Effect of moisture content and loading orientation on elasticity of cocoyam cormel during transit and storage

Abdulganiy Olayinka Raji[1], Babatunde Olayinka Oyefeso[2]*

(1. *Department of Agricultural and Environmental Engineering, University of Ibadan, Ibadan, Nigeria*;
2. *Department of Post Harvest Engineering, Oyo State College of Agriculture and Technology, PMB 10, Igboora, Oyo State, Nigeria*)

Abstract: Cocoyam (*Xanthosoma sagittifolium)* is one of the major staple food items in Nigeria. The crop is recently gaining attention and there is urgent need to intensify research efforts towards fully exploiting its promising potentials. Information on the elastic properties of the cocoyam cormels are necessary for understanding their behaviour under loading and in the design of equipment for proper handling of the cormels during processing and storage. This study investigated the effects of moisture content and orientation of loading on the elasticity of cocoyam cormels. White-fleshed and pink-fleshed varieties of the *X. sagittifolium* cormels were used for this study. The elastic properties of the cormels along the three mutually-perpendicular axes were determined. Deformation at rupture, modulus of elasticity (MOE), degree of elasticity (DOE) after first and third cycles along the longitudinal, cross-sectional and transversal directions ranged from 5.14 and 11.64 mm, 3.03 and 11.70 N mm^{-2}, 0.51 and 0.73 mm, 0.45 and 0.70 mm, respectively. The degrees of elasticity of the cormels decreased with the increasing number of loading and unloading cycles thereby, limiting the stack height of cocoyam cormels in transit and storage to reduce mechanical damage and subsequent postharvest losses. The study provides the information which can serve as guidelines in ensuring proper handling of cocoyam cormels in transit and storage.

Keywords: Cocoyam cormels, elastic property, moisture content, loading orientation

Citation: Raji, A. O., and B. O. Oyefeso. 2017. Elasticity of cocoyam cormel as influenced by moisture content and loading orientation when in transit and storage. Agricultural Engineering International: CIGR Journal, 19(4): 193–199.

1 Introduction

Cocoyam (*Xanthosoma sagittifolium)* is cultivated mainly for its corms and cormels, which are utilized for different purposes. Cocoyam cormels serve as main food items in many parts of the tropics including Nigeria and its promising potentials are yet to be fully exploited (Ogunlakin et al., 2012). Its production on commercial basis has been adversely affected by some unsavoury socio-cultural perceptions and unfavourable comparative economic considerations (Ekwe et al., 2009). Cocoyam has a high level of post-harvest losses due to its susceptibility to accelerated bio-deterioration although this can be prevented through immediate processing of the freshly harvested cormels into cocoyam flour and other post-harvest products with better storability (Iwuoha and Kalu, 1995). The presence of anti-nutritional contents such as calcium oxalate which causes irritation of the throat when eaten can be reduced through some processing operations such as peeling, grating, boiling, soaking and fermenting (Abdul-Rashid and Agwunobi, 2009). These unit operations help enhance leaching, decomposition and increase solubility of calcium oxalate and other anti-nutritional contents in the cocoyam cormels (Owuamanam et al., 2013; Kumoro et al., 2014).

Some of the unit operations which are carried out in its conversion from cocoyam cormel to some final products such as cocoyam chips, fufu and flour include cleaning (washing and peeling), size reduction (slicing), heat treatments (frying and drying), dry milling, separation (sedimentation and screening) and packaging. However, most of these processing operations are carried out manually in most of the developing countries where they are consumed. The reason is that cocoyam is less prestigious compared with some other root and tuber

Received date: 2017-03-10 **Accepted date:** 2017-08-01
*** Corresponding author: Babatunde Olayinka Oyefeso**, Email: oyefesobabatunde@gmail.com.

crops such as yam and it is often considered as poor men's food. The need to diversify into an agro-based economy and development and production of food products from rare and unutilised crops, one of which is cocoyam, requires a sound knowledge of the mechanical properties of the cormels which are needed in the design of equipment for handling and processing of the cormels (Akinoso and Raji, 2011).

Cocoyam cormels are usually harvested and conveyed in baskets and woven bags in Nigeria and some other developing countries where they are cultivated, before being transported from the farm to the store or directly to the market for sale (Opara, 1999). The cormels are highly susceptible to mechanical injury during post-harvest handling and transportation and proper care is necessary to avoid damage which may result in rapid deterioration during subsequent handling and storage. Knowledge of the elasticity of the cormels would help understand the behaviour of the cormels under compressive loading and the maximum deformation that they could withstand without rupture or any substantial damage to them. This would subsequently result in the reduction of post-harvest losses and improvement in the profit-making capability of those that are involved in the production and processing of the cormels. This study, therefore, investigated the deformation at rupture, modulus of elasticity (MOE) and degree of elasticity (DOE) of cocoyam cormels as affected by moisture content and orientation of loading.

