EFFECT OF MOISTURE CONTENT AND LOADING ORIENTATION ON SELECTED MECHANICAL PROPERTIES OF COCOYAM CORMELS

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ABSTRACT
Cocoyam, *Xanthosoma sagittifolium*, is a major staple food in many African countries including Nigeria. The crop has been under-utilized and there is need for more research input to fully exploit it. There is dearth of information especially in terms of the mechanical properties among other important engineering properties which are significant in designing equipment for handling and processing the cormels. This study therefore, investigated the effect of moisture content and orientation of loading on some mechanical properties of the cocoyam cormels. White- and pink-fleshed varieties of the *X. Sagittifolium* cormels were used for this study. Selected mechanical properties namely rupture force, compressive strength, stiffness and toughness of the cormels along the three mutually-perpendicular axes were determined at four moisture content levels using Universal Testing Machine (UTM). The rupture force, compressive strength, stiffness and toughness of the cocoyam cormels along the longitudinal, cross-sectional and transverse directions ranged between 361.40 and 1,093.60N, 0.53 and 2.51 Nmm^{-2}, 3.03 and 11.70 Nmm^{-2} and 0.62 and 5.37 Nm respectively. The study further confirmed the moisture-dependence and anisotropic nature of cocoyam cormel as a biological material.

KEYWORDS: Cocoyam cormels, mechanical properties, anisotropicity, moisture content, loading orientation.

1. INTRODUCTION

Cocoyam, *Xanthosoma sagittifolium*, is cultivated for the main purpose of utilizing its corms, cormels and leaves for various applications such as food products for human consumption, animal feed and as raw materials for industrial usage. The corms and cormels can be eaten boiled, baked, fried in oil, made into flour to be used as soup thickeners or pounded into *fufu* and eaten with soup. Cocoyams, including *X. sagittifolium*, have some promising potentials such as suitability as a binding agent in tablets manufacturing, formulation of weaning food, production of pasta from its flour blends, production of lager beer etc (Odeku *et al.*, 2005; Aderolu, 2009; Owusu-Darko *et al.*, 2014, Oyefeso and Raji, 2020). Its leaves also serve as vegetable in some places all over the world (Owusu-Darko *et al.*, 2014).

Although cocoyam serves as main food items in many parts of the tropics including Nigeria, the crop has been termed under-exploited and deserving more research input (Ogunlakin *et al.*, 2012). It has been abandoned in terms of research and development input due to several unsavoury socio-cultural perceptions and unfavourable comparative economic considerations (Onwuka and Eneh, 1998; Ekwe *et al.*, 2009). Its high susceptibility to post-harvest losses is another discouraging factor although this can be prevented by immediate processing of the harvested cormels into other products of better storage stability such as cocoyam flour and flakes (Iwuoha and Kalu, 1995).

Some of the unit operations involved in the processing of cocoyam cormels include cleaning (washing and peeling), size reduction (slicing), drying, dry milling, separation and packaging. However, many of processing operations are carried out manually in most of the developing countries where cocoyam is consumed, with the attendant challenges such as drudgery, time wastage, low productivity etc. There is therefore, need for mechanization of the processing operations so as to increase capacity, improve ef.ficiency, reduce the drudgery involved and ensure timeliness of operations (Oriola and Raji, 2013).

Mechanization involves the process of designing, fabricating and evaluating the performance of equipment for processing and handling agricultural materials. However, the degree of success achieved by any mechanized system depends largely on the availability of information on the engineering properties of the crop being considered under different conditions and operational parameters (Oriola and Raji, 2015). This has resulted in the determination of engineering properties of various agricultural materials by many researchers. Selected engineering properties have been determined for pre-treated shea nuts (Olaniyan and Oje, 2002), onion cultivars (Bahnasawy *et al.*, 2004), Cheryl laurel (Çalışır and Aydin, 2004), gumbo fruit (Akar and Aydin, 2005), *Prosopis africana* pod and seed (Akaaimo and Raji, 2006), yam setts (Aluko and Koya, 2006), peanut and kernel (Aydin, 2007), oil-palm fruit (Owolarafe *et al.,* 2007), *Garcinia* kola seeds (Igbozulike and Aremu, 2009), rice straw (Zareiforoush *et al.*, 2010), barn-yard millet grain and kernel (Singh *et al.*, 2010) and tomato fruits (Zhiguo *et al.*, 2011). Adetan *et al.* (2003) and Oriola and Raji (2015) determined the root peel penetration force per unit length of knife-edge and compressive strength properties of fresh cassava roots respectively. Tensile strength, compressive strength and elasticity of IITA-improved TMS 4(2) 1425 cassava tubers were determined experimentally under five moisture content levels by Kolawole *et al.* (2007). Raji and Ahemen (2011) also determined some engineering properties of *Tacca involucrata* tubers, namely coefficients of friction, deformation, stress and Young's Modulus at break point, under a compressive load, with a view to providing data that will be useful in the design and development of handling and processing machines to replace the commonly used manual or traditional methods for *Tacca* tubers. Compressive strength of taro (*Colocasia esculenta*) under a compressive load and some physical properties which are relevant in the design of equipment and facilities for handling, conveying, separating and processing were determined by Balami *et al.* (2012). Raji and Oyefeso (2017) investigated the elastic properties (deformation at rupture, modulus of elasticity and degree of elasticity) of tannia cormels under compressive loading as experienced during transportation and storage. These studies emphasize the importance of engineering properties in the development, analysis and optimization of processing and handling equipment for the crops considered. Effect of some variables such as moisture content, age or maturity, varieties or cultivars, loading orientation, loading rate or speed etc on the selected engineering properties of agricultural and food materials have also been investigated in these studies with the aim of optimizing and simulating the processing operations.

