COMPRESSIVE STRENGTH PROPERTIES OF CASSAVA ROOTS AS AFFECTED BY MOISTURE CONTENT

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ABSTRACT
In Nigeria, recent transformation of cassava into an industrial raw material has made the need for mechanization of its postharvest processing operations imperative for sustainable rural development as a means of achieving Millennium Development Goals (MDGs). Processing technologies presently available for processing cassava roots have low efficiencies due to dearth of relevant data on the engineering properties of the root. This paper presents the studies on strength properties of cassava roots that are considered useful for the mechanization of cassava postharvest processing operations. Improved cassava variety (TMS 30572) roots harvested twelve months after planting was used in the study. The properties studied include stress at peak, energy to break and the Young's modulus of the roots. The tests were conducted at moisture contents of 50, 55, 60, 65 and 70% (wet basis) using the Universal Testing Machine (UTM). Results obtained were analyzed to evaluate the strength, toughness and stiffness of cassava as well as the influence of moisture contents on these three parameters. The stress at peak, energy to break and the stiffness modulus ranged from 0.61 to 0.88 N/mm^2; 4.80 to 6.67 Nm and 4.81 to 9.28N/mm^2 respectively within the range of moisture content studied. A non-linear relationship-3rd order polynomial was observed between moisture content and the strength properties studied.

Keywords: Strength, toughness, stiffness, moisture content, mechanization.

1. INTRODUCTION

Cassava is now a popular household and industrial crop worldwide due to its multi-purpose nature especially in the area of global food security and bio fuel production as it constitute a major source of human and animal diet in the lowland tropics and much of the sub-humid tropics of West and Central Africa. It is grown in tropical parts of Africa, Brazil, China, Phillipine, and Indonesia (FAO, 2004). Nigeria is the largest producer of the crop, contributing about 34 metric tons annually (Ajibola, 2000) and this output has continued to increase yearly till date with a total annual output of 49 metric tons (Uthman, 2011). Consumption of cassava-based products relative to other root and tuber crops among Nigerian households comparatively rank high (Kolawole *et al*., 2007a). The global market for cassava chips and pellet is also growing with China being the largest buyer of chips. It imported 4 million tons of cassava chips in 2011 out of 'the 6 million tons domestic demand for the product with Nigeria being one of the suppliers. This and others point to the imperative of mechanized production and processing of the crop for sustainable rural development as ameans of achieving Millennium Development Goal (MDG).

Generally, freshly harvested cassava roots start deteriorating almost immediately after harvest depending on the variety of cassava (Oriola and Raji, 2013). Roots of some cassava cultivars deteriorate within 24 hours after harvest while a few can still remain wholesome for about a week (Ilori and Adetan, 2013). Therefore, it is imperative to process them into shelf-stable forms immediately after harvest. Cassava processing operations, however, are still being carried out predominantly using the traditional methods which have been roundly described as arduous, time-consuming, unwholesome, unhygienic, thus, unsuitable for large scale processing operations (Adetan *et al.,* 2003; Quaye *et al.,* 2009). Efforts at mechanizing these operations were reviewed by Oriola and Raji (2013). Most of the technological outcomes of these efforts have been widely acknowledged as being inefficient (Adetan *et al*., 2006; Davies *et al*., 2008; Kolawole *et al.*, 2010). A major constraint is the poor quality of the products from these machines resulting from low efficiencies of these technologies. A review work by Oriola and Raji (2013) highlighted some of the problems with the machines which include peeling off of unacceptable percentage of useful flesh during mechanical peeling, reduction of peeling efficiency with time resulting to increased time of operation, production of grated mash or cassava chips with uneven particles size resulting in varying and low product qualities between processors and between batches. The dewatering machines (hydraulic or screw type) only increases the processing (dewatering) capacity per batch but still takes the usual longer time to dewater to acceptable moisture content thereby promoting fermentation of the cassava mash. Locally fabricated flash dryers are yet to be efficient (IITA, 2006).