2 Materials and methods

White-fleshed (NXs. 001) and pink-fleshed (NXs. 002) varieties of *X. sagittifolium* cormels, widely cultivated in South Western part of Nigeria, were used for the study. The cormels were cleaned, peeled manually using a sharp stainless steel knife and prepared for use in carrying out the experiments.

The initial average moisture content of the cocoyam cormels were determined by hot air oven method using ASABE Standards (2008a). This involved drying thin slices of cocoyam of a known initial weight at 130°C for 4 hrs. The mass of moisture removed from the cormel (M_w) was obtained by subtracting the final mass of the dry matter in the cormel after drying (M_{dp}) from the initial mass of the fresh sample before drying. The moisture contents (dry basis) of the cormels were determined according to Equation (1).

$$MC_{db} = \frac{M_W}{M_{dp}} \quad (1)$$

where, MC_{db} = moisture content of the cocoyam cormel (% dry basis); M_w = mass of moisture removed from the cormel (kg); M_{dp} = 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 MC, which was higher than the initial or pre-drying the samples. Some samples were left at the initial moisture level while higher moisture levels were obtained by soaking some samples in water for 6 and 12 hrs, after which they were conditioned for the moisture to equilibrate within the samples. Some samples were also pre-dried at a relatively low temperature (40°C) for 1 hour and allowed to cool down prior to compression tests. Soaking of cocoyam cormels in water and drying are some of the operations involved in the processing of the cormels into fufu.

Elastic properties of the cormels namely deformation at rupture, MOE and DOE were determined on a Universal Testing Machine (UTM) (Testometric M500-100AT, Rockdale, England) with a digital data logging system as shown 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 in the study by taking the samples along the three mutually-perpendicular directions namely longitudinal, transversal and cross-sectional directions. These properties were determined experimentally at four moisture contents for each of the varieties. The initial moisture contents of the fresh white and pink cocoyam cormels were 250% and 125% (db), respectively.

Cylindrical-shaped samples with 30 mm height and 22 mm diameter were taken with a borer along the three orientations to examine the elastic properties of interest. The dimensions of the samples 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 the tests on the UTM. Each sample was placed on the base platform provided on the UTM for compression test and then loaded at a speed of 30 mm min^{-1} (ASABE Standards, 2008b). The loading continued, until the failure of the samples occurred, to obtain the MOE and maximum deformation before rupture or failure of the cormel occurred. All the experiments for determination of the selected elastic properties were done in three replicates.

Figure 1 Experimental set-up for determination of elastic properties

The DOE of the white and pink cocoyam cormels were determined by loading the samples within the elastic limit to a point below the breaking point (up to 250 N which was determined through preliminary studies) and unloading the samples (no load). The loading and unloading were done in 3 cycles at the speed of 30 mm min^{-1} (ASABE Standards, 2008b). The recoverable (or elastic) deformation and residual (or plastic) deformations which resulted from the experiments were recorded accordingly. The dimensionless degree of elasticity (DOE) was obtained from the relationship established with the recoverable and plastic deformations as shown in Equation (2) (Mohsenin, 1986).

$$\text{Degree of elasticity, } \mathrm{DOE} = \frac{D_e}{D_p + D_e} \quad (2)$$

where, D_e = elastic or recoverable deformation (mm); D_p = plastic or residual deformation (mm).

3 Results and discussion

Elastic properties of white and pink cocoyam cormels were determined with respect to the moisture content and orientation of loading. The most appropriate regression models for the relationships between the measured properties and moisture content of the cormels were selected based on the highest coefficients of determination (R^2). The regression equations (linear, exponential, logarithmic, quadratic and cubic) and their corresponding R^2 values showing the trends followed by the deformation at rupture for both varieties are presented in Table 1. Variations in deformation at rupture with moisture content are shown in Figures 2 and 3.

