Frictional Properties of Canarium Schweifurthii Engl. Fruits and Their Interaction with Moisture Content and Shape

J. C. Ehiem, V. I. O. Ndirika, G. S. Vijaya Raghavan

Abstract— **The effect of shape and moisture content on frictional properties (angle of repose, coefficient and angle of internal friction) of three varieties of *canarium schweifurthii engl* fruits (small, large and long varieties) were studied at five moisture content levels: 40.9%, 34.9%, 23.4%, 18.5% and 11.0% wb, so as to design and develop bulk handling and mechanical processing equipment for the fruits. This will replace and overcome conventional method and its associated problems. Coefficient of friction on different material surfaces (plywood, metal and glass) was also investigated. The results obtained revealed that moisture content and shape were negatively correlated to frictional properties. Coefficient and angle of static friction of *Canarium Schweifurthii* small and long varieties increased linearly with decrease in moisture content and shape. The surface of long variety of *Canarium Schweifurthii* ($CSHT_L$) is rougher and slightly round, while the small variety is smoother and less round in shape. Besides, friction on material surfaces increased with decrease in moisture content. Metal surface had the highest rough surface with *canarium schweifurthii* fruits for all the varieties and surfaces studied. Moisture content and shape also influenced angle of repose significantly ($p<0.05$) while *canarium schweifurthii* small fruits ($CSHT_s$) had the highest pile angle. Frictional properties of *canarium schweifurthii* fruits differ significantly *($p<0.05$)* with the varieties.**

Index Terms— **Coefficient, friction, moisture content, roundness.**

I. INTRODUCTION

Canarium schweifurthii plant is a tree crop that belongs to the family of ***Burseraceae.*** The English name is ***African bush candle.*** It is grown widely in the equatorial forest region of East, West and Central Africa [1]. In Nigeria, it is mostly grown in the south east part of the country. It has low fertility and moisture demand of about 900 – 2200 mm rainfall annually. The tree grows up to 40 -50 m tall with straight and cylindrical shape of about 4.5 m diameter above the heavy swollen roots. The tree produces edible fruits which contains 20.43% crude protein, 23% crude fat, 0.75% crude fiber, 20.10% carbohydrate, 11.8% cellulose and 3.25% ash [2]. The fruit pulp and kernel contain about 30 to 50% oil [4], which are used industrially to manufacture shampoo and waxes, and pharmaceutically to produce drugs for treatment of wounds and microbial infections.

Handling, processing and storage of these fruist are conventionally done which has resulted in postharvest losses of about 40% annually [3]. Technological handling, processing and storage of *canariun schweifurthii engl* fruits is necessary to enhance their shelf life and overcome the problems associated with conventional processing techniques. Adequate knowledge of the magnitude of frictional force existing between the products and material surfaces is required to design and develop suitable equipment for this purpose.

It offers solution to challenges of flow of bulk agricultural product experienced during handling process. For instance, coefficient of internal friction and angle of friction are useful in estimating the chute and conveyor angle of inclination in order to maintain free flow of product materials through the handling equipment [6]. They are also useful for calculating the power requirement for transporting the products. Storage bins and their wall are affected by lateral and vertical pressures due to internal frictional force between product to product and product to storage bin walls. During filling and emptying of storage bin, the knowledge of coefficient of internal friction is important when estimating the product flow rate and quantity required to fill a given storage bin. Repose angle known as the angle which a heap of product makes with the horizontal base is a function of coefficient of internal friction between product surfaces in contact and shape. Angle of repose is very important in filling of flat storage facility when grain is not piled at a uniform bed depth [7] and in calculating belt conveyor with quantity of product that can fill a bin [8].

Many research work has been reported on frictional properties of agricultural products: three canola seeds (orient, Hyola and SLM); sunflower seeds at moisture range of 10 – 18% wet basis; simarouba fruit and kernel; two varieties of corn (Sc 704 and De 370) on three surfaces (metal, plywood and plastic); African yam bean; oil bean seed on five different [9 - 14] respectively. For all these reports, no information has been presented on the influence of moisture and shape on friction properties of *canarium schweifurthii* fruits. The aim

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of this work therefore is to determine the effect of shape and moisture content on the frictional properties of *canarium schweifurthii engl* fruits relevant for bulk handling and mechanical processing and compare the properties of three varieties.

