SOME PHYSICAL PROPERTIES OF Taro Cocoyam REVELANT TO THE DESIGN OF ITS PROCESSING MACHINES

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Abstract: Information on physical properties of cocoyam is essential for efficient development of equipment / machines for its processing. In this work, some physical properties of Taro Cocoyam (Colocassia esculenta) were investigated using standard engineering principles. The results revealed that average length, width, thickness and unit mass obtained at the sample moisture content of 70.50 ± 3.8% (w.b.) were 63.67 ± 12.91 mm, 31.88 ± 5.99 mm, 34.27 ± 6.12 mm and 52.65 ± 22.59g, respectively. The values of computed geometric mean, arithmetic mean, square mean and equivalent diameters were 40.88 ± 6.55 mm, 43.27 ± 6.79 mm, 41.88 ± 6.62 mm and 42.01 ± 6.65 mm, respectively. The value of the sample distribution skewness was -0.29. The aspect ratio, sphericity, surface area, volume, solid density, bulk density, porosity and angle of repose were 0.55 ± 0.13 (dec.), 65.46 ± 10.26%, 5384.85 ± 1646.64 mm², 38449.90 ± 16926.30 mm³, 0.0014 ± 0.0003 g / mm³, 0.00085 ± 0.00015 g / mm³, 60.7 ± 8.40% and 32.15 ± 4.51°, respectively. The coefficient of static friction on plywood, glass and galvanized iron surfaces were 0.22 ± 0.045, 0.15 ± 0.045 and 0.19± 0.046, respectively. The values of coefficient of variation for all the parameters, except unit mass, were low. This implies that the data were uniformly dispersed around their average values.

Key words: Physical properties, taro cocoyam, design, processing machines

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In West Africa, Taro Cocoyam, otherwise known as *Colocassia esculenta*, is one of essential root crops (Figure 1), especially in the tropics. Many varieties of cocoyam can give up to 37-75 ton/ha. Taro Cocoyam cormels and corms are good sources of digestible starch, vitamins and minerals [1]. The growing significance of taro cocoyam, other root crops as well as their accessibility to contemporary processing and stowage techniques requires a sound understanding of their engineering properties. However, it is essential to comprehend the physical principles regulating the raw products responses during handling and various unit operations to have better final end products. For example, shape as a physical property, is a very crucial parameter in predicting the behavior of biomaterials under certain stress or loading conditions. This is very useful in the development of various handling and processing equipment [2].

![Fig. 1. Few samples of Taro Cocoyam](image)

A lot of works have been done by many researchers on some physical and engineering properties of seeds, grains, nuts, tuber crops and vegetables so as to offer valuable information which may be used in the development of crop and food processing machines [3, 4, 5, 6]. These physical and engineering properties are geometric mean diameter, sphericity, coefficient of friction, static and dynamic angles of repose, unit mass (weight), specific gravity, volume, aspect ratio, surface area, porosity, bio-yield, true, solid and bulk densities, elastic deformation, hardness, stiffness, compressibility, shear resistance, etc., [7, 8, 6]. Therefore, in order to develop improved Taro Cocoyam processing equipment and vessels, some of these physical properties such as unit mass, size and shape functions [axial dimensions (length, width and thickness), geometric mean, arithmetic mean, square mean and equivalent diameters, aspect ratio, sphericity], surface area, volume, solid density, bulk density, porosity, angle of repose and coefficient of static friction with respect to sample initial moisture content were studied. Nevertheless, food processors and scientists may use these information provided in this study for further works and product development.