Table 1 Regression models for deformation of cocoyam cormels at rupture

Orientation	Model	R^2 for white cormels	R^2 for pink cormels
Longitudinal	Linear	0.91	0.84
	Exponential	0.93	0.84
	Logarithmic	0.94	0.79
	Polynomial (Order 2)	0.94	0.92
	Polynomial (Order 3)	1.00	1.00
Cross-sectional	Linear	0.65	0.58
	Exponential	0.64	0.59
	Logarithmic	0.74	0.60
	Polynomial (Order 2)	0.92	0.60
	Polynomial (Order 3)	1.00	1.00
Transversal	Linear	0.97	0.82
	Exponential	0.94	0.87
	Logarithmic	0.92	0.88
	Polynomial (Order 2)	1.00	0.93
	Polynomial (Order 3)	1.00	1.00

Deformation of the cocoyam cormels at rupture decreased as the moisture content increased, which clearly indicated that the cocoyam cormels were structurally weaker as the moisture content level increased. White and pink cocoyam cormels at higher moisture content were 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. The relationships were established between moisture content and deformation at rupture ranged between linear and cubic models with consistently high R^2 values. Statistical analysis (ANOVA) showed that there were significant differences (p<0.05) between the deformation at rupture for white and pink cocoyam cormels measured at different moisture contents and orientations of loading. Similar results were obtained for DOE under all the conditions considered.

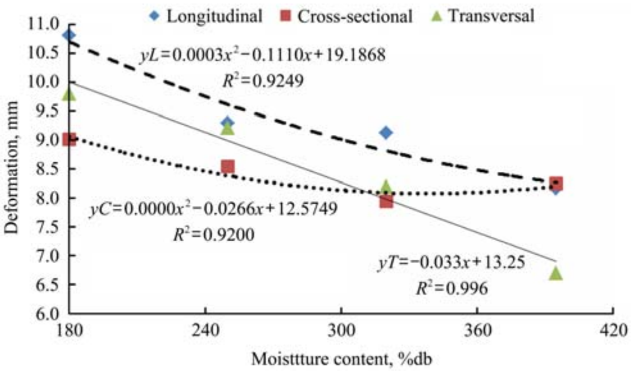

Figure 2 Deformation at rupture for white cocoyam

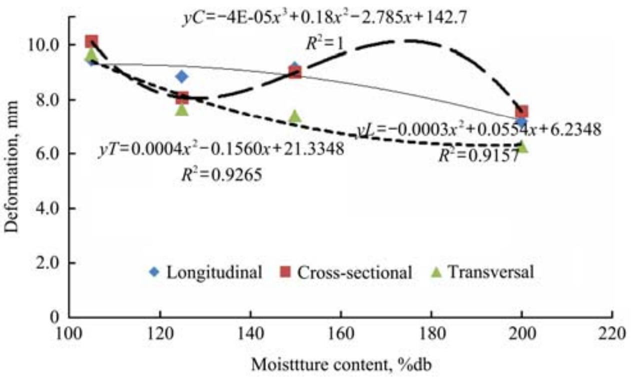

Figure 3 Deformation at rupture for pink cocoyam

The regression equations (linear, exponential, logarithmic, quadratic and cubic) and their corresponding R^2 values showing the trends followed by MOE of the cormels are presented in Table 2. Variations in MOE of white and pink cormels with moisture contents are shown in Figures 4 and 5, respectively.

Table 2 Regression models for MOE of cocoyam cormels

Orientation	Model	R^2 for white cormels	R^2 for pink cormels
Longitudinal	Linear	0.19	0.92
	Exponential	0.16	0.92
	Logarithmic	0.12	0.88
	Polynomial (Order 2)	0.95	0.95
	Polynomial (Order 3)	1.00	1.00
Cross-sectional	Linear	0.94	0.34
	Exponential	0.97	0.35
	Logarithmic	0.88	0.39
	Polynomial (Order 2)	1.00	0.56
	Polynomial (Order 3)	1.00	1.00
Transversal	Linear	0.48	0.97
	Exponential	0.43	0.94
	Logarithmic	0.36	0.99
	Polynomial (Order 2)	0.97	1.00
	Polynomial (Order 3)	1.00	1.00

