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 fruit are conventionally done which has resulted in postharvest losses of about 40% annually [3]. Technological handling, processing and storage of canarium 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 schwefurthii engl fruits relevant for bulk handling and mechanical processing and compare the properties of three varieties.

II. MATERIALS AND METHODS

Three varieties of canarium schwefurthii engl fruits (canarium schwefurthii small (CSHT₃), canarium schwefurthii large (CSHT₁) and canarium schwefurthii (CSHT₄)) 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 at 105°C 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:

\[ \theta = \tan^{-1} \frac{h}{x} \]  

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 CSHT₃, CSHT₁ and CSHT₄ respectively. It also increased as shape values decreased for all the varieties evaluated Fig. 1-a-c. CSHT₄ manifested the highest values of angle and coefficient of internal friction, followed by CSHT₄ while CSHT, 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 schwefurthii 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%.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Moisture Content (% w.b.)</th>
<th>Mass (g)</th>
<th>Angle of Repose (degrees)</th>
<th>Coefficient Of internal friction</th>
<th>Angle of internal friction (degrees)</th>
<th>Coefficient of friction</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSHT&lt;sub&gt;s&lt;/sub&gt;</td>
<td>40.9</td>
<td>4.87</td>
<td>22.5</td>
<td>0.348</td>
<td>19.2</td>
<td>0.539</td>
</tr>
<tr>
<td></td>
<td>34.9</td>
<td>3.99</td>
<td>22.7</td>
<td>0.369</td>
<td>20.3</td>
<td>0.566</td>
</tr>
<tr>
<td></td>
<td>23.4</td>
<td>3.46</td>
<td>36.9</td>
<td>0.384</td>
<td>21.0</td>
<td>0.588</td>
</tr>
<tr>
<td></td>
<td>18.5</td>
<td>3.18</td>
<td>48.7</td>
<td>0.447</td>
<td>24.1</td>
<td>0.612</td>
</tr>
<tr>
<td></td>
<td>11.0</td>
<td>2.74</td>
<td>60.4</td>
<td>0.672</td>
<td>33.9</td>
<td>0.646</td>
</tr>
<tr>
<td>CSHT&lt;sub&gt;L&lt;/sub&gt;</td>
<td>40.9</td>
<td>11.4</td>
<td>12.9</td>
<td>1.06</td>
<td>46.7</td>
<td>1.36</td>
</tr>
<tr>
<td></td>
<td>34.9</td>
<td>10.3</td>
<td>15.2</td>
<td>1.19</td>
<td>50.1</td>
<td>1.55</td>
</tr>
<tr>
<td></td>
<td>23.4</td>
<td>9.18</td>
<td>22.6</td>
<td>1.30</td>
<td>52.5</td>
<td>1.79</td>
</tr>
<tr>
<td></td>
<td>18.5</td>
<td>8.51</td>
<td>28.7</td>
<td>1.19</td>
<td>50.1</td>
<td>1.64</td>
</tr>
<tr>
<td></td>
<td>11.0</td>
<td>8.04</td>
<td>48.1</td>
<td>2.64</td>
<td>69.3</td>
<td>1.49</td>
</tr>
<tr>
<td>CSHT&lt;sub&gt;LG&lt;/sub&gt;</td>
<td>40.9</td>
<td>9.68</td>
<td>28.3</td>
<td>0.605</td>
<td>31.2</td>
<td>0.366</td>
</tr>
<tr>
<td></td>
<td>34.9</td>
<td>8.95</td>
<td>30.1</td>
<td>0.755</td>
<td>37.1</td>
<td>0.497</td>
</tr>
<tr>
<td></td>
<td>23.4</td>
<td>7.09</td>
<td>31.8</td>
<td>0.904</td>
<td>42.1</td>
<td>0.546</td>
</tr>
<tr>
<td></td>
<td>18.5</td>
<td>6.68</td>
<td>32.0</td>
<td>0.952</td>
<td>43.6</td>
<td>0.609</td>
</tr>
<tr>
<td></td>
<td>11.0</td>
<td>6.22</td>
<td>32.8</td>
<td>1.19</td>
<td>50.1</td>
<td>0.662</td>
</tr>
</tbody>
</table>

Fishers Least Significant Difference (F-LSD)

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
Coefficient of internal friction:
F-LSD (5%) of the difference between two moisture content means = 0.0258