Mechanization involves the design and development of equipment and its success is largely dependent on availability of relevant data on the engineering properties of the crop. The design of equipment for handling and processing of cassava requires a thorough understanding of the engineering properties of cassava roots. Physical properties of cassava roots influence the level of damage sustainable by it during handling operations (Kolawole *et al.*, 2007b). In realization of this, there have been a lot of research attempts at determining the engineering properties of cassava roots towards the development of appropriate mechanical systems for its postharvest operations (Owhovoriole *et al*., 1988; Adetan *et al*., 2003; Kolawole *et al*., 2007a; Nwagugu and Okonkwo, 2009; Kolawole, 2012; Ademosun *et al*., 2012; Ilori and Adetan, 2013). Few of these studies focused on the compressive strength properties of the crop which is as important as the other engineering properties of cassava such as physical properties and frictional properties that were mostly focused by researchers. Owhovoriole *et al.* (1988) experimented with a novel peeling concept involving compression of unpeeled tubers of cassava against a sharp-edged rig and rolling off the peels without disturbing the flesh (peel-flesh separation through compression). The data on the compressive strength properties of cassava as determined by Owhovoriole *et al.* (1988) were used in the design of a cassava peeler by the same author and 92% efficiency was obtained with the peeler. This same principle was built upon by Adetan (2002) using the knowledge of compressive strength properties of the roots to develop an experimental mechanical peeling machine. This peeling concept was found to be invaluable, reliable and promising (Adetan *et al.*, 2006) as no useful flesh loss was recorded. However, some of the roots got crushed during the process of compression. This may be due to the misleading results emanating from the improvised method used in determining the compressive properties of the roots as evidently reported by Ilori and Adetan (2013). Kolawole *et al.* (2007b) earlier determined the strength and elastic properties of the roots similarly with improvised tools and reported a positive relationship between the stress (tensile and compressive) and strain of cassava while Nwagugu and Okonkwo (2009) reported a negative relationship between strength and moisture content. This work was therefore conducted to study the compressive strength properties of cassava roots with a more sensitive equipment in order to enhance a better understanding of the behavior of the roots in compression and particularly to provide data for the development of economical and more efficient cassava processing machines.

2. MATERIALS AND METHODS

Experimental samples used in this study were prepared from fresh tubers of TMS 30572 harvested from the Teaching and Research Farm of the Department of Agricultural Engineering, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria, 12 Months After Planting. Twenty five cylindrical samples of length 60mm and diameter 30mm were used (Kolawole *et al.*, 2007b). The initial moisture content of the samples was first determined with the use of Halogen moisture analyzer. Thereafter, the samples were placed in an oven which had already attained a temperature of 70^{o}C. They were brought out in batches (5 samples per batch) after attaining the desired moisture contents of 50, 55, 60, 65, and 70% (wb) and placed in a desiccators for an hour to allow for moisture equilibration before being used for experimentation. The compressive strength tests were conducted with the Universal Testing Machine (UTM). Cassava samples were set between the upper and lower jaws of the UTM, one at a time and compressed to failure at plunger speeds of 50mm per minute. The force-deformation plots of the tests were automatically generated on the computer attached to the universal testing machine. Data were analyzed using the Origin Lab 8.5.

3. RESULTS AND DISCUSSION

Results of the compressive strength tests are presented in Table 1. A typical (sample) compression curve as recorded in force-deformation coordinate system for the studied cassava variety is shown in Figure 1.

Table 1: Mean Compressive Strength Properties of Cassava

Moisture Content (% w.b)	Peak Force (N)	Energy to Break (Nm)	Peak Stress (N/mm^2)	Young's Modulus (N/mm^2)
50	428.34	4.80	0.61	4.81
55	551.68	6.37	0.78	5.74
60	518.30	4.91	0.73	6.24
65	571.34	5.65	0.81	9.28
70	624.68	6.67	0.88	8.13

