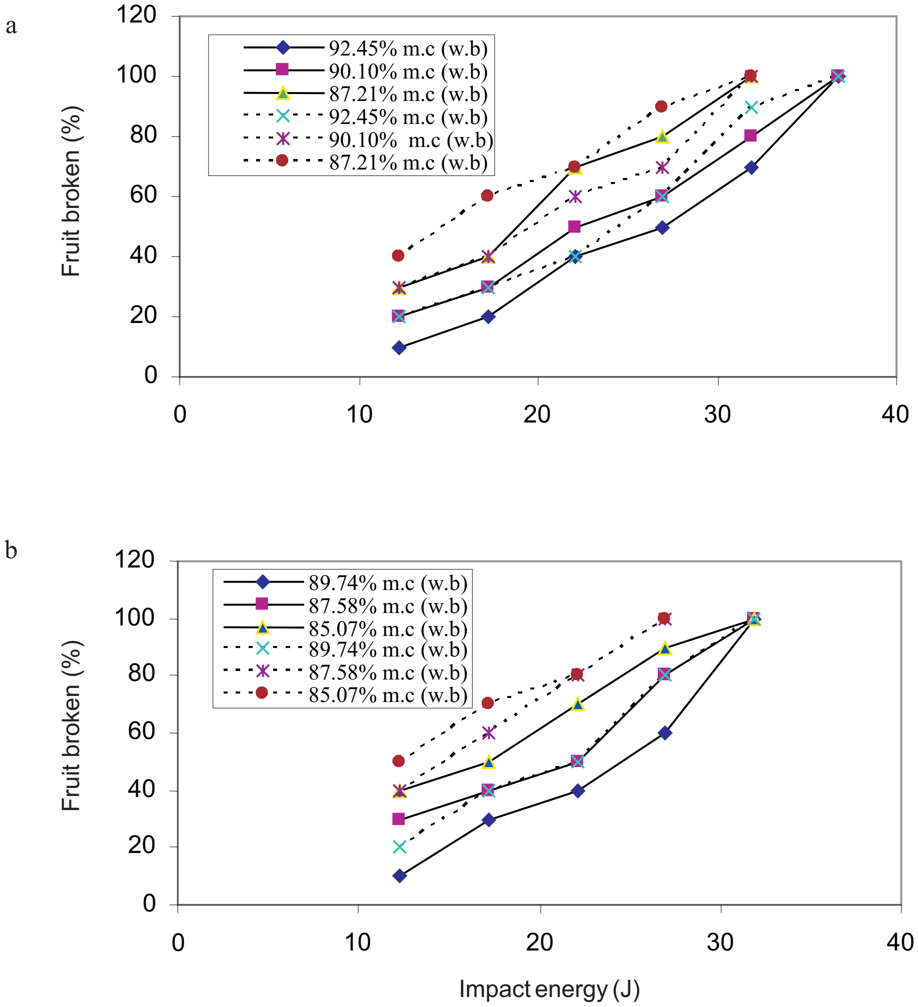

Fig. 7. Variation of percentage of fruit broken with impact energy on *Citrullus colocynthis* (a) and *Citrullus lanatus* (b) guna fruit at different moisture contents and loading orientation (lateral loading – broken line, longitudinal loading – solid line).

the impact strength at lateral loading. Generally, the impact strength of *Citrullus colocynthis* was higher than that of *Citrullus lanatus*. This implies that more energy would have to be expended in processing *Citrullus colocynthis* fruits for seed extraction than would be needed for *Citrullus lanatus* under the same processing conditions.

The impact strength of guna fruits is higher than that of sheanut (Oluwole, 2004) and apple (Mohsenin and Gohlich, 1962).

Mechanical properties

The mechanical properties of *Citrullus colocynthis* and *Citrullus lanatus* guna fruits determined at their fresh state moisture contents and lateral and longitudinal loading orientations are presented in Table 3. The comparison of means of the properties (T-ratio) for the two guna varieties shows that the bioyield, yield and rupture points are significantly higher for the *colocynthis* than for the *lanatus*, and at the longitudinal orientation than at the lateral loading. The same trend holds for the bioyield strength, compressive strength, rupture strength and modulus of stiffness of the fruits as well as their modulus of elasticity. This confirms the fact that more energy will be required in processing the *Citrullus colocynthis* fruits during seed extraction than would be needed for the same quantity of *Citrullus lanatus* fruits at similar processing conditions.