**MATERIALS AND METHODS**

Exactly one hundred and fifteen (115) sets of Taro Cocoyam were purchased from Akpan Andem Market, Uyo, Akwa Ibom State. The samples were picked at random, cleaned to eliminate foreign materials such as dust, dirts, wounded or blemished samples and stones.
The initial moisture content of the 10 unpeeled samples was found using gravimetric method \([9, 6, 10]\). Fifty (50) unpeeled samples were chosen and their masses measured using electronic digital weighing balance. Besides, their length (\(L\)), width (\(W\)) and thickness (\(T\)) were measured using digital vernier calipers of 0.01 mm calibration and tape rule as shown in Figure 2. These dimensions were employed in the determination of some physical properties of the unpeeled cocoyam samples using Equation 1 to 15. However, in order to examine the sample size distribution, they were grouped based on equivalent diameter (\(D_E\)), into three size ranges: small \((25.0 \text{ mm} \leq D_E < 35.0 \text{ mm})\), medium \((35.0 \text{ mm} \leq D_E < 45.0 \text{ mm})\) and large size ranges \((45.0 \text{ mm} \leq D_E < 55.0 \text{ mm})\). The mean, standard deviation and coefficient of variation of each property were computed using Data Acquisition Template powered by Microsoft Excel™. Furthermore, based on equivalent diameter (\(D_E\)), skewness of the sample size distribution was also found, and the mean differences (MD) among geometric mean, arithmetic mean, square mean and equivalent diameters were also assessed using analysis of variance (ANOVA) at 5% level of probability.

**Determination of Some Physical Properties of Taro Cocoyam Samples**

(a) Moisture Content (MC) Determination

The initial moisture content of Taro Cocoyam samples was determined using Equation 1.

\[
\% \text{MC}_{wb} = \frac{M_i - M_f}{M_i} \times 100\% 
\]  

(1)

Where,

\(\% \text{MC}_{wb}\) = moisture content (% wet basis),
\(M_i\) = initial mass of the sample (g)
\(M_f\) = mass of the sample at bone dry condition (g).

(b) Sample Size and Shape

Sample geometric mean diameter (\(D_G\)) was calculated using Equation 2 [6]:

\[
D_G = \left( L \times T \times W \right)^{1/3} 
\]  

(2)

Fig. 2. The principal dimensions of Taro Cocoyam sample

Where, \(L\) = sample length (mm),
\(T\) = sample thickness (mm),
\(W\) = sample width (mm).

Sample size distribution skewness was determined using Equation 3:

\[
\text{Skewness} \left( S_k \right) = 3 \times \left( \frac{\text{Mean} - \text{Median}}{\text{Standard deviation}} \right) 
\]  

(3)
Sample arithmetic mean diameter ($D_A$) was found using Equation 4:
\[
D_A = \frac{(L + T + W)}{3}
\] (4)

Sample square mean diameter ($D_S$) was calculated using Equation 5 [11, 12]:
\[
D_S = \left( \frac{(LT) + (LW) + (WT)}{3} \right)^{1/2}
\] (5)

Sample equivalent diameter ($D_E$) was [11, 12] determined using Equation 6:
\[
D_E = \left( \frac{D_G + D_A + D_S}{3} \right)
\] (6)

Sample aspect ratio (AR) was computed using Equation 7 [11, 12]:
\[
AR = \frac{T}{L}
\] (7)

Sample sphericity was calculated using Equation 8 [13]:
\[
\text{Sphericity } (\psi) = \frac{D_G}{L} \times 100 \%
\] (8)

Note: An object is regarded as a sphere when its sphericity is $\geq 0.6$ (i.e. 60%) [14, 6].

(c) Sample Surface Area

Taro Cocoyam samples may be described as a sphere, based on the sample sphericity value obtained in this work; hence, the sample surface area ($S_c$) was computed using Equation 9 [7, 15]:
\[
S_c = \pi \times (D_G)^2
\] (9)

(d) Sample Volume

The volume of Taro Cocoyam sample ($V_c$) was computed using Equation 10 [7]:
\[
V_c = \frac{\pi (D_G)^3}{6}
\] (10)

Where, $\pi$ (pie) = 3.142

(e) Sample Density

The density of Taro Cocoyam sample ($\rho_c$) was computed by dividing its unit mass by its volume [7]:
\[
\rho_c = \frac{M_c}{V_c}
\] (11)