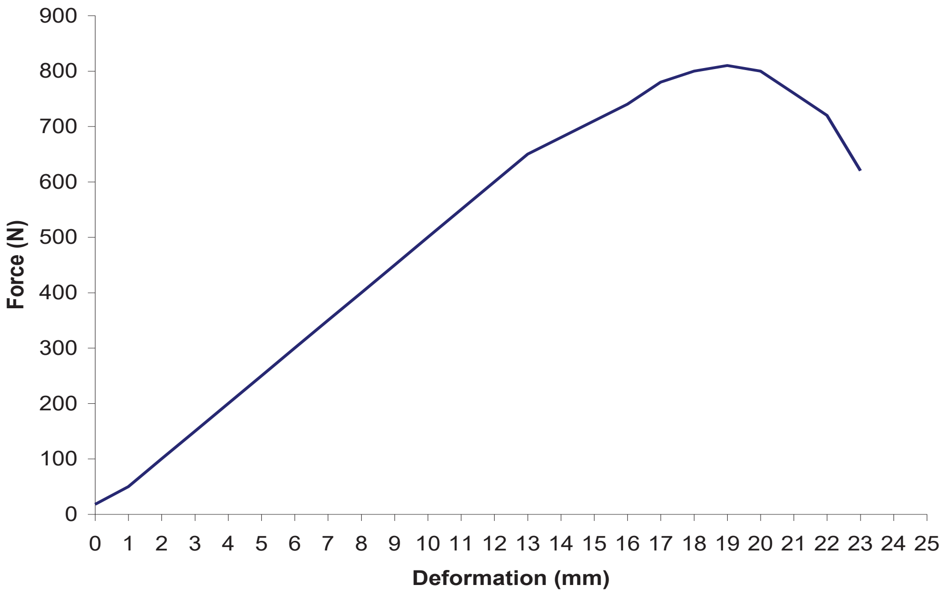

Figure 1: Typical Compression Curve of Cassava Tuber

The curves generally have two major parts, the linear part which corresponds with the limit of elasticity, and the curved part, the crest of which depicts the peak force, from where its corresponding deformation at peak could be determined. The lower part of the curve (to the right) extends, occasionally, irregularly, indicating a yield, and eventually ended with failure. This is evident in the results of the Force and Stress at break which were lower than those of the peak values. This pattern of deformation has been reported for different crops: apple (Rebouillat and Peleg, 1988); cocoa pods (Maduako and Faborode, 1994); sweet cassava (Nwangugu and Okonkwo, 2009) and palm kernel seed (Ozumba and Obiakor, 2011). The stress-strain curve of the compressive strength tests reported by Kolawole *et al*., (2007b) for some tubers of an improved cassava variety (TMS 4(2) 1425 also gave this shape, a linear portion with a downward facing curve that ended with failure.

The mean peak compressive force of the roots, as shown in Table 1, ranged between 428.34 and 624.68 N which correspond to a peak stress of 0.61 and 0.88 N/mm^2 respectively. These values of force at peak are close to the 499 N reported by Nwagugu and Okonkwo (2009) for compressive force along the fibre direction of the sweet cassava root but the stress values are far above the 0.080 – 0.047 N/mm^2 and 0.032 – 0.093 N/mm^2 reported by Kolawole *et al*. (2007b) for tubers of an improved cassava variety. The large variation may be due to the improvised tools used by the latter. Results reported by Ilori and Adetan (2013) for two cassava varieties may not be directly comparable as they worked only with unpeeled cassava roots, although the lower limits of the range of values of compressive force they reported: 504.65 – 1770.19 N for TMS 30572and 428.32 -1721.95 N) for TMS 4(2) 1425 were within the range obtained from this study. Table 1 also shows that, within the moisture content range used in this study, the least peak force and stress were obtained at 50% moisture content (wet basis) while the highest occurred at moisture content of 70%. The peak force and stress also increased rapid from 428.34 N and 0.61 N/mm^2 at 50% moisture content to 551.68 N and 0.78 N/mm^2 respectively when the moisture content of the samples was increased to 55%. It was, however, observed that the strength of the roots reduced slightly 518.30 N (0.73 N/mm^2) when the moisture content was further increased to 60%. Beyond this moisture level, the strength of the samples continued to increase up to 70% moisture content. This means that the molecules of the roots gave in a bit to re-arrange themselves to offer more resistance to increased stress (Baryeh, 1990) at elevated moisture contents. Figure 2 shows that the strength of the roots increased non-linearly with increased moisture content. This perhaps provides a scientific reason for the practice of harvesting the root mostly during the rainy season when the strength increases with each rainfall. The non-linear relationship between root strength (y) and moisture content (x) as depicted in Figure 2 is $y = 0.0175x^3 – 0.1625x^2 + 0.5x + 0.262$ (Equation 1) ($R^2 = 0.9157$).

This is, however, in contrast to the negative and linear relationships reported by Nwagugu and Okonkwo (2009) and Kolawole *et al.* (2007b) respectively for cassava even though the values were within the range reported by the former. Results of the analysis of variance showed that moisture content significantly influenced the strength of the roots ($P<0.05$).

The toughness of the roots, represented by the energy to break, ranged from 4.80 to 6.67 Nm. This followed the same trend as the peak stress, increasing between the moisture content of 50 and 55% but, just like peak stress it decreased slightly at 60% beyond which it increased steadily up to 70%. The non-linear relationship between root toughness and moisture content as depicted in Figure 3 is

$$y = 0.2758x^3 - 2.4039x^2 + 6.3402x + 0.69 \quad \text{(Equation 2)}$$

($R^2 = 0.7414$).