II. MATERIALS AND METHODS

Three varieties of *canarium schweifurthii engl* fruits (*canarium schweifurthii small* ($CSHT_S$), *canarium schweifurthii large* ($CSHT_L$) and *canarium schweifurthii* ($CSHT_{LG}$)) used for this study were purchased from Ebonyi State (6° 15' N 8° 05' E) state of Nigeria. The fruits were cleaned of all foreign materials and stored in refrigerator for two days to attain uniform moisture content. The samples were conditioned to five different moisture levels using oven dry method. Moisture content wet basis was calculation as shown below, [11]:

$$M.C._{w.b} = \frac{M_1 - M_2}{M_1} \times 100 \qquad (1)$$

where: *$M.C._{wb}$ = Moisture content wet basis*; *M_1 = Initial mass*; *M_2 = Final mass.*

Shape of the fruits

The shape of the fruits was determined by measuring the fruits roundness which was obtained by tracing each fruit in its rest position on a transparent paper using a sharp pencil. The radius of inscribed circle at the sharpest corner and the circumscribed circle were measured and areas calculated. Roundness was estimated as:

$$R = \frac{A_p}{A_c} \qquad (2)$$

Where*;* A_p = area of the sharpest corner, A_c = area of the circumscribed circle, R = roundness

Angle and coefficient of internal friction

A topless and bottomless rectangular box of 21.5 cm x 12 cm x 10 cm was filled with *canarium* samples and placed under similar box of 14 cm x 10 cm x 5 cm with samples. Portable electronic scale of 0.01kg accuracy was attached to the top box and was pulled until the box and the content begin to slide. The force that cause the empty box and the box with content to slide were recorded as F_1 and F_2 respectively. Coefficient of internal friction (μ_i) was determined as, (15);

$$\mu_i = \frac{F_2 - F_1}{F} \qquad (3)$$

where: F = force due to sample weight in the box (volume of the box × sample bulk density)

Volume = length × breath × height

Angle of internal friction (φ_i) was calculated as: $\varphi_i = (\tan \mu_i)^{-1}$ (4)

Coefficient of friction on material surfaces:

The same topless and bottomless rectangular box of 14 x 10 x 5 cm was filled with the samples and placed on top of three different material surfaces (metal, plywood and glass). Portable electronic scale of 0.01kg accuracy was attached to the box when empty and when filled with the fruits and pulled until the products begin to move. Coefficient and angle of friction on the material surfaces were calculated as shown in the Eq. 3 and 4 [15].

Angle of repose

Filling method was used to determine the angle of repose. In this method, a box of dimensions 15 cm by 15 cm by 20 cm high with open top and slidable front plate was filled with sample at various moisture contents and gradually the plate was removed, the height to which the resulting pile surface made with the horizontal surface in which it rest was measured and angle of repose (θ) was calculated as:

$$\theta = \tan^{-1}\frac{h}{x} \qquad (5)$$

where, h = height of the inclined plane, x = horizontal surface

The experiment was repeated three times for each sample variety. Excel and GENSTAT statistical packages were used for the analysis.

III. RESULTS AND DISCUSSIONS

Angle and coefficient of internal friction

The values of angle and coefficient of internal friction are summarized in Table 1. Analysis of variance (ANOVA) and regression equations of various varieties at 40.9 to 11.0% moisture content wet bases are presented in Tables 2 and 3 respectively. From Table 1, it was observed that as moisture content decreased from 40.9% to 11.0%, angle and coefficient of internal friction increased from 19.2 - 33.9° and 0.348- 0.672; 46.7 - 69.3° and 1.06- 2.64; and 31.1 - 50.1° and 0.605 - 1.20 for $CSHT_s$, $CSHT_L$ and $CSHT_{LG}$ respectively. It also increased as shape values decreased for all the varieties evaluated Fig. 1a-c. $CSHT_L$ manifested the highest values of angle and coefficient of internal friction, followed by $CSHT_{LG}$ while $CSHT_s$ had the least values for all the moisture levels considered. This result could be because of low shape values which cause the fruits not to roll and at lower moisture content, the grains on *canarium schweifurthii engl* fruit surfaces are sharper making sliding difficult.