The need to diversify into an agro-based economy and development and production of food products from rare and under-utilised crops, one of which is cocoyam, calls for a knowledge of the mechanical properties of cocoyam (*X. sagittifolium*) cormels which will foster sound understanding of the behaviour of the cormels under applied forces and which are also needed in the design of equipment for handling and processing the cormels (Goyal *et al.*, 2007; Akinoso and Raji, 2011). This study therefore investigated the effects of moisture content and orientation of loading on rupture force, compressive strength, stiffness and toughness of the cormels. Data on these properties will be useful in determining the force and energy requirements in carrying out size reduction of the cormel and thereby, enhance the optimization of the process. Proper design of suitable handling and processing machines for the cocoyam cormels can also be ensured based on the knowledge of these selected mechanical properties.

2. MATERIALS AND METHODS

2.1 Sample Preparation

White-fleshed (NXs. 001) and pink-fleshed (NXs. 002) varieties of *X. sagittifolium* cormels used for this study were purchased at Ogunmakin market, Ogunmakin town, Ogun State, Nigeria. The cormels were cleaned, peeled manually and prepared for use in carrying out the experiments by using a core borer to take cylindrical-shaped samples (28 mm height and 22 mm diameter) for examining the mechanical properties of interest. The initial average moisture content of the cocoyam cormels were determined by hot air oven method as described by Aghbashlo *et al.* (2008) using ASABE (2008) standard. This involved keeping cocoyam sample of known weight in an oven maintained at a temperature of 105±2°C until the differences between three consecutive weights were within 0.05g. The quantities of moisture removed from the samples were obtained and the moisture content (dry basis) determined according to Equation 1.

$$MC_{db} = \frac{M_w}{M_{dp}} \times 100 \qquad (1)$$

Where: MC_{db} is the moisture content (percentage, dry basis), M_w is the mass of the moisture removed from the cormel (kg) and M_{dp} is the mass of the dry matter in the cormel (kg).

The moisture contents were then adjusted to the desired levels by soaking in water as described by Olaniyan and Oje (2002) to obtain moisture content levels higher than the initial moisture content while the samples were pre-dried to obtain moisture content levels below the initial moisture content.

2.2 Determination of Mechanical Properties of Cocoyam Cormels

The mechanical properties of the cormels namely rupture force, compressive strength, stiffness and toughness of the cormels were determined on a Universal Testing Machine (UTM) (Testometric M500-100AT, Rockdale, England) with a digital data logging system as presented in Figure 1, at the National Centre for Agricultural Mechanization (NCAM), Idofian, Kwara State, Nigeria. Anisotropicity and non-homogeneity of agricultural materials were taken into consideration by taking the samples along three mutually-perpendicular directions namely longitudinal, transverse and cross-sectional directions. These properties were determined experimentally at four moisture content levels for each of the varieties.

The dimensions of the samples (30 mm height and 22 mm diameter) were within the average range of linear dimensions along the three mutually perpendicular axes as reported by Raji and Oyefeso (2010). All linear dimensions were measured with the aid of a digital vernier calliper (Carrera Precision, 0 – 150 mm range, d = 2, CP5906). The samples were then subjected to tests on the UTM. All samples were placed on the base platform provided on the UTM for compression test and then loaded at a speed of 30 mm/min (ASABE Standards, 2008). The loading continued until the failure of the samples occurred. All the experiments for determination of the selected mechanical properties were done in three replicates. Force and the accompanied deformation were recorded up to the break point to determine the maximum compressive force that the cocoyam cormels could withstand before rupture occurred.

Statistical Package for Social Sciences (SPSS 16.0, 2007 Version) was used to carry out the analysis of variance (ANOVA at $p \leq 0.05$) on the measured mechanical properties under various conditions of moisture content and orientation of loading.