This means that the root is brittle in nature at low moisture content. This perhaps is the reason for the high rate of breakage of the roots when harvested during the dry season when the moisture content of the soil as well as the roots would have reduced considerably. The trend however improves with the advent of rain. The relationship of toughness, as well as other strength parameters (peak compressive stress and stiffness), with moisture content is also shown in Figures 2 – 4 and it is non-linear. The regression equations produced by the graphs suggest a 3rd order polynomial. The influence of moisture content was, however, not significant ($P>0.005$)

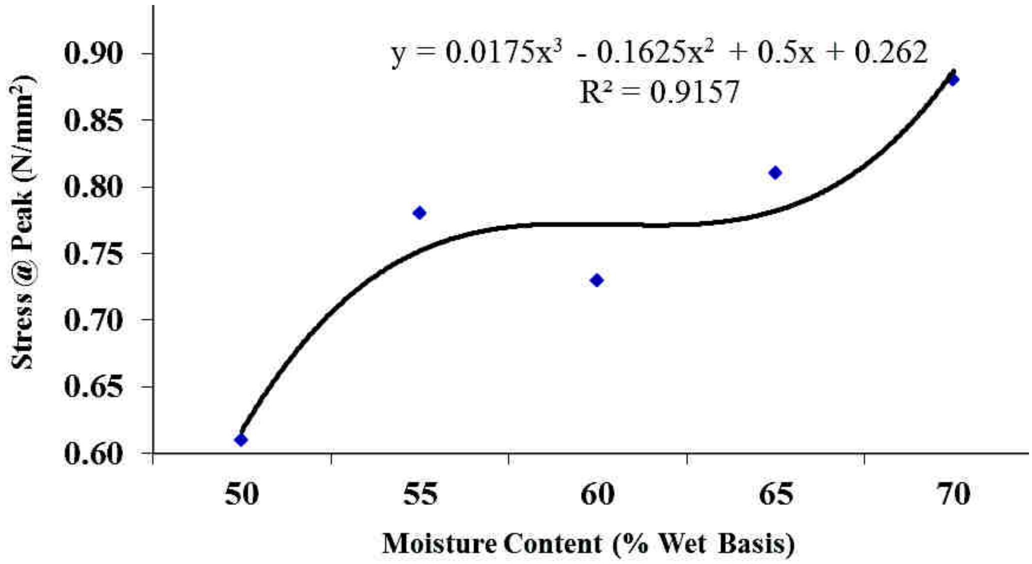

Figure 2: Peak Stress of Cassava Root at different Moisture Content

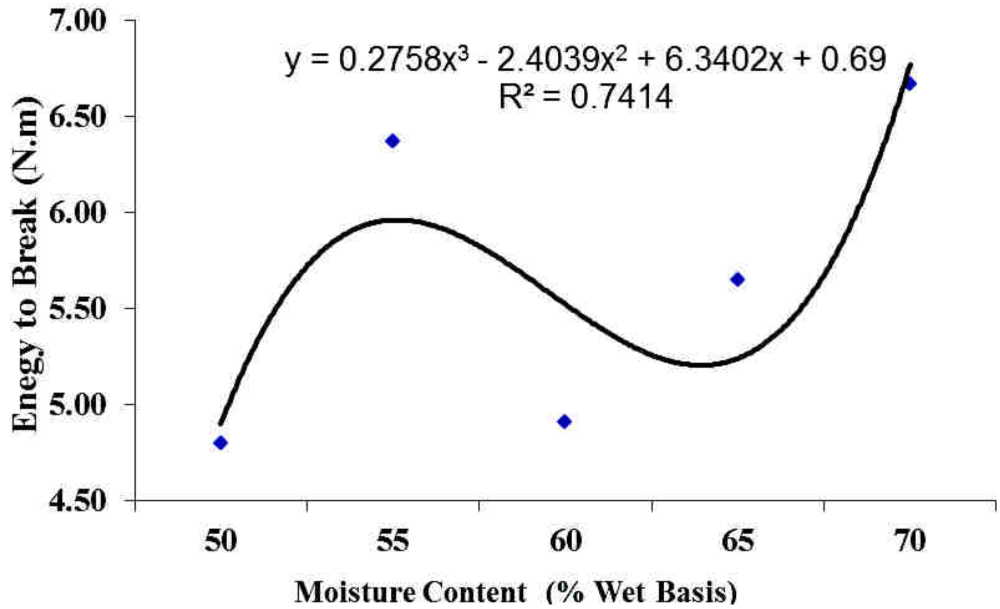

Figure 3: Toughness of Cassava Root with Moisture Content

The stiffness modulus, represented by the Young's modulus of the samples also ranged from 4.81 to 9.28 N/mm^2. It was observed to increase steadily from 4.81 to 6.24 N/mm^2 between moisture contents of 50 and 60% after which it increased rapidly to 9.28 N/mm^2 within the moisture region of 60 and 65% (Figure. 4).

$y = -0.3133x^3 + 2.7043x^2 - 5.6824x + 8.24$ (Equation 3)
$R^2 = 0.899$