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

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>Angle of Repose</th>
<th>Coefficient of internal friction</th>
<th>Angle of internal friction</th>
<th>Surface angle of friction</th>
<th>5%</th>
<th>1%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samples</td>
<td>2</td>
<td>3.03&lt;sup&gt;**&lt;/sup&gt;</td>
<td>15.4&lt;sup&gt;**&lt;/sup&gt;</td>
<td>139.7&lt;sup&gt;**&lt;/sup&gt;</td>
<td>248.4&lt;sup&gt;**&lt;/sup&gt;</td>
<td>506&lt;sup&gt;**&lt;/sup&gt;</td>
<td>241.5&lt;sup&gt;**&lt;/sup&gt;</td>
</tr>
<tr>
<td>Moisture content</td>
<td>4</td>
<td>5.01&lt;sup&gt;**&lt;/sup&gt;</td>
<td>3.68&lt;sup&gt;**&lt;/sup&gt;</td>
<td>18.5&lt;sup&gt;**&lt;/sup&gt;</td>
<td>3.99&lt;sup&gt;**&lt;/sup&gt;</td>
<td>1.99&lt;sup&gt;**&lt;/sup&gt;</td>
<td>2.03&lt;sup&gt;**&lt;/sup&gt;</td>
</tr>
<tr>
<td>Interaction</td>
<td>4</td>
<td>10.7&lt;sup&gt;**&lt;/sup&gt;</td>
<td>2.94&lt;sup&gt;**&lt;/sup&gt;</td>
<td>0.75&lt;sup&gt;**&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** 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%.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>CSHT&lt;sub&gt;s&lt;/sub&gt;</th>
<th>CSHT&lt;sub&gt;L&lt;/sub&gt;</th>
<th>CSHT&lt;sub&gt;LG&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle of Repose (degrees)</td>
<td>0.032h&lt;sup&gt;2&lt;/sup&gt; - 3.049h + 91.19</td>
<td>0.050h&lt;sup&gt;2&lt;/sup&gt; - 3.746h + 82.36</td>
<td>-0.004h&lt;sup&gt;2&lt;/sup&gt; + 0.076h + 32.30</td>
</tr>
<tr>
<td>Coefficient of internal friction</td>
<td>0.045h + 1.071</td>
<td>0.003h&lt;sup&gt;2&lt;/sup&gt; - 0.230h + 4.586</td>
<td>-0.42ln(h) + 2.204</td>
</tr>
<tr>
<td>Angle of internal friction (degrees)</td>
<td>0.029h&lt;sup&gt;2&lt;/sup&gt; - 1.984h + 51.57</td>
<td>0.041h&lt;sup&gt;2&lt;/sup&gt; - 2.747h + 92.28</td>
<td>0.579h + 55.73</td>
</tr>
<tr>
<td>Plywood</td>
<td>0.001h&lt;sup&gt;2&lt;/sup&gt; - 0.223h + 35.08</td>
<td>-0.023h&lt;sup&gt;2&lt;/sup&gt; + 1.121h + 46.50</td>
<td>-0.004h&lt;sup&gt;2&lt;/sup&gt; - 0.154h + 35.49</td>
</tr>
<tr>
<td>Mild steel</td>
<td>-3.41ln(h) + 32.47</td>
<td>-0.012h&lt;sup&gt;2&lt;/sup&gt; + 0.665h + 43.18</td>
<td>-4.44ln(h) + 37.40</td>
</tr>
<tr>
<td>Glass</td>
<td>0.002h&lt;sup&gt;2&lt;/sup&gt; - 0.281h + 24.36</td>
<td>-0.025h&lt;sup&gt;2&lt;/sup&gt; + 1.263h + 27.87</td>
<td>0.005h&lt;sup&gt;2&lt;/sup&gt; - 0.421h + 24.67</td>
</tr>
</tbody>
</table>

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 may also be due to weight which added to their inertia. Regression analysis revealed that these properties had high coefficient of determination (R²) 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, 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, CSHT, and CSHT 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 presented the highest value of static coefficient of friction for all the material surfaces studied, followed by CSHT while CSHT 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, had the highest angle of repose (60.4°) at 11.0%wb and least shape values, followed by CSHT (48.1°) and CSHT (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 R². 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**

![Graph a](attachment:image1.png)

(a)  

\[
AR_{\text{small}} = 0.159Y^2 - 13.04Y + 286.6 \quad R^2 = 0.977
\]

\[
CF_{\text{small}} = 0.0012Y^2 - 0.129Y + 2.822 \quad R^2 = 0.921
\]

**CSHT large**

![Graph b](attachment:image2.png)

(b)  

\[
AR_{\text{large}} = 0.001 Y^2 - 0.129 Y + 2.822 \quad R^2 = 0.921
\]

\[
CF_{\text{large}} = 0.513 Y^2 - 51.09 Y + 1271 \quad R^2 = 0.661
\]
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**REFERENCES**