Figure 1: Experimental Set-up for Determination of Mechanical Properties of Cocoyam Cormel

3. RESULTS AND DISCUSSION

The mechanical properties investigated for white and pink cocoyam cormels are as presented in Tables 1 and 2 respectively. The initial average moisture content of the white and pink cormels were 250 and 125% moisture content (dry basis) respectively. The cormels of the white variety used for the experiment were at 180, 250, 320 and 395% MC (db) while the pink cormels were at 105, 125, 150 and 200% (db). The maximum rupture force, compressive strength, stiffness and toughness obtained for white-fleshed cocoyam cormels were 765.91 N, 2.01 Nmm^{-2}, 7.53 Nmm^{-2} and 3.38 Nm respectively along the longitudinal direction; 641.66 N, 1.69 Nmm^{-2}, 9.39 Nmm^{-2} and 2.92 Nm respectively along the cross-sectional direction, and 584.73 N, 1.54 Nmm^{-2}, 7.77 Nmm^{-2} and 2.29 Nm respectively along the transverse direction. The maximum rupture force, compressive strength, stiffness and toughness obtained for pink-fleshed variety were 817.03 N, 2.15 Nmm^{-2}, 11.70 Nmm^{-2} and 3.34 Nm respectively along the longitudinal direction; 955.58 N, 2.51 Nmm^{-2}, 7.89 Nmm^{-2} and 5.37 Nm respectively along the cross-sectional direction and 772.01 N, 2.03 Nmm^{-2}, 11.15 Nmm^{-2} and 3.04 Nm respectively along the transverse direction. These results are within the ranges obtained for similar crops such as cassava tubers (Oriola and Raji, 2015), tacca tubers (Raji and Ahemen, 2011) and taro (Balami *et al.*, 2012). These results indicate that white cocoyam cormels are stronger when loaded along the longitudinal direction compared to cross-sectional and transverse orientations. However, the pink cormels demonstrated greater strength properties when loaded along the cross-sectional direction than longitudinal and transverse orientations. The observed differences in the behaviour of white and pink cormels under compressive loading along different orientations could be attributed to the differences in the structural properties of the tissues constituting both varieties.

Table 1: Mechanical Properties of White-fleshed Cocoyam Cormels

S/No	Orientation	Compressive strength (Nmm^{-2})	Stiffness (Nmm^{-2})	Toughness (Nm)
180% moisture content (db)				
1	Longitudinal	1.76 ± 0.30	5.17 ± 0.60	2.82 ± 0.61
2	Cross-sectional	1.22 ± 0.66	4.50 ± 0.34	2.17 ± 0.35
3	Transverse	1.52 ± 0.02	5.22 ± 0.23	2.26 ± 0.05
250% moisture content (db)				
1	Longitudinal	1.49 ± 0.13	4.39 ± 0.49	2.43 ± 0.27
2	Cross-sectional	1.09 ± 0.53	4.89 ± 0.59	2.15 ± 0.60
3	Transverse	0.70 ± 0.04	4.12 ± 0.32	2.01 ± 0.05
320% moisture content (db)				
1	Longitudinal	1.27 ± 0.42	4.21 ± 1.36	2.36 ± 1.01
2	Cross-sectional	1.20 ± 0.14	5.89 ± 1.03	2.00 ± 0.18
3	Transverse	0.58 ± 0.07	5.15 ± 0.40	1.96 ± 0.26
395% moisture content (db)				
1	Longitudinal	1.39 ± 0.15	6.27 ± 1.61	2.26 ± 0.79
2	Cross-sectional	1.34 ± 0.14	7.44 ± 1.75	2.32 ± 0.57
3	Transverse	0.80 ± 0.17	6.87 ± 1.50	1.41 ± 0.46

Table 2: Mechanical Properties for Pink-fleshed Cocoyam Cormels

S/No	Orientation	Compressive Strength (Nmm^{-2})	Stiffness (Nmm^{-2})	Toughness (Nm)
105% Moisture Content (db)				
1	Longitudinal	1.84 ± 0.27	5.32 ± 0.35	2.61 ± 0.59
2	Cross-sectional	1.96 ± 0.64	5.85 ± 0.49	3.70 ± 1.48
3	Transverse	1.82 ± 0.20	6.44 ± 0.65	2.62 ± 0.43
125% Moisture Content (db)				
1	Longitudinal	1.78 ± 0.47	6.37 ± 1.78	2.58 ± 0.59
2	Cross-sectional	1.53 ± 0.08	7.53 ± 0.50	2.44 ± 0.18
3	Transverse	1.59 ± 0.30	8.11 ± 0.52	2.16 ± 0.38
150% Moisture Content (db)				
1	Longitudinal	1.52 ± 0.14	6.28 ± 1.28	2.82 ± 0.48
2	Cross-sectional	1.50 ± 0.06	6.95 ± 0.33	2.90 ± 0.59
3	Transverse	1.67 ± 0.31	9.84 ± 1.22	2.45 ± 0.52
200% Moisture Content (db)				
1	Longitudinal	1.41 ± 0.14	8.91 ± 2.43	2.14 ± 0.30
2	Cross-sectional	1.32 ± 0.16	7.33 ± 0.41	2.03 ± 0.46
3	Transverse	1.11 ± 0.43	7.07 ± 1.91	1.45 ± 0.72

The results were similar to the findings of Raji and Ahemen (2011) for tacca tubers and Balami *et al.* (2012) for taro when loaded along the natural position of rest (horizontally) and vertically. Based on the results from this study, it could be observed that both white and pink cocoyam cormels are relatively stable in terms of strength.