Thereafter, it decreased to 8.13 N/mm^2 at 70% moisture content (Table 1). The range of 0.5 – 2.497 N/mm^2 reported by Kolawole *et al*. (2007b) for the stiffness modulus of cassava roots within the same moisture range grossly underestimated the stiffness of the roots. Again, the improvised tools used for conducting their experiments might be responsible for this very wide variation. The influence moisture content on the stiffness modulus of the roots was found to significant.

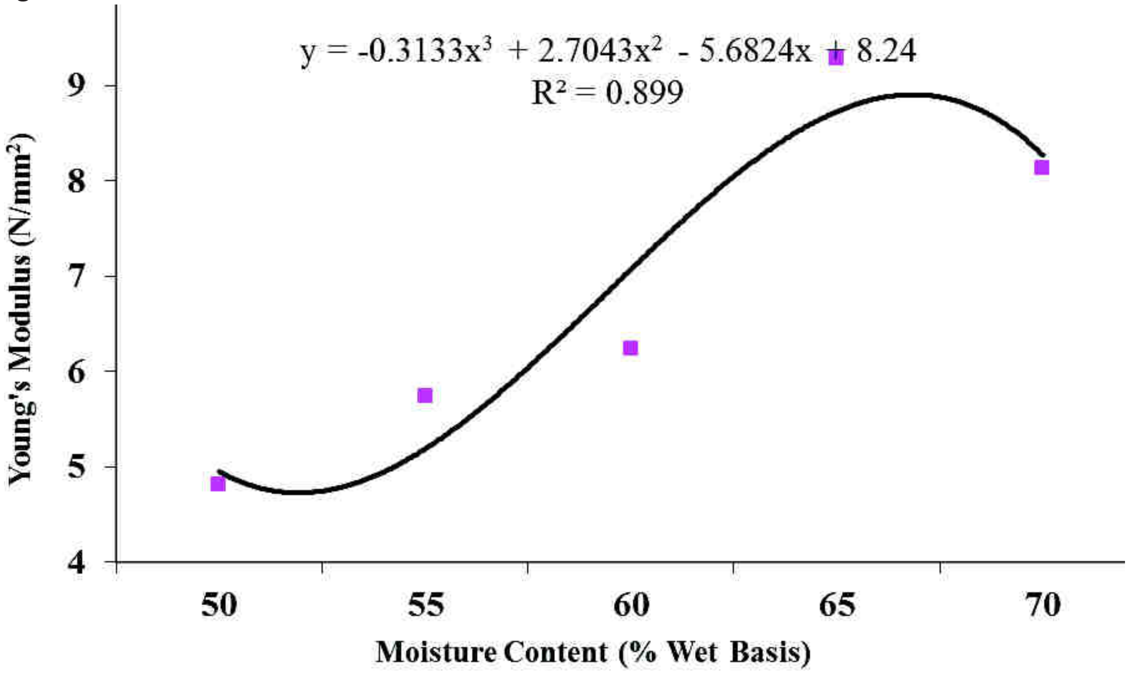

Figure 4: Stiffness of Cassava Root with Moisture Content

4. CONCLUSIONS

This study has shown that the stress at peak, energy to break and the stiffness modulus ranged from 0.61 to 0.88N/mm^2; 4.80 to 6.67Nm and 4.81 to 9.28N/mm^2 respectively, within the range of moisture content studied, which shows that the strength properties of the cassava roots are generally low and they increased with increase in moisture content. The roots also attained a yield point before fracture and the relationship of the strength properties with moisture content is non-linear in nature in contrast with earlier reports. This information would be useful in the design and development of cassava root harvesting and processing machinery.

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