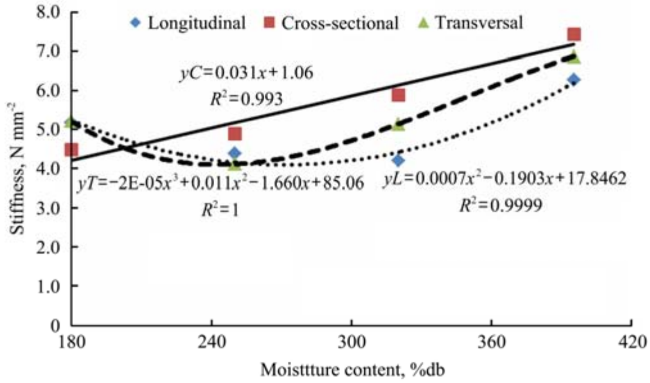

Figure 4 MOE of white cocoyam

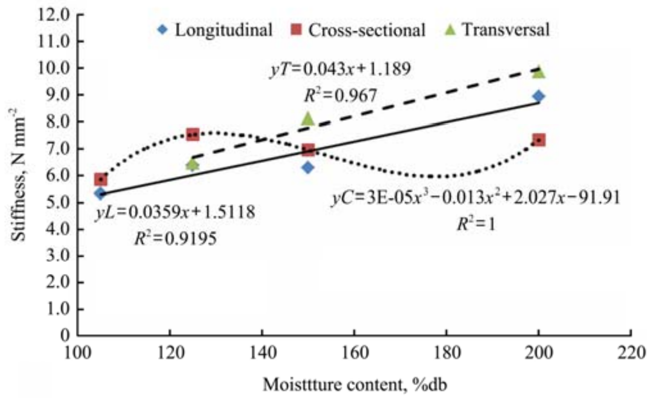

Figure 5 MOE of pink cocoyam

MOE of the cocoyam cormels increased with the increasing moisture contents. The effect of moisture content on the MOE of white cocoyam along longitudinal and transversal directions was quadratic (polynomial of order 2) while that of cross-sectional orientation was linear in nature. Relationships established between moisture content and MOE of pink cocoyam along longitudinal and transversal directions were linear while that of cross-sectional orientation was cubic. MOE of white cocoyam along cross-sectional direction and MOE of pink cocoyam along longitudinal and transversal directions increased as the moisture content increased. The relationship between MOE and moisture content for white cocoyam along longitudinal and transversal directions were sinusoidal in nature with interplay of increasing and decreasing trends. Similar trend was observed for pink cocoyam along cross-sectional direction. The increase in MOE predominantly was observed as moisture content increased, which showed that cocoyam cormels exhibited better visco-elastic properties at higher moisture content. This result showed that for a given strain, the white and pink cocoyam cormels were able to withstand more compressive load 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 relatively lower at higher moisture levels.

There were no significant differences ($p<0.05$) between MOE of white cocoyam measured at different moisture contents while there were significant differences ($p<0.05$) between MOE of pink cocoyam measured at different moisture content levels. There were significant differences ($p<0.05$) between MOE of white cocoyam measured along different orientations while there were no significant differences ($p<0.05$) between MOE of pink cocoyam measured along different orientations.

The DOE (first and third cycles) of the white and pink cocoyam cormels at different moisture contents are as presented in Tables 3 and 4. Elasticity curves showing elastic and plastic deformations during the loading and unloading cycles for white cocoyam cormels at 180% MC (db) along the longitudinal, cross-sectional and transversal orientations are presented in Figures 6, 7 and 8, respectively.

Table 3 Degree of elasticity of white cocoyam cormels

Orientation	Moisture content, % db	Total deformation, mm	DOE (1st cycle)	DOE (3rd cycle)
Longitudinal	180	4.91	0.64	0.51
Longitudinal	250	7.11	0.59	0.52
Longitudinal	320	4.29	0.62	0.56
Cross-sectional	180	4.86	0.62	0.56
Cross-sectional	250	5.32	0.65	0.61
Cross-sectional	320	4.22	0.68	0.63
Transversal	180	3.39	0.59	0.52
Transversal	250	6.04	0.57	0.53
Transversal	320	4.57	0.63	0.60

Table 4 Degree of elasticity of pink cocoyam cormels

Orientation	Moisture content, % db	Total deformation, mm	DOE (1st cycle)	DOE (3rd cycle)
Longitudinal	125	3.47	0.65	0.60
Longitudinal	150	3.30	0.67	0.63
Longitudinal	200	2.43	0.68	0.64
Cross-sectional	125	3.26	0.57	0.51
Cross-sectional	150	4.44	0.60	0.56
Cross-sectional	200	3.57	0.66	0.62
Transversal	125	5.27	0.60	0.53
Transversal	150	2.51	0.68	0.67
Transversal	200	2.62	0.72	0.68