The results of the analysis of variance (ANOVA) for the investigated mechanical properties of white and pink cocoyam cormels along the three mutually-perpendicular axes are presented in Tables 3 and 4 respectively while the results of the Duncan's New Multiple Range Test (DNMRT) are presented in Tables 5 and 6 for white and pink cormels respectively. ANOVA and DNMRT results showed that there were no significant differences ($p \leq 0.05$) between the rupture force, compressive strength and toughness of white-fleshed cocoyam cormels determined at different moisture content levels for all the orientations considered while the effect of moisture content variation on stiffness of the white cormels was significant at $p \leq 0.05$. The results of the statistical analysis also showed that there were significant differences ($p \leq 0.05$) between the rupture force, compressive strength and toughness of the white cormels determined along different orientations considered while the variation in stiffness of the white cormels showed no significant difference ($p \leq 0.05$) along different orientations considered. No significant difference ($p \leq 0.05$) was observed in the selected mechanical properties of pink-fleshed cormel for all moisture content and loading orientations considered. The combined effects of moisture content and loading orientations were not significant on all the selected mechanical properties at $p \leq 0.05$ for both varieties.

Table 3: Results of ANOVA for White Cocoyam Cormel

Mechanical properties	A	B	A x B
Rupture Force	0.1084	0.0086*	0.5155
Compressive Strength	0.1084	0.0086*	0.5155

Stiffness	0.0033*	0.3990	0.4229
Toughness	0.0628	0.0136*	0.5690

*Significant at $p \leq 0.05$
A – Moisture Content (%, db); B – Loading Orientation

Table 4: Results of ANOVA for Pink Cocoyam Cormel

Mechanical properties	A	B	A x B
Rupture Force	0.9354	0.2607	0.3175
Compressive Strength	0.9291	0.3198	0.4182
Stiffness	0.2287	0.2848	0.1583
Toughness	0.4921	0.3190	0.4573

*Significant at $p \leq 0.05$
A – Moisture Content (%, db); B – Loading Orientation

Table 5: DNMRT for White-Fleshed Cocoyam Cormel

Moisture Content (%, db)	Rupture Force	Compressive Strength	Stiffness	Toughness
180	570.4500[a]	1.5000[a]	4.9633[a]	2.4167[a]
250	415.7947[a]	1.0933[a]	4.4667[a]	2.1967[a]
320	386.6383[a]	1.0167[a]	5.0833[a]	2.1067[a]
395	447.4863[a]	1.1767[a]	6.6800[b]	1.9967[a]
Loading Orientation				
Longitudinal	561.8933[b]	1.4775[b]	5.0100[a]	2.4675[b]
Cross-sectional	461.1138[ab]	1,2125 [ab]	5.6800[a]	2.1600[ab]
Transverse	342.2700[a]	0.9000[a]	5.3400[a]	1.9100[a]

* Values with the same alphabet are not significant from each other at $p \leq 0.05$

Table 6: DNMRT for Pink-Fleshed Cocoyam Cormel

Moisture Content (%, db)	Rupture Force	Compressive Strength	Stiffness	Toughness
105	702.4287[c]	1.8733[c]	5.8700[a]	2.9767[ab]
125	621.1567[bc]	1.6333[ab]	7.3367[a]	2.3933[a]
150	594.5357[b]	1.5633[ab]	7.6900[a]	2.7233[ab]
200	486.7840[a]	1.2800[a]	7.7700[a]	1.8733[a]
Loading Orientation				
Longitudinal	588.5143[a]	1.5475[a]	6.7200[a]	2.5375[a]
Cross-sectional	599.9233[a]	1.5775[a]	6.9150[a]	2.7675[a]
Transverse	615.2413[a]	1.6375[ab]	7.8650[a]	2.1700[a]

* Values with the same alphabet are not significant from each other at $p \leq 0.05$

The DNMRT results showed that the stiffness of the white cormel at 395% MC (db) was significantly different ($p \leq 0.05$) from those at other moisture content. Variation in moisture content of the pink cormel had significant effect ($p \leq 0.05$) on the selected mechanical properties except for stiffness. Effect of loading orientation was not significant on all selected mechanical properties of the pink cormel. However, the compressive strength along the transverse direction was significantly different ($p \leq 0.05$) from the other orientations.

Variations in compressive strength of white and pink-fleshed cocoyam cormels against the moisture content are presented in Figures 2 and 3 respectively. The effect of moisture content on the compressive strength of the white cocoyam along longitudinal and transverse directions was quadratic (polynomial of order 2) while that of the cross-sectional orientation was sinusoidal or cubic (polynomial of order 3). Relationship between moisture content and compressive strength of pink cocoyam along longitudinal orientation was linear while those of transverse and cross-sectional orientations were quadratic. These findings are similar to those reported by Oriola and Raji (2015) for TMS 30572 cassava tubers although they contradict linear increase in strength reported by Kolawole *et al.* (2007) for TMS 4(2) 425 cassava variety. The compressive strength of white cormel loaded along the longitudinal and transverse directions decreased non-linearly from 1.76 and 1.52 Nmm^{-2} at 180% MC to 1.39 and 0.80 Nmm^{-2} at 395% MC. The strength of white cormel loaded along the cross-sectional direction decreased from 1.22 Nmm^{-2} at 180% MC to 1.09 Nmm^{-2} at 250% MC and then increased to 1.27 and 1.34 Nmm^{-2} at 320% and 395% MC respectively. This showed that white cocoyam cormels are stronger when the moisture content is lower, thereby showing decreasing strength as the moisture content increased up to 395% MC.