Table 1: *Frictional Properties of three varieties of Canarium Schweifurthii fruit at moisture range of 40.9% - 11.0%*

Samples	Moisture Content (% w.b.)	Mass (g)	Angle of Repose (degrees)	Coefficient Of internal friction	Angle of internal friction (degrees)	Coefficient of friction		
						Plywood	Mild steel	Glass
	40.9	4.87	22.5	0.348	19.2	0.539	0.359	0.315
	34.9	3.99	22.7	0.369	20.3	0.566	0.375	0.329
$CSHT_S$	23.4	3.46	36.9	0.384	21.0	0.588	0.395	0.348
	18.5	3.18	48.7	0.447	24.1	0.612	0.413	0.367
	11.0	2.74	60.4	0.672	33.9	0.646	0.453	0.397
	40.9	11.4	12.9	1.06	46.7	1.36	1.17	0.756
$CSHT_L$	34.9	10.3	15.2	1.19	50.1	1.55	1.24	0.896
	23.4	9.18	22.6	1.30	52.5	1.79	1.29	0.984
	18.5	8.51	28.7	1.19	50.1	1.64	1.22	0.873
	11.0	8.04	48.1	2.64	69.3	1.49	1.16	0.819
	40.9	9.68	28.3	0.605	31.2	0.366	0.379	0.292
$CSHT_{LG}$	34.9	8.95	30.1	0.755	37.1	0.497	0.404	0.309
	23.4	7.09	31.8	0.904	42.1	0.546	0.423	0.323
	18.5	6.68	32.0	0.952	43.6	0.609	0.455	0.328
	11.0	6.22	32.8	1.19	50.1	0.662	0.506	0.384

Fishers Least Significant Difference (F-LSD)

Sphericity:
F-LSD (5%) of the difference between two varieties means = 0.02397
F-LSD (5%) of the difference between two moisture content means = 0.1652
Angle of repose:
F-LSD (5%) of the difference between two moisture content means = 0.2555^o
Coefficient of internal friction:
F-LSD (5%) of the difference between two moisture content means = 0.0258
Angle of internal friction:
F-LSD (5%) of the difference between two moisture content means = 0.6262^o
Angle of friction on the materials:
F-LSD (5%) of the difference between two moisture content means = 0.4727^o
F-LSD (5%) of the difference between two material surface means = 0.5825^o

Table 2: *ANOVA summary of frictional parameters of Canarium Schweifurthii engl fruit studied at moisture range of 40.9% - 11.0%*

Source of variation	df	Angle of Repose	Coefficient of internal friction	Angle of internal friction	Surface angle of friction			5%	1%
					Plywood	Metal	Glass		
Samples	2	3.03^{ns}	15.4^{**}	139.7^{**}	248.4^{**}	506^{**}	241.5^{**}	4.46	8.65
Moisture content	4	5.01^{*}	3.68^{ns}	18.5^{**}	3.99^{*}	1.99^{ns}	2.03^{ns}	3.84	7.01
Interaction	4	10.7^{*}	2.94^{*}	0.75^{ns}				2.63	3.89
Error	8								

*** Highly significant; * Significant; ns Not significant*

Table 3: *Regression equations for frictional properties of Canarium Schweifurthii engl fruit at moisture range of 40.9% - 11.0%*

	$CSHT_S$		***$CSHT_L$***		***$CSHT_{LG}$***	
Parameters	Regression equation	R^2	Regression equation	R^2	Regression equation	R^2
Angle of Repose (degrees)	$0.032h^2 - 3.049h + 91.19$	0.99	$0.050h^2 - 3.746h + 82.36$	0.99	$-0.004h^2 + 0.076h + 32.30$	0.99
Coefficient of internal friction	$0.045h + 1.071$	0.96	$0.003h^2 - 0.230h + 4.586$	0.85	$-0.42\ln(h) + 2.204$	0.98
Angle of internal friction (degrees)	$0.029h^2 - 1.984h + 51.57$	0.96	$0.041h^2 - 2.747h + 92.28$	0.82	$0.579h + 55.73$	0.97
			Angle of surface friction			
Plywood	$0.001h^2 - 0.223h + 35.08$	0.98	$-0.023h^2 + 1.121h + 46.50$	0.96	$-0.004h^2 - 0.154h + 35.49$	0.96
Mild steel	$-3.41\ln(h) + 32.47$	0.99	$-0.012h^2 + 0.665h + 43.18$	0.93	$-4.44\ln(h) + 37.40$	0.98
Glass	$0.002h^2 - 0.281h + 24.36$	0.99	$-0.025h^2 + 1.263h + 27.87$	0.88	$0.005h^2 - 0.421h + 24.67$	0.93

h = moisture content

Dissimilar observation has been reported for African yam bean at 4 – 16% *wb* moisture levels [15]; sunflower seed at 10-18% *wb* [10]; canola seed at 5.27-23.69% *wb* [9]. This could be because the above products do maintain their surface smoothness and shape even at lower moisture content. Higher values of $CSHT_L$ may also be due to weight which added to their inertia. Regression analysis revealed that these properties had high coefficient of determination (R^2) as shown in Table 3. The ANOVA of Table 2 presented a highly significant difference (5%) for both frictional parameters for all the varieties studied. Besides, F-LSD test at 5% also showed that moisture content had no significant effect on the angle of internal friction.

