<https://doi.org/10.36293/sfj.2019.0018>

FRictional PROPERTIES OF CASSAVA AS AFFECTED BY ROOT AGE AND MOISTURE CONTENT

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Abstract

Efforts at mechanizing cassava postharvest operations have recorded modest success due to scarce publications on its engineering properties, frictional properties inclusive. This study determined the influence of moisture content (MC), tuber age and variety on Coefficients of Friction (COF), Internal Friction (CIF) and Rolling Resistance (CRR) of two cassava cultivars (TMS 30572 and TME 7) on Stainless Steel (SS), Galvanized Sheet (GS) and Wood Surfaces (WS) at MC of 40 – 60% (wet basis). The roots were harvested at 12, 15 and 18 Months after Planting (MAP). Data were analyzed using ANOVA at $p=0.05$. The COF of TMS 30572 across ages ranged from 0.16 to 0.29, 0.42 to 0.53 and 0.61 to 0.79 on the three surfaces, respectively. TME 7 had the least COF on GS and WS at 15 MAP. The CIF peaked at 15 MAP for all the varieties. On all the surfaces, CRR peaked at 15 MAP for TMS 30572. The CIF decreased while COF increased with increase in MC. Age and MC affected COF and CIF while peel affected CRR. High COF on wood suggested high angle of inclination in wooden storage structures. Low CRR implied that the roots would not slide but roll on all the surfaces.

Keywords: Coefficient of friction, Coefficient of internal friction, Coefficient of rolling resistance, Oko-iyawo, Tuber age

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Introduction

Cassava is a tuberous root crop grown majorly in the tropical regions of the world such as Southern America, Sub-Sahara Africa, and Asia. Its drought tolerance and ability to thrive in marginal soils have been widely acknowledged (Kolawole *et al.*, 2007; Uthman, 2011; Juliati, 2011) and this made the crop a front-liner in global food security discusses.

Cassava is known globally as a cheap source

of calorie in human diet and animal feeds especially in Africa. Currently, it is fast becoming a foreign exchange earner as 60% of cassava output is used for industrial purposes (Olusegun and Ajiboye, 2010). Presently, large quantities of cassava chips are being ordered from Nigeria to Asian countries for industrial uses. In Nigeria, a Federal Government directive on 10% cassava flour utilization in wheat-based baking flour has triggered a serious hike in demand for cassava.

This implies increased cassava production, processing and handling operations which consequently make the mechanization of these processes imperative in order to remove the negative attributes of the traditional processing methods currently in use and promote large scale production under hygienic conditions. Mechanization, however, depends solely on thorough understanding of the engineering properties of the roots such as frictional properties among others. Alonge and Antia 2014 and Irtwange and Igbeka (2002) underscored the importance of frictional properties of fruits and vegetables against machine parts as one of the main causes of mechanical injuries during handling.

Sufficient data have been published on frictional properties of grains, fruits and seeds as a function of moisture content (Alonge and Antia, 2014; Ebubekir, 2015; Pawar *et al.*, 2012 and Simonyan *et al.*, 2008). However, related data for cassava and its products are scanty.

Therefore, it is essential to study the frictional properties of cassava as a function of different factors such as moisture content and variety since cassava features are dependent on genotype (variety) and environmental conditions (Alves, 2002), vis-à-vis moisture content.

Furthermore, processing of cassava roots is very essential to reduce its perishability since it deteriorates within few days after harvesting. The high perishable nature of the roots in the absence of any acceptable modern storage technologies leaves cassava farmers with the only option of leaving the roots in-ground until when needed which promotes easy and flexible harvesting time and year round availability of the crop.

The roots, however, progressively become fibrous and woody with time. The influence of age on root yield, dry matter and starch accumulation, culinary quality of cooked roots, as well as the quality and physico-chemical properties of the starch and flour produced from them have been reported (Chatakanonda *et al.*, 2003; Chotineeranat *et al.*, 2006; Apea-Bah *et al.*, 2011). Kolawole *et al.* (2007b) studied the influence of tuber age on the dewatering parameters of grated cassava mash and concluded that the 15 months old samples compressed more than the 12 and 9 months old samples.