For pink cocoyam cormels, the compressive strength for longitudinal direction reduced linearly from 1.84 Nmm^{-2} at 105% MC to 1.41 Nmm^{-2} at 200% MC while the strength reduced non-linearly from 1.96 and 1.82 Nmm^{-2} at 105% MC to 1.32 and 1.11 Nmm^{-2} at 200% MC for cross-sectional and transverse directions respectively. This showed that both white and pink cocoyam cormels at higher moisture content are weaker and highly susceptible to rupture under less compressive loads. This necessitates proper attention during handling to ensure that the cocoyam cormels are not exposed to excess load in storage or transit which could result in mechanical damage to the cormels and subsequent post-harvest loss.

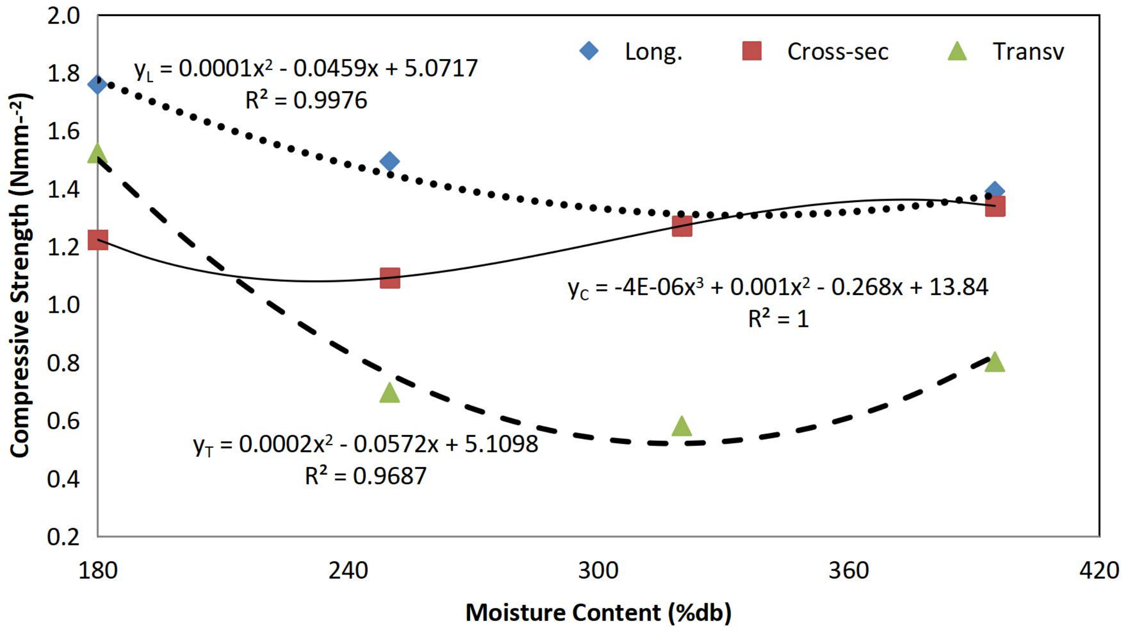


Figure 2: Compressive Strength of White Cocoyam

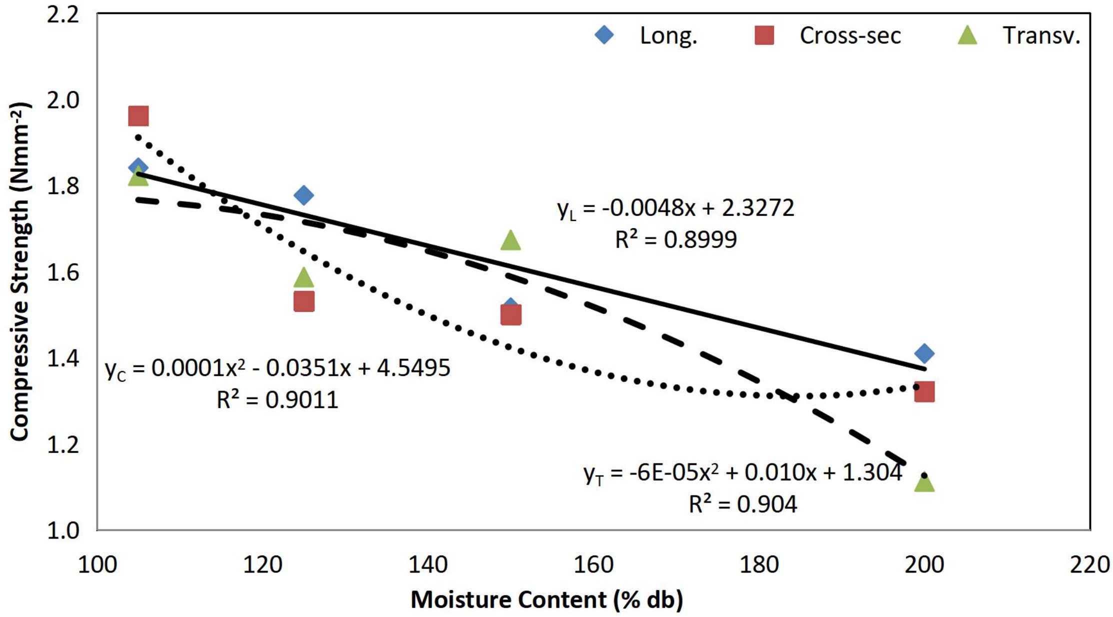
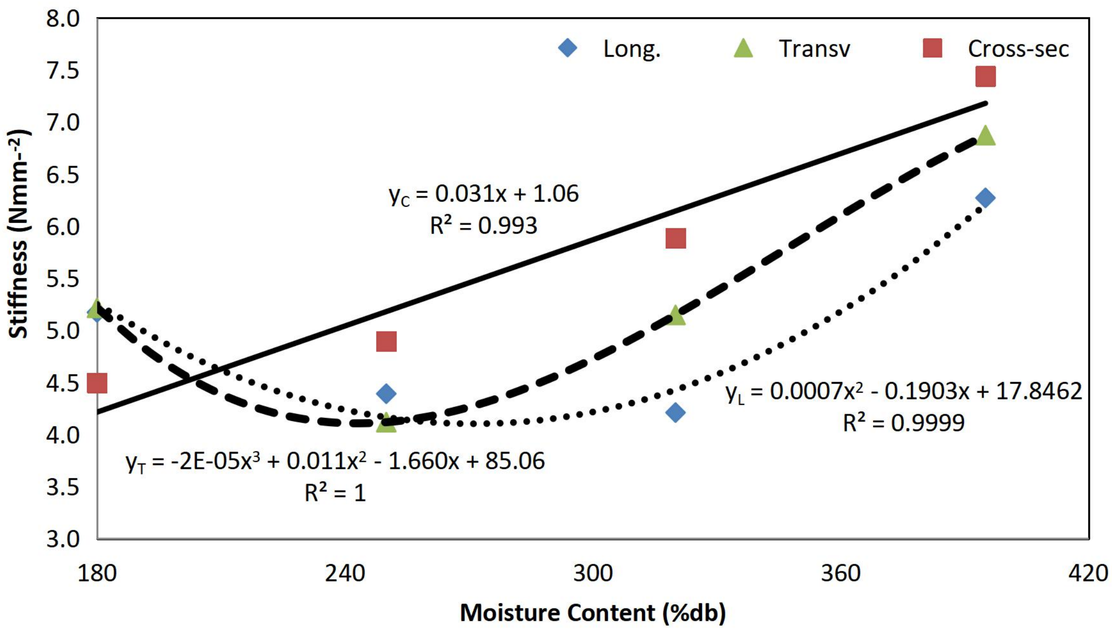


Figure 3: Compressive Strength of Pink Cocoyam

Variations in stiffness of white and pink-fleshed cocoyam cormels against the moisture content are presented in Figures 4 and 5 respectively. The effect of moisture content on stiffness of white cocoyam along longitudinal and transverse directions was non-linear (polynomial of order 2) which is similar to those reported by Oriola and Raji (2015) while that of cross-sectional orientation was linear in nature, similar to the findings of Kolawole *et al.* (2007).