Where, $M_c$ = mass of Taro Cocoyam sample (g)

(f) Sample Bulk Density

The bulk density is basically the density of the sample when loaded in a container. It was found as described by the relation [6]:
\[
\rho_{sb} = \frac{M_{cs} - M_{ec}}{V_{ec}}
\] (12)
Where,
\( \rho_{sb} \) = sample bulk density (g/\( \text{mm}^3 \)),
\( M_{ec} \) = mass of empty container (g),
\( M_{es} \) = mass of container and samples (g)
\( V_{ec} \) = volume of empty container (\( \text{mm}^3 \)).

\((g)\) Porosity

The porosity of the samples was computed thus [6]:

\[
P_s = \left( 1 - \frac{\rho_{sb}}{\rho_c} \right) \times 100 \%
\] (13)

Where, \( P_s \) = sample porosity (%)

\((h)\) Sample Angle of Repose

Angle of repose of Taro Cocoyam samples was found using a cylindrical container which was opened at both ends as described by [16], [17].

\[
\theta = \tan^{-1} \left( \frac{2H}{R} \right)
\] (14)

Where,
\( H \) = vertical depth (cm)
\( R \) = pile radius (cm).

\((i)\) Sample Coefficient of Static Friction

With the aid of static frictional apparatus (Figure 3), plywood was placed on the sliding surface and the sample carefully rested on it. Then, the surface was gently raised up until the sample began to slide down the plane. The angle between the sliding surface and the base was measured as \( \Theta \).

The procedure was repeated with the rest of the samples. The plywood was replaced with glass and galvanized iron surfaces, and the experimental run repeated. The coefficient of static friction of Taro Cocoyam samples was calculated using Equation 15.

\[
\mu = \tan \Theta
\] (15)

Fig. 3. Static frictional apparatus
RESULTS AND DISCUSSIONS

The results of the investigation are presented in Table 1 and Figure 4.

Table 1: Some physical properties of Taro Cocoyam samples

<table>
<thead>
<tr>
<th>Properties</th>
<th>Total No. of Observations</th>
<th>Mean ± S.D.</th>
<th>C.V. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content (% w.b.)</td>
<td>10</td>
<td>70.50 ± 3.80</td>
<td>5.39</td>
</tr>
<tr>
<td>Unit mass, $M_c$ (g)</td>
<td>50</td>
<td>52.65 ± 22.59</td>
<td>42.92</td>
</tr>
<tr>
<td>Length, $L$ (mm)</td>
<td>50</td>
<td>63.67 ± 12.91</td>
<td>20.27</td>
</tr>
<tr>
<td>Width, $W$ (mm)</td>
<td>50</td>
<td>31.88 ± 5.99</td>
<td>18.80</td>
</tr>
<tr>
<td>Thickness, $T$ (mm)</td>
<td>50</td>
<td>34.27 ± 6.12</td>
<td>17.86</td>
</tr>
<tr>
<td>Geometric mean diameter, $D_{G}$ (mm)</td>
<td>50</td>
<td>40.88 ± 6.55*</td>
<td>16.02</td>
</tr>
<tr>
<td>Table 1. A continuation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arithmetic mean diameter, $D_{A}$ (mm)</td>
<td>50</td>
<td>43.27 ± 6.79*</td>
<td>15.70</td>
</tr>
<tr>
<td>Square mean diameter, $D_S$ (mm)</td>
<td>50</td>
<td>41.88 ± 6.62*</td>
<td>15.82</td>
</tr>
<tr>
<td>Equivalent diameter, $D_E$ (mm)</td>
<td>50</td>
<td>42.01 ± 6.65*</td>
<td>15.84</td>
</tr>
<tr>
<td>Aspect ratio, AR (decimal)</td>
<td>50</td>
<td>0.55 ±0.13</td>
<td>23.20</td>
</tr>
<tr>
<td>Sphericity, $\psi$ (%)</td>
<td>50</td>
<td>65.46 ± 10.26</td>
<td>15.68</td>
</tr>
<tr>
<td>Surface area, $S_c$ (mm$^2$)</td>
<td>50</td>
<td>5384.85 ± 1646.64</td>
<td>30.58</td>
</tr>
<tr>
<td>Volume, $V_c$ (mm$^3$)</td>
<td>50</td>
<td>38449.90 ± 16926.30</td>
<td>44.00</td>
</tr>
<tr>
<td>Solid density, $\rho_c$ (g/mm$^3$)</td>
<td>50</td>
<td>0.0014 ± 0.0003</td>
<td>19.53</td>
</tr>
<tr>
<td>Bulk density, $\rho_{sb}$ (g/mm$^3$)</td>
<td>50</td>
<td>0.00085 ± 0.00015</td>
<td>12.11</td>
</tr>
<tr>
<td>Porosity, $P_s$ (%)</td>
<td>50</td>
<td>60.7 ± 8.40</td>
<td>10.33</td>
</tr>
<tr>
<td>Angle of repose, $\theta$ ($^\circ$)</td>
<td>50</td>
<td>32.15 ± 4.51</td>
<td>14.02</td>
</tr>
<tr>
<td>Coefficient of static friction, $\mu$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plywood surface</td>
<td>50</td>
<td>0.22 ± 0.045</td>
<td>20.40</td>
</tr>
<tr>
<td>Glass surface</td>
<td>50</td>
<td>0.15 ± 0.045</td>
<td>30.20</td>
</tr>
<tr>
<td>Galvanized iron surface</td>
<td>50</td>
<td>0.19 ± 0.046</td>
<td>23.74</td>
</tr>
</tbody>
</table>