However, other researchers (Ejovo *et al.*, 1988; Adetan *et al.*, 2005) only observed that the tuber age might have influenced their results but no effort was made at studying the effects that the age could actually have on the engineering properties of the tubers, hence, the aim of this study was to determine the coefficients of friction (COF), internal friction (CIF) and rolling resistance (CRR) of two cassava varieties at three different ages and as a function of moisture content.

Materials and Methods

Two cassava cultivars were used for the study namely TMS 30572 and TME 7. TMS 30572 is an improved variety while TME 7 is a local cultivar known as *oko iyawo* which is very popular among cassava farmers in the South Western part of Nigeria.

The stems of the improved cultivar were obtained from the International Institute for Tropical Agriculture (I.I.T.A), Ibadan while the local cultivar was locally sourced and planted at the Teaching and Research Farm of Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, Nigeria to ensure that the actual harvesting periods to be investigated were adhered to.

The samples used for the experiments were prepared from freshly harvested roots at 12, 15 and 18 Months after Planting (MAP). The roots used were cleaned, carefully peeled, cut manually into sizes and their initial moisture content determined using an OHAUS MB 35 Halogen moisture analyzer. Thereafter, the samples were placed in a DHG 9101.1SA (UK) oven which had already attained a temperature of 50 °C for conditioning to the desired moisture content and brought out in batches after attaining moisture contents of 40, 45, 50, 55, and 60% (wb) then placed in a desiccator for about an hour for moisture equilibration before being used for experimentation.

The coefficient of friction of the chips was determined using the inclined plane with adjustable top. Cassava chips of size $30 \times 20 \times 10 \text{ mm}^3$ (Chijindu *et al.*, 2008; Palaniswami and Peters, 2008; Tunde-Akintunde and Afon, 2009) was placed on the table and tilted until sliding occurred. The angle at which this occurred was noted and recorded. The tangent of this angle gave the coefficient of friction of the chip (Raji and Ahemen, 2008). This experiment was replicated five times each and the values averaged. This was done on stainless steel, galvanized sheet and wood surfaces.

The coefficient of internal friction of cassava tubers was determine using chip samples of size $30 \times 20 \times 10 \text{ mm}^3$. A big wooden frame of size $30 \times 20 \times 10 \text{ cm}^3$ and a smaller guide block of size $20 \times 10 \times 10 \text{ cm}^3$ were filled with chip samples and the smaller frame placed atop the bigger. A light chord attached to the smaller frame was passed over a frictionless pulley. The other end of the chord bored the scale pan. Weights were then added to the scale pan until sliding occurs.

The weight (W_1) causing the sliding was noted

and recorded. The smaller block was then emptied and placed back on the bigger frame and the experiment repeated. The weight (W_2) causing sliding of the empty frame was also noted (Raji and Ahemen, 2008). The coefficient of internal friction was then calculated as;

$$\mu = \frac{W_2 - W_1}{i} \quad (1)$$

where, W is the weight due to the sample materials in the cell given by the product of the volume of cell (cm^3) and the bulk density (g/cm^3) and μ is the coefficient of internal friction. Five replicates of each experiment were produced at each moisture level.

The Coefficient of Rolling Resistance (CRR) was determined using 60mm long samples cut out from the straight portions of the roots. Each sample was carefully placed on an inclined plane with adjustable angle of inclination (tilting top).

The angle of inclination of the top part of the table was then raised, with the specimen on it, until the tuber started rolling down the plane. The angle at which this occurred was measured and recorded (Ejovo *et al.*, 1988). This was done using the periderm, the cortex, and the tuber flesh in turns against stainless steel, galvanized sheet and wood surfaces. Each measurement was replicated five times for each variety of cassava and the values averaged. The coefficient of rolling resistance was calculated from the formula,

$$\mu = R \tan i \quad (2)$$

Where R is the average radius of the tuber and i is the angle of inclination at the start of rolling.

Coefficient of friction

The means of the Coefficient of Friction (COF) of the cassava roots on the three surfaces of stainless steel, galvanized sheet and wood are presented in Table 1.