The values of the above properties are higher for guna fruits than orange (Churchill *et al*., 1980; Haque *et al*., 2001), apple (Mohsenin and Gohlich, 1962; Abbott and Lu, 1996), kiwi fruit (Abbott and Massie, 1995) and sea buckthorn berries (Khazaei and Mann, 2004), but lower for guna fruits than corn cobs (Anazodo and Norris, 1981) and cashew nuts (Oloso and Clarke, 1993).

T a b l e 3. Some mechanical properties and T-ratio of fresh *Citrullus colocynthis* and *Citrullus lanatus* guna fruits at the moisture contents of 92.45% (w.b.) and 89.74% (w.b.), respectively

Property	Loading orientation				T-ratio (cultivars as a source of variation)
	Lateral		Longitudinal		
	C . colocynthis	*C. lanatus*	*C . colocynthis*	*C. lanatus*	
Bioyield point (N)	59.17 (3.12)	32.50 (2.07)	67.65 (3.81)	43.13 (3.03)	23.809**
Yield point (N)	985.83 (11.09)	586.67 (6.27)	1214.12 (23.81)	869.38 (9.53)	13.670**
Rupture point (N)	862.50 (9.03)	441.67 (5.24)	1136.47 (19.34)	678.75 (5.53)	23.815**
Bioyield strength (N m^{-2})	$6.57 x 10^3$ (70.23)	$6.43 x 10^3$ (55.08)	$8.19 x 10^3$ (67.00)	$7.63 x 10^3$ (51.27)	1.667^{NS}
Compressive strength (N m^{-2})	$1.04 x 10^5$ (98.11)	$9.21 x 10^4$ (67.31)	$1.14 x 10^5$ (87.07)	$1.14 x 10^5$ (91.14)	1.000^{NS}
Rupture strength (N m^{-2})	$9.19 x 10^4$ (70.00)	$6.55 x 10^4$ (57.04)	$1.06 x 10^5$ (79.31)	$8.73 x 10^4$ (51.61)	5.857^{NS}
Modulus of stiffness (N m^{-1})	$2.61 x 10^4$ (83.18)	$2.48 x 10^4$ (77.44)	$3.83 x 10^4$ (91.07)	$3.59 x 10^4$ (88.53)	3.364^{NS}
Modulus of elasticity (N m^{-2})	$3.37 x 10^5$ (101.00)	$2.98 x 10^5$ (96.43)	$3.47 x 10^5$ (100.61)	$3.20 x 10^5$ (98.62)	5.500^{NS}

Numbers in parentheses are standard deviations. Significant at: *1% level, **5% level, ^{NS} no significant difference.

CONCLUSIONS

1. The moisture content of guna fruits decreased with increase in storage duration and was significantly higher for the *colocynthis* variety than for the *lanatus* at 1% level of significance.

2. The dimensions and volume of the fruits increased with increase in moisture content and varied with variety, with the values for the *colocynthis* variety being significantly higher than those of the *lanatus* under the same storage conditions.

3. The fruit, pod and pulp masses as well as the pod-fruit and pulp-fruit mass ratios increased with increase in moisture content, while the average seed mass was not significantly affected by moisture content. The seed-fruit mass ratio decreased with increase in moisture content and did not show any significant difference for both fruit varieties.

4. The true and bulk densities of the fruits increased with increase in moisture content and significantly varied with variety.

5. The percentage fruit breakage increased with increase in impact energy but decreased with increase in moisture content, with the impact strength of the fruit being higher at the longitudinal loading than at the lateral loading.

6. The mechanical properties of the fruits evaluated at the fresh state confirmed that more energy would be required in processing the *Citrullus colocynthis* fruits during seed extraction than the same quantity of *Citrullus lanatus* fruit at the same processing conditions.

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