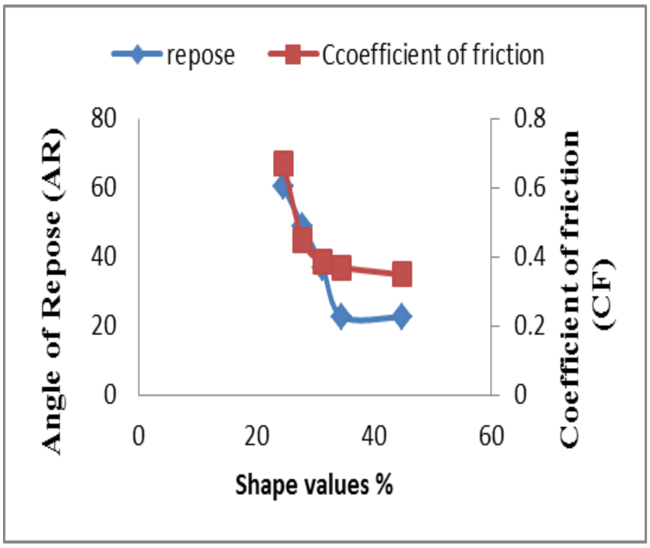
Coefficient of friction on material surfaces

Coefficient of friction on material surfaces: metal sheet, plywood and glass for various *canarium schweifurthii* fruits are presented in Table 1. It was seen from the table that the coefficient of friction of all the varieties had linear relationship with moisture content except $CSHT_L$ fruits on metal sheet, plywood and glass surfaces that exhibited polynomial behavior. Many researchers have investigated the static coefficient of friction of agricultural products on different material surfaces and reported similar linear behaviors for Fenugreek, caper seed, three varieties of sorghum and edible squash (*Cucurbita pepo* L.) [16 - 19]. Coefficient of static friction between the fruits and material surfaces increased with decrease in moisture content. For instance, $CSHT_s$, $CSHT_L$ and $CSHT_{LG}$ increased by 13.8%, 18.9% and 19.2%; 4.61%, 5.75% and 16.7%, and 35.6%, 22.6% and 22.6% for metal sheet, plywood and glass surfaces respectively. This could be probably due to high surface roughness of the fruits as their moisture content get lower. This result was not in agreement with the findings for canola and sunflower seeds [9 - 10], because, canola and sunflower seeds maintain their surface smoothness at lower moisture content. The static coefficient of friction against metal sheet was the greatest (1.79) for all the moisture levels studied while glass is the least (0.292). Among the varieties, $CSHT_L$ presented the highest value of static coefficient of friction for all the material surfaces studied, followed by $CSHT_{LG}$ while $CSHT_s$ is the least. The ANOVA of Tab. 2 showed that static coefficient of friction between sample varieties and material surfaces are highly significant at both 5% and 1% levels. Besides, moisture content affected static coefficient of friction against plywood significantly ($p<0.05$) while other surfaces are not. Regression equation in Table 3 revealed high coefficient of determination showing good fit.

Angle of repose

The average values of repose angle at various moisture levels studied are shown in Table 1 while the relationship between shape and angle of repose for all the varieties are presented in Figures 1a-c. Angle of repose increased with decrease in moisture content and decreased with increase in shape values for all the varieties studied. $CSHT_s$ had the highest angle of repose (60.4°) at 11.0%*wb* and least shape values, followed by $CSHT_L$ (48.1°) and $CSHT_{LG}$ (32.8°). This could be attributed to the fruits high surface roughness at low moisture content and inability to roll due to low shape values resulting in higher pile than other varieties. Angle of repose against moisture content is significant (5%) while no significant difference exists between the sample varieties, Table 2. Regression analysis of Table 3 showed that angle of repose related linearly with moisture content having high values of R^2. This result is not the same with the observations for sunflower seeds [10], barberry fruits [20] and African yam bean (15). This may be due to high surface roughness of *canarium schweifurthii* fruits as their moisture level decreases which imposes resistance to fruits sliding on one another. This information on coefficient of internal friction and angle of repose will contribute to solving problems of failure associated with lateral pressures on the walls of storage bins and in designing of hopper wall for free flow of products under gravity.