Results and Discussion

Table 1: Mean Coefficient of Friction of Cassava Cultivars with Tuber Age

		TMS 30572				TME 7		
Surface	MC	12mths	15Mths	18mths		12mths	15Mths	18mths
	40	0.20a	0.23a	0.16a		0.21a	0.18a	0.18a
Stainless	45	0.21ab	0.25a	0.17b		0.22ab	0.19a	0.20a
Steel	50	0.23b	0.26b	0.18bc		0.23abc	0.21b	0.21a
	55	0.26c	0.28b	0.19cd		0.24bc	0.23c	0.21a
	60	0.28d	0.29b	0.20d		0.25c	0.25c	0.23a
	40	0.42a	0.44a	0.45a		0.43a	0.37a	0.39a
Galvanized	45	0.45ab	0.45a	0.46ab		0.47ab	0.39a	0.43b
Steel	50	0.46bc	0.47a	0.47ab		0.49ab	0.42b	0.45b
	55	0.52c	0.49a	0.48bc		0.53bc	0.46c	0.47c
	60	0.53c	0.51a	0.50d		0.55c	0.48d	0.49d
	40	0.61a	0.68a	0.65a		0.61a	0.58a	0.68a
	45	0.67ab	0.71ab	0.66ab		0.62a	0.60b	0.75b
Wood	50	0.69bc	0.74bc	0.67ab		0.67a	0.63c	0.79bc
	55	0.74bd	0.78c	0.68bc		0.75b	0.66d	0.83cd
	60	0.76d	0.79c	0.71c		0.78b	0.70e	0.89d

*Means with same letter(s) across rows (along column) are not significantly different at $p < 0.05$

Table 1 show that the COF of TMS 30572 increased from 12 to 15 MAP and later declined at 18 MAP. The graph of COF of TMS 30572 on stainless steel surface over the period of study with the regression equation of each of them is presented in Figure 1.

It shows that the COF increased with increase in moisture contents at all ages even though the 15 MAP samples gave the highest. This may be due to the fact that the moisture made the starchy surface of the samples to become stickier thereby increasing the force of adhesion between the surface of the samples and that of the stainless steel as the samples' moisture content increased. Besides, cassava starch is known to have high swelling power (Nwokocha *et al.*, 2009) in water which

results in increased surface area of its granules coupled with the fact that this is the peak starch production age (Ngedahayo and Dixon, 1988), thereby making the surface of the 15 months old samples to stick best, consequently producing the highest COF.

The lowest COF obtained at 18 months is simply attributable to the reduced starch deposit in the flesh as the plant age exceeded 15 months. The range of values of COF (0.16-0.29) was however in good agreement with that (0.213) reported by Ejovo *et al.* (1988) for cassava flesh on aluminum. The slight difference may be due to age, moisture content and different cassava varieties used in the two studies as well as differences in the structural composition of aluminum and

Figure 1: Coefficient of friction of TMSs 30572 on stainless steel surface

The COF as affected by moisture content on galvanized sheet as presented in Figure 2 also shows a positive linear relationship. However, the COF only increased with age at low moisture content up to about 50% (wb) beyond which the highest COF were obtained at the age of 12 months while the lowest were obtained from 18 months old samples. The combination of the effects of fibre formation and the level of starch available at the surface of the samples may be responsible for this

behaviour. The least value of coefficient of friction of TMS 30572 on galvanized sheet surface (0.42) was, however, higher than the 0.364 reported by Ejovo *et al.* (1988) for cassava flesh (unspecified cultivar) on mild steel at 72% moisture content thereby making comparison difficult. The high R^2 values (0.975-1) show that the linear equations perfectly explain the relationship that exists between the COF and moisture content of the samples.

Figure 2: Coefficient of friction of TMS 30572 on galvanized sheet

Also, Figure 3 shows that the coefficient of friction of TMS 30572 on wood surface increased with increase in moisture. The COF values were generally highest at 15MAP and lowest at 18MAP except at moisture contents below 45% where the 12 months old samples gave the lowest COF. At 45% moisture content, the coefficient of friction was the same for both 12 and 18 months old cassava samples, beyond which the 18 months old samples exhibited the lowest coefficient of friction while the values of the 12 months old samples increased steadily approaching those of the 15 months old. The same factors responsible for the behaviour on galvanized sheet may have caused this. Expectedly, the

values of the COF on wood were the highest, while those on stainless were the least, due to the difference in the degree of smoothness of the surfaces, wood being the least smooth. The lowest COF value (0.61) on wood obtained in this study is however slightly higher than the 0.404 reported by Ejovo *et al.* (1988) for cassava flesh on wood while the highest COF value (0.76) is also slightly higher than the 0.68 used by Bangboye and Adebayo (2009) in designing a cassava chipping machine. Influence of tuber age and moisture content was found to be statistically significant ($P < 0.05$) on the three surface for TMS 30572 cultivar.