Fig

ure 4: Stiffness of White Cocoyam

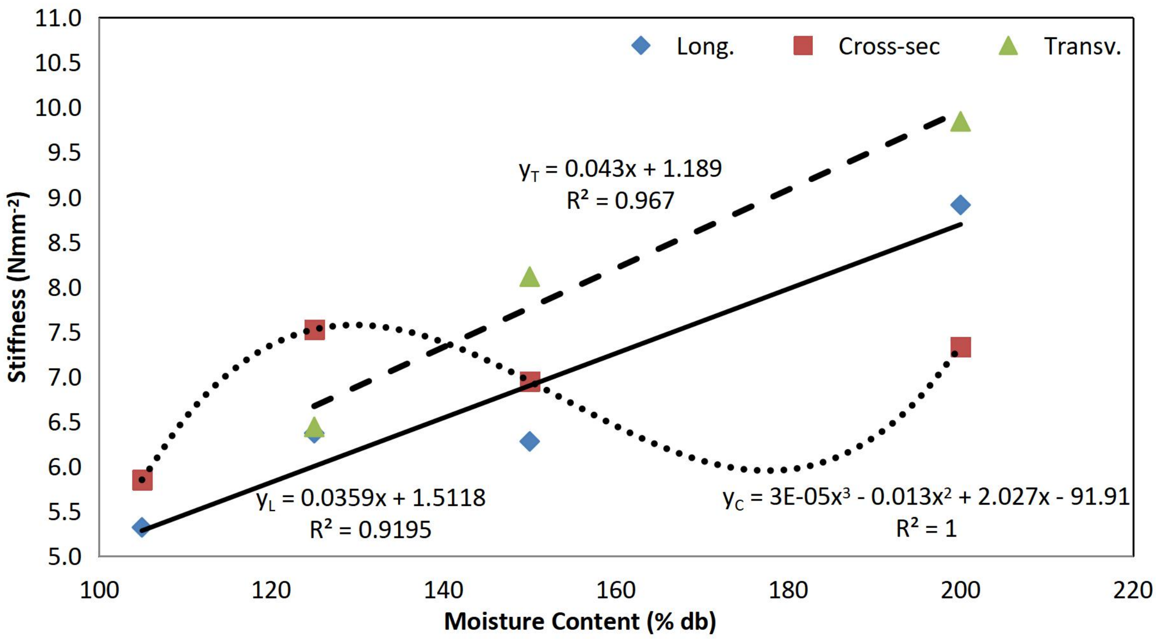


Figure 5: Stiffness of Pink Cocoyam

Relationships established between moisture content and stiffness of pink cocoyam along longitudinal and transverse directions were linear while that of cross-sectional orientation was cubic in nature. Stiffness of white cocoyam along cross-sectional direction and stiffness of pink cocoyam along longitudinal and transverse directions increased non-linearly from 5.23 and 5.22 Nmm^{-2} at 180% MC to 6.27 and 6.87 Nmm^{-2} at 395% MC as the moisture content increased. Stiffness of pink cocoyam cormel loaded along cross-sectional direction increased from 5.85 Nmm^{-2} at 105% MC to 7.53 Nmm^{-2} at 125% MC, then decreased to 6.95 Nmm^{-2} at 150% MC, followed by an increase to 7.33 Nmm^{-2} at 200% MC. The increase in stiffness predominantly observed as moisture content increased showed the high level of rigidity of the cormels as moisture content increased. This showed that for a given strain, the white and pink cocoyam cormels were able to withstand more compressive stress before rupturing as the moisture content of the cormels increased. This also clearly indicated that for a given compressive load on the cocoyam cormels in storage or transit, the strain (ratio of deformation to the original dimension) would be low at higher moisture levels. These findings are in agreement with the findings of Kolawole *et al.* (2007).

Variations in toughness of white and pink-fleshed cocoyam cormels against the moisture content are presented in Figures 6 and 7 respectively. Effects of moisture content on the toughness of white and pink cocoyam cormels along longitudinal, cross-sectional and transverse directions were quadratic, cubic and linear respectively.