CSHT small

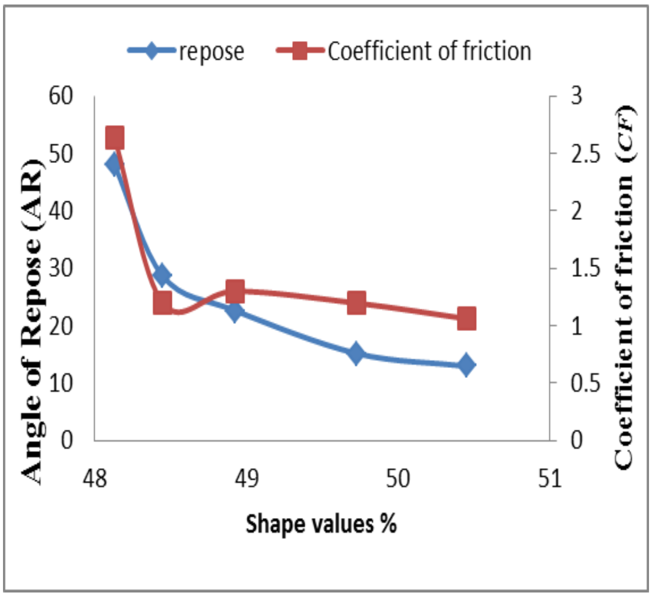


(a)

$$AR_{small} = 0.159Y^2 - 13.04Y + 286.6 \qquad R^2 = 0.977$$

$$CF_{small} = 0.0012Y^2 - 0.129Y + 2.822 \qquad R^2 = 0.921$$

CSHT large

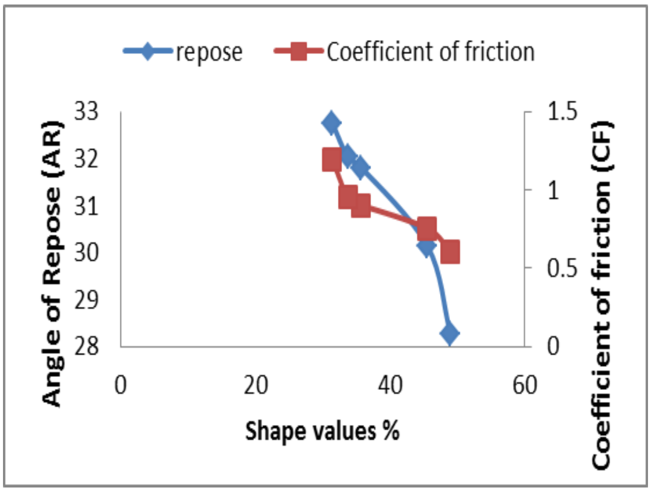


(b)

$$AR_{large} = 0.001\ Y^2 - 0.129\ Y + 2.822 \qquad R^2 = 0.921$$

$$CF_{large} = 0.513\ Y^2 - 51.09\ Y + 1271 \qquad R^2 = 0.661$$

CSHT long



(c)

$$AR_{long} = -0.008\ Y^2 + 0.488\ Y + 25.89 \qquad R^2 = 0.967$$

$$CF_{long} = 0.001\ Y^2 - 0.148\ Y + 4.306 \qquad R^2 = 0.909$$

$$Y = Roudness$$

Fig. 1; *The plot of roudness against angle of repose and coefficient of static friction of canarium schweifurthii engl small fruit (a), large fruit (b) and long fruits (c).*

IV. Conclusions

From the investigation of effect of shape and moisture content on friction properties of *canarium schweifurthii* fruits, it can be concluded that:

1. Coefficient and angle of static friction increased linearly as moisture content and shape values decreased.

a. $CSHT_L$ grains are rougher and slightly round in shape than that of $CSHT_{LG}$ and $CSHT_s$.

2. Coefficient and angle of internal friction of $CSHT_s$, $CSHT_L$ and $CSHT_{LG}$ differ from each other significantly ($p<0.05$).

3. Coefficient and angle of static friction on metal sheet, plywood and glass increased with decrease in moisture content

4. Metal sheet surface is rougher with *canarium schweifurthii* fruits than other studied surfaces, hence, must not be considered during fabrication of hoppers.

5. Moisture affected angle of repose significantly ($p<0.05$) and $CSHT_s$ had the highest pile angle than other varieties.

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