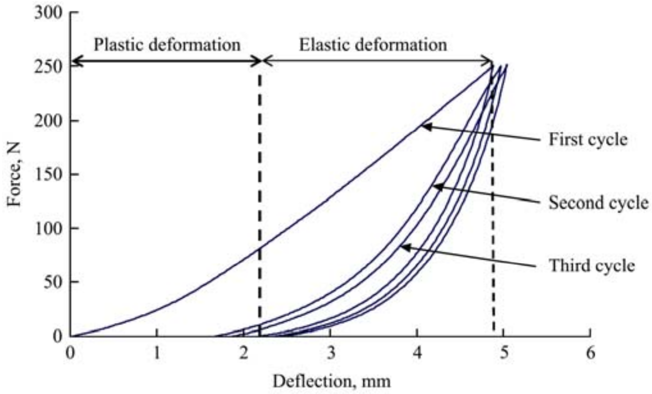

Figure 6 DOE of white cocoyam at 180% mc (db) along longitudinal direction

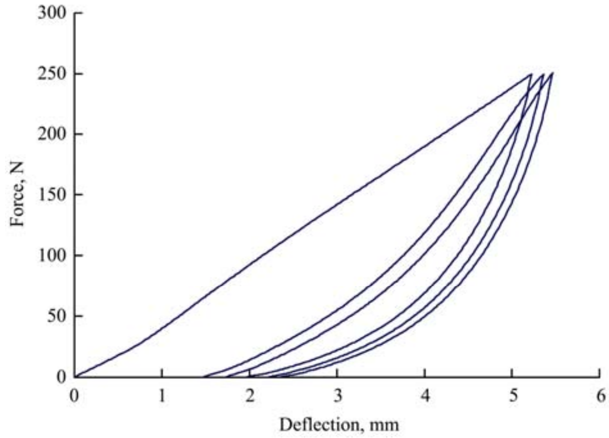

Figure 7 DOE of white cocoyam at 180% mc (db) along cross-sectional direction

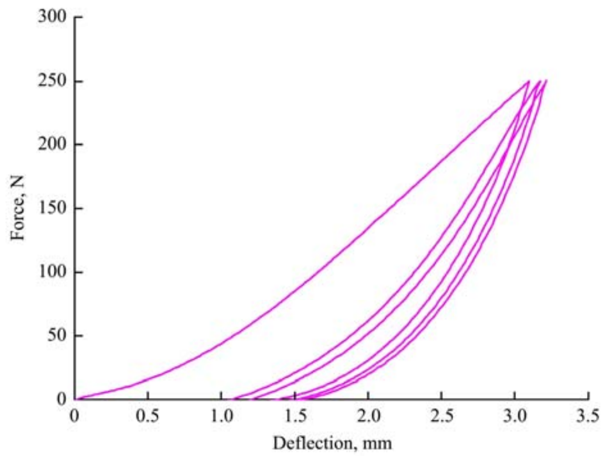

Figure 8 DOE of white cocoyam at 180% mc (db) along transversal direction

The DOE of the cormels increased with the increasing moisture contents and along the three orientations considered (Tables 3 and 4). This result showed that the ability of the cocoyam cormels to return to the original dimension increased as the percentage of water in the cormels increased. The loading and unloading curves in all the cases considered did not coincide and residual deformations which indicated the rheological property of cocoyam cormels as bio-materials were observed. Total deformation, recoverable (elastic) deformation and residual (plastic) deformation were obvious from the elasticity curves (Figures 6 to 8). The DOE of the cocoyam cormels also reduced as the number of loading and unloading cycles increased and this reduction could be observed from the increasing residual or plastic deformation as the number of cycles increased.

The average DOE during the first loading and unloading cycle for white cormels along the longitudinal, cross-sectional and transversal directions were within the ranges of 0.58-0.68, 0.60-0.69 and 0.51-0.66 respectively while for the pink cocoyam cormels, they were within the ranges of 0.61-0.70, 0.55-0.67 and 0.54-0.73 respectively. The DOE obtained during the third cycle of loading and unloading for white cormels along the longitudinal, cross-sectional and transversal directions were within the ranges of 0.50-0.57, 0.55-0.65 and 0.45-0.64, respectively while for the pink cocoyam cormels, the values were within the ranges of 0.58-0.68, 0.50-0.63 and 0.48-0.70, respectively.