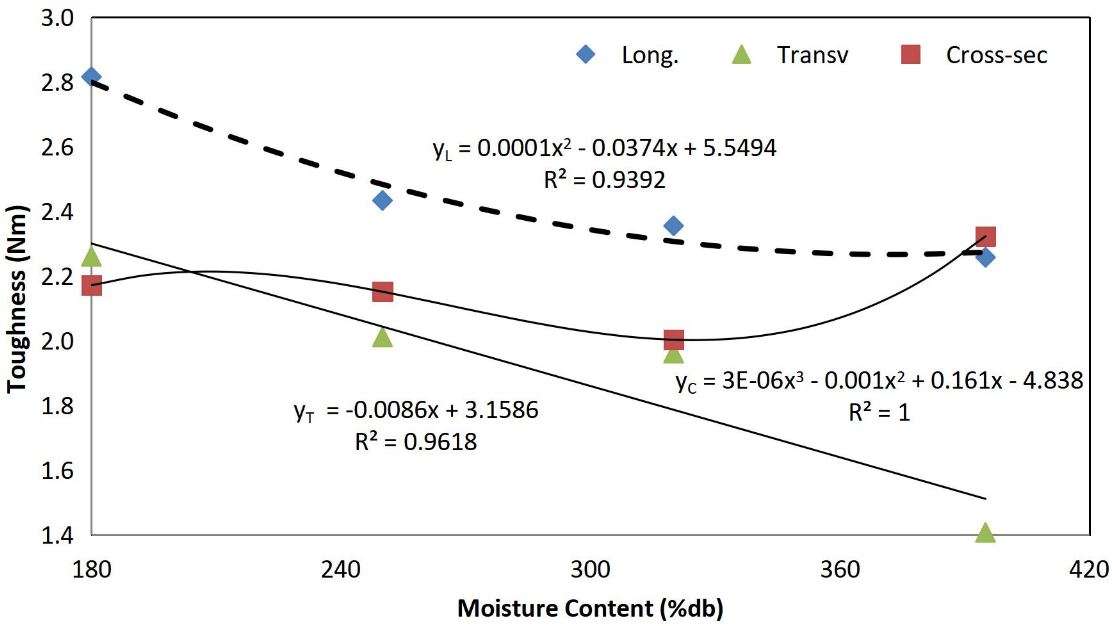


Figure 6: Toughness of White Cocoyam

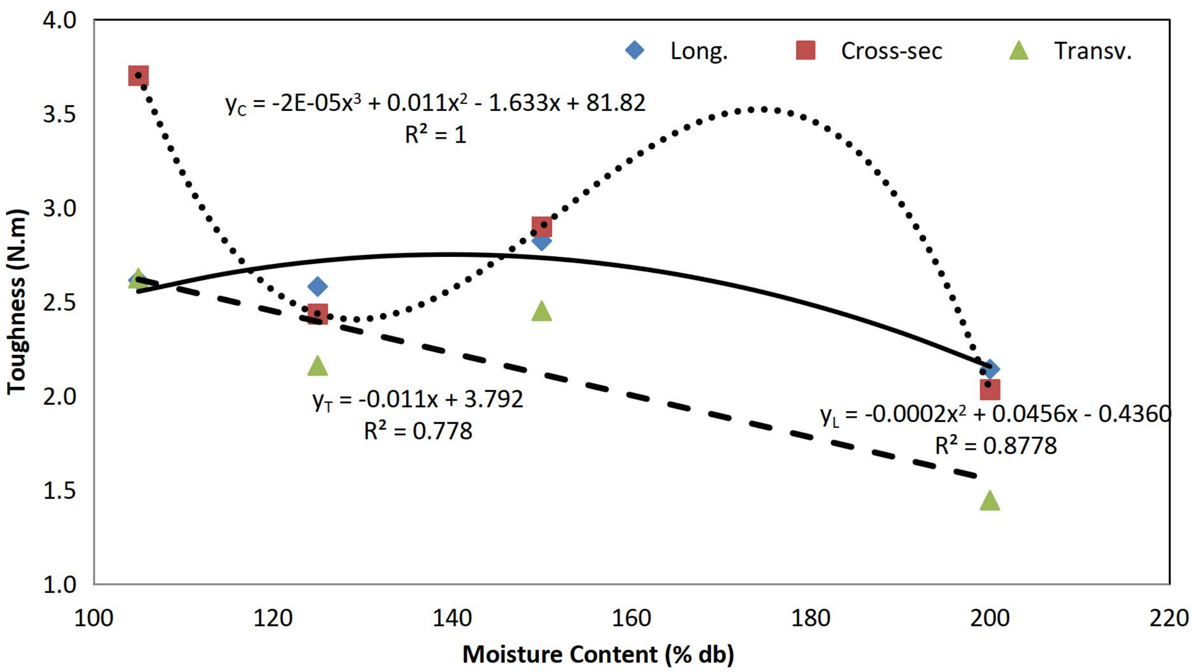


Figure 7: Toughness of Pink Cocoyam

Toughness of white cocoyam cormel decreased non-linearly from 2.82 Nm at 180% MC to 2.26 Nm at 395% MC for longitudinal loading orientation while it decreased linearly from 2.26 Nm at 180% MC to 1.41 Nm at 395% MC. However, toughness of white cocoyam cormel loaded along the transverse direction decreased from 2.17 Nm at 180% MC to 2.15 and 2.00 Nm at 180 and 320% MC respectively, followed an increase to 2.32 Nm at 395% MC. Toughness of pink cocoyam cormel decreased non-linearly from 2.63 Nm at 105% MC to 2.14 Nm at 200% MC for longitudinal loading orientation while it decreased linearly from 2.63 Nm at 105% MC to 1.45 Nm at 200% MC for transverse orientation. However, toughness of white cocoyam cormel loaded along the cross-sectional direction decreased from 3.70 Nm at 105% MC to 2.44 Nm at 125% MC, then increased to 2.90 Nm at 150% MC, followed by a decrease to 2.03 at 200% MC. The reduction in toughness of the cocoyam cormels as the moisture content increased showed that the cocoyam cormels were structurally weaker and absorbed less energy before rupturing under compressive load at higher moisture content levels. This showed that processing of the cocoyam cormels at higher moisture content, for instance during production of cocoyam fufu, would help to minimize the energy requirement by the processing equipment and some savings in total cost of production. The decreasing trend observed for toughness as moisture content increased in this study contradicts the findings of Kolawole *et al.* (2007) and Oriola and Raji (2015) for improved cassava varieties. ….

4. CONCLUSION

Selected mechanical properties of white- and pink-fleshed varieties of cocoyam cormels were determined in the study. Rupture force, compressive strength, stiffness and toughness of the cormels ranged from 422.13 to 955.58 N, 1.11 to 2.51 Nmm^{-2}, 3.48 to 11.70 Nmm^{-2} and 1.41 to 5.37 Nm, respectively, within the range of moisture content and loading orientations considered. These investigated mechanical properties were clearly dependent on the level of moisture content and orientation of loading the cormels during handling and processing. Cocoyam cormels are relatively stable in terms of strength and the knowledge of these properties will enhance proper design of processing equipment for the cormel as well as optimization of some of the unit operations involved in its processing.

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