Figure 3: Coefficient of friction of TMS 30572 on wood surface

The COF of TME 7 (*Oko iyawo*) on stainless steel surface at the ages of 12, 15, and 18 respectively is presented in Figure 4 while the mean are as presented in Table 1. It shows that the values of the COF were lowest at the 18MAP and highest at 12 MAP within the range of moisture content studied, indicating that the COF decrease with increase in tuber age. It, however, increased with increase in the moisture contents of the samples (Figure 4). The high R^2 values of the graphs strongly suggest a linear relationship between the COF and moisture content.

The behaviour of the samples across age with respect to COF suggests that the younger the tubers and the higher the moisture content the

higher the coefficient of friction. This may be a pointer to the fact that the fibres of the roots of this variety of cassava (TME 7) matures earlier and produces most of its starch within the first 12 months which probably led to a high adhesive force between the surface of the samples and the very smooth surface of the stainless steel while a low level of starch at older age in spite of more woody fibre may be responsible for the lowest COF values obtained at the 18th month as the effects of the rough fibers of the tubers at 18 MAP was unable to offset that of the strong adhesive strength between the 12 months old samples and the stainless steel surface.

Figure 4: Coefficient of friction of TME 7 on stainless steel surface

Figure 5 shows that the coefficient of friction of this TME 7 cassava cultivar increased with increase in moisture content on galvanized sheet and it was highest at the age of 12 but lowest at 15 months old – a slight shift from what was observed on stainless steel. This may be due to the influence of the interactions of the micro-structures of the biomaterials (cassava samples) and galvanized sheet. The range of values of the coefficient of friction of this cassava variety on galvanized sheet (0.37-0.55) are in agreement with the range (0.34-0.48) reported by Raji and Ahemen (2008) for *Tacca tuber* on galvanized, especially for the 15 months old samples.

The range of values of coefficient of friction of *TME 7* on wood at 12 months was 0.61 – 0.78. The corresponding values at 15 month was 0.58 – 0.70, while it was 0.68 – 0.89 at 18 months (Table 1). Figure 6 shows the graph of the coefficient of friction of TME 7 on wood surface across the ages studied. These values were well above the range (0.49-0.56) reported by Raji and Ahemen (2008) for another tuber (*Tacca tuber*) on wood surface. Also, the COF being reported here for the local cassava variety (TME 7) on the three surfaces were generally higher than those reported for aluminum, mild steel and galvanized sheet by Ejovo et al. (1988).

Figure 5: Coefficient of friction of TME 7 on galvanized sheet surface

The coefficient of friction of TME 7 on wood surface were the highest (out of the two varieties used) ranging between 0.68 and 0.89 across all the ages and moisture contents studied, and this was obtained at the age of 18 months. The effect of age and moisture content on coefficient of friction of this cultivar on wood surface (and the two other surfaces) over the range of ages studied was found to be highly significant ($P < 0.05$). However, out of the two varieties of cassava studied, the 30572 cultivar had the lowest COF on stainless steel surface (at 12 MAP) at low (40%) moisture content and the highest COF when the moisture content was raised to 60%. It also had the highest COF at 15 MAP on all the three structural surfaces used

irrespective of the moisture content of the samples. It, however, had the least COF on stainless steel and wood at 18 MAP. TME 7, however, had the highest COF at 12 and 18 (Table 1). This suggests that cassava has a strong genetic component with some characteristics inherent to each of the cassava varieties as reported by Sriroth *et al.* (1999) for cassava tubers and Ngeve (1995) for cassava starch, which by extension may affect the granule structure and granule size distribution which interact with the granules of the surfaces (wood, stainless steel and galvanized sheet) that resulted in the observed frictional behaviour

Figure 6: Coefficient of friction of TME 7 on wood surface

Coefficient of internal friction

The coefficient of internal friction (CIF) of TMS 30572 ranged from 0.57-0.44 at 12 MAP, the corresponding values at 15 MAP

ranged from 0.64 to 0.51, while the values at 18MAP ranged from 0.59 to 0.51, respectively over the same range of moisture content (Table 2).