The residual or plastic deformation in the elasticity (loading and unloading) curves of the white and pink cocoyam cormels could be attributed to initial setting of the constituents of the material under the compressive load and this could be as a result of the presence of pores or void spaces, rupture of weak cells and tissues of the cormels, microscopic cracks and other discontinuities in the structure of the cocoyam cormels (Mohsenin, 1986). The knowledge of the elastic properties of the cocoyam cormels would be useful in general postharvest handling of the cormels such as packaging and transportation. The cormels are harvested and put in baskets and woven bags before transportation in Nigeria and some other African countries where cocoyams are cultivated. It is recommended that direct compressive loads should be avoided without cushioning materials on top of the cocoyam cormels so as to prevent mechanical damage to the cormels and the consequent deterioration which could result in economic loss to the farmers.

The data obtained on the selected rheological properties of cocoyam cormels namely deformations at rupture, MOE and DOE would foster a sound understanding of the behaviour of the cormels when subjected to compressive loading. Consequently, the proper design of equipment for handling and packaging the cormels can be ensured by the design engineers on the basis of the properties investigated in this study.

4 Conclusions

Deformations at the point of rupture, degree of elasticity and modulus of elasticity, among other important rheological properties, have been examined in this study. The elasticity of the cormels was better at higher moisture content. Increased number of compressive loading and unloading cycles on the cormels reduced the ability of the cormels to withstand rupture or mechanical damage in transit and during storage. All the properties investigated were dependent on the different moisture contents in the cormels and orientation of loading. The study has provided the information which would be useful in ensuring proper handling of cocoyam cormel in transit and storage.

References

Abdul-Rashid, M., and L. N. Agwunobi. 2009. Taro cocoyam (*Colocasia esculenta*) as feed ingredient in poultry. *Pakistan Journal of Nutrition*, 8(5): 668–673.

Akinoso, R., and A. O. Raji. 2011. Physical properties of fruit, nut and kernel of oil palm. *International Agrophysics*, 25(1): 1–6.

ASABE Standards, 55th Ed. 2008a. S352.2. Moisture measurement – Unground grain and seeds. St. Joseph, MI: American Society of Agricultural and Biological Engineers (ASABE)

ASABE Standards, 55th Ed. 2008b. S368.4. Compression test of food materials of convex shape. St. Joseph, MI: American Society of Agricultural and Biological Engineers (ASABE).

Ekwe, K. C., K. I. Nwosu, C. C. Ekwe, and I. Nwachukwu. 2009. Examining the underexploited values of cocoyams (*Colocasia* and *Xanthosoma spp.*) for enhanced household food security, nutrition and economy in Nigeria. *International Symposium on Underutilized Plants for Food Security, Nutrition, Income and Sustainable Development*, 2(806): 71–77.

Iwuoha, C. I., and F. A. Kalu. 1995. Calcium oxalate and physicochemical properties of cocoyam: *Colocasia esculenta* and *Xanthosoma sagittifolium* tuber flours as affected by processing. *Journal of Food Chemistry*, 54(1): 61–66.

Kumoro, A. C., C. S. Budiyati, and D. S. Retnowati. 2014. Calcium oxalate reduction during soaking of giant taro (*Alocasia* *macrorrhiza* (L.) Schott) corm chips in sodium bicarbonate solution. *International Food Research Journal,* 21(4): 1583–1588.

Mohsenin, N. N. 1986. *Physical properties of plant and animal materials (2nd Revised and Updated Ed).* New York, USA: Gordon and Breach Science Publishers Inc.

Ogunlakin, G. O., M. O. Oke, G. O. Babarinde, and D. G. Olatunbosun. 2012. Effect of drying methods on proximate composition and physico-chemical properties of cocoyam flour. *American Journal of Food Technology,* 7(4): 245–250.

Olaniyan, A. M., and K. Oje. 2002. Some aspects of the mechanical properties of shea nut. *Biosystems Engineering,* 81(4): 413–420.

Opara, L. U. 1999. *Storage of edible aroids. Agro-Processing Engineering, CIGR Handbook of Agricultural Engineering, Volume IV.* St. Joseph, MI: American Society of Agricultural Engineers.

Owuamanam, C. I., B. Okolue, J. N. Nwosu, C. C. Ogueke, and R. Tobor. 2013. Thermal treatment effects on the calcium oxalate and mineral contents of *Xanthosoma atrovirens* (ede ocha): A cocoyam species. *Journal of Biology, Agriculture and Healthcare,* 3(14): 55–60.

Raji, A. O., and B. O. Oyefeso. 2010. Mass and volume modelling of tacca (*Tacca involucrata*) and cocoyam (*Xanthosoma sagittifolium*) tubers using their geometrical attributes. In *Proceedings of the 10th International Conference of the Nigerian Institution of Agricultural Engineers*, 69–77. Enugu, Enugu State, Nigeria, 8–10 October.