Table 2: Mean Coefficient of Internal Friction of Cassava with Age

MC (%)	TMS 30572				TME 7		
	12 mths	15 mths	18 mths		12 mths	15 mths	18 mths
40	0.57b	0.64c	0.59d		0.58b	0.61c	0.56b
45	0.56b	0.62c	0.56cd		0.57b	0.60bc	0.54b
50	0.56b	0.56b	0.54bc		0.54b	0.59bc	0.54b
55	0.46a	0.52a	0.53ab		0.41a	0.58ab	0.52ab
60	0.44a	0.51a	0.51a		0.40a	0.56a	0.50a

*Means with same letter(s) across rows (along column) are not significantly different at $p < 0.05$

Generally, the highest CIF were obtained at the age of 15MAP while the lowest were obtained at 12 months old. However, as the moisture content approached 60%, the 18 months old samples gave the highest CIF (Figure 7). The 18 months old samples shared the same CIF with the 12 and 15 months old sample when the moisture content was about 42% and 58%, respectively. This suggests that moisture contents of 42 and 58% (wb) are critical to the influence that age could have on the internal coefficient of friction of the TMS

30572 cassava cultivar. The plot of the relationship between the CIF and moisture content (Figure 7) shows a negative linear relationship exists irrespective of the age of the tubers. This may be due to the ability of moisture to reduce the friction between two surfaces such that every increase in moisture is accompanied by a reduction in the CIF, hence, as the moisture content increased the friction between the surfaces of the cassava samples decreased.

The age 15 months at which the highest coefficient of internal friction was obtained could be due to the level of starch available at the two contacting surfaces which was expected to be at the peak at this age and the lowest values which were obtained from the 12 months old samples may be due to the

tenderness of the fibers of the roots at that early age coupled with the relatively low starch content of the tubers at this developmental stage.

Figure7: Coefficient of internal friction of TMS 30572 at different moisture contents across ages

The coefficient of internal friction of TME 7 ranged from 0.40 to 0.58 at 12 MAP, the corresponding CIF at 15 MAP ranged from 0.56 to 0.61 while the range was 0.50 to 0.56 at 18 MAP respectively (Table 2). The variation of the CIF across ages is presented in Figure 8. It shows that the CIF values peaked at the age of 15 months beyond which it declined as the tubers grew older. This trend is similar to that observed with TMS 30572. The same reasons adduced for 30572 sufficed for this. The plot of CIF against moisture content shows that the

CIF was highest at 15 months and lowest at 12 months at moisture contents above 45% (wb), while the 18 months old samples had the least coefficient of friction at moisture contents below 45% (Figure 8). The results of the ANOVA across ages showed that the influence of age and moisture content on the coefficient of internal friction of the three cassava varieties was very significant ($P < 0.05$). TME 7 generally produced the least CIF.

Figure 8: Coefficient of internal friction of TME 7 at different moisture contents across Ages.

Coefficient of rolling resistance

The values of coefficient of rolling Resistance (CRR) of roots of TME 30572 were generally

the highest when the periderm was used on all the three surfaces at each age while the flesh of the tubers gave the least CRR (Table 3).

Table 3: Average Coefficient of Rolling Resistance on Different Surfaces

	Surface	12 months			15 months			18 months		
		Stainless	Galvanize	Wood	Stainless	Galvanize	Wood	Stainless	Galvanize	Wood
TMS 30572	Periderm	0.14a	0.22a	0.25a	0.24a	0.33a	0.41a	0.14a	0.18a	0.20a
	Cortex	0.10ab	0.16ab	0.21ab	0.22a	0.27ab	0.36ab	0.11ab	0.14ab	0.17a
	Flesh	0.08b	0.12b	0.15b	0.17b	0.23b	0.27b	0.08b	0.11b	0.12b
TME 7	Periderm	0.15a	0.26a	0.31a	0.15a	0.23a	0.29a	0.17a	0.21a	0.30a
	Cortex	0.13a	0.19b	0.28a	0.12b	0.20a	0.24ab	0.14b	0.15b	0.24b
	Flesh	0.08b	0.14b	0.19b	0.07c	0.13b	0.19b	0.09c	0.12c	0.21c

*columns with same letter are not significant different at $p < 0.05$

Also, the over – all highest CRR were obtained when the periderm was used on wood and the least obtained with the flesh on stainless steel surfaces. This also applies to the roots of the TME 7 cultivar. This is in strong support of the report of Ejovo *et al.* (1988). It is due to the high degree of roughness of the periderm compared to the cortex and the flesh likewise the high degree of roughness of the wood compared to the other two surfaces. In addition, the CRR values vary with the age of the tubers as it increased from 12 MAP to reach the peak at 15 MAP before declining to values that were lower than those of 12 months old samples, especially on galvanized sheet and wood. Expectedly, the highest value of the CRR (0.41) was obtained on wood at the tuber age of 15 MAP while the least value (0.08) was obtained on stainless steel surface at both 12 and 18 MAP. This may not be unconnected with the size of the tuber at each stage of development of the crop as the results of the CRR tends to follow the same trend as that of the physical properties tests reported by Oriola and Raji (2013) which showed that the sizes of the tubers were highest at 15MAP and, expectedly, the inertial of the tubers would vary with size. These values of CRR as presented in Table 3 are, however, quite low to those reported by Eovo *et al.* (1988) which ranged from 6.00 to 8.73 and averaged 7.66 on wood. Varietal differences coupled with environmental conditions at the time of harvest may be responsible for this. Influence of age and coverings (periderm, cortex and flesh) on the three surfaces were found to be highly significant for TMS 30572.

The mean CRR of TME 7 on the three surfaces used in this study are as present in Table 3. The mean coefficient of rolling resistance of the periderm on stainless steel increased from the age of 12 months old up till 18 months ranging from 0.15 at 12 months to 0.17 at 18 months old. The values however, decreased

steadily with age on galvanized sheet and wood but with higher CRR values (0.26-0.19) on galvanized sheet and (0.30-0.29) on wood.

The variations in the behaviour as noticed in this cultivar compared to the others could be the due to the influence of characteristics inherent to this variety. The CRR value of the cortex of the tubers against stainless steel surface was highest at 18 months and least at 15 months old. It however, peaked at the age of 15 months and least at 18 months on galvanized sheet surface.

The CRR of the flesh on stainless steel were also least at 15 months and highest at 18 months. The CRR of the flesh on galvanized sheet, however, declined steadily with age while it was least at 15 months and highest at 18 months on wood. Again, the influence of interactions of the size and size distribution of the starch granules of cassava on one hand, and the interaction of this micro-structure and that of the grains (micro structure) of the structural surfaces on the other is suspected to be responsible for the undefined frictional behavioral pattern observed.

Results of the analysis of variance showed that the influence of age on the coefficient of rolling resistance of this cassava cultivar is not statistically significant on any of the three surfaces. However, results of the ANOVA test for the effects of tuber coverings (periderm, cortex and flesh) on CRR of TME 7 on the three surfaces showed that it has a strong influence on all the surfaces (Table 3).

Conclusions

TME 7 had the least coefficient of friction on galvanized sheet and wood at 15 MAP. The coefficient of internal friction peaked at 15 MAP for the two cassava varieties. The coefficient of internal friction decreased while coefficient of friction increased with

increase in moisture content. On all the surfaces, coefficient of rolling resistance peaked at 15 MAP for TMS 30572 and decreased on stainless steel and wood surfaces for TME 7 at this same age. Age and moisture content significantly affected coefficient of friction and coefficient of internal friction while peel (periderm) significantly affected coefficient of rolling resistance.

High coefficient of friction on wood suggested high angle of inclination in wooden container design and storage structures. Low coefficient of rolling resistance implied that the roots would not slide but roll on all the surfaces.

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