Note: The values of mean and standard deviation are designated as Mean ± S.D.; C.V = coefficient of variation; Same superscripts in the Mean ± S.D column show no statistical significant mean difference (MD) at P = 0.05.

Fig. 4. Histogram showing the % sample size distribution of Taro Cocoyam samples
Moisture Content of Taro Cocoyam Samples

The average moisture content of Taro Cocoyam samples was determined as 70.50 ± 3.8% (w.b.). The minimal value (5.39%) of coefficient of variation (C.V.) shows uniform dispersion of the data collected were around their average value. However, moisture content is a very useful parameter which finds application in the design of some efficient unit operations such as dehydration, packaging and culinary. The observed value is an indication that Taro Cocoyam could quickly deteriorate due to high moisture level which creates conducive environment for micro-organisms to strive freely.

Unit Mass of Taro Cocoyam Samples

The average unit mass of Taro Cocoyam samples was found as 52.65 ± 22.59 g. The C.V. (42.92%) of the samples distribution was a bit high. This implies that the sample mass distribution was not uniformly dispersed about its average value. The observed value of mass may be used in the design of cocoyam weighing, conveying and foreign particle separating system.

Size Distribution of Taro Cocoyam Samples

The average length ($L$), thickness ($T$), width ($W$), geometric mean diameter ($D_G$), arithmetic mean diameter ($D_A$), square mean diameter ($D_S$) and equivalent diameter ($D_E$) of Taro Cocoyam samples were 63.67 ± 12.91 mm, 31.88 ± 5.99 mm, 34.27 ± 6.12 mm, 40.88 ± 6.55 mm, 43.27 ± 6.79 mm, 41.88 ± 6.62 mm and 42.01 ± 6.65 mm, respectively, while their corresponding C.V. were 20.27%, 18.80%, 17.86%, 16.02%, 15.70, 15.82% and 15.84%, respectively (Table 1). The observed C.V. values were low. These imply that each of them was found to disperse evenly about their mean values. The sample length was approximately two times the width as well as thickness. Hence, the width was 0.9 of the sample thickness. In addition, there were no statistical significant mean differences (MD) among different types of diameters. Percentage size distributions obtained were 18% small, 46% medium and 36% large size ranges. The computed value of skewness for the sample size distribution was -0.29 (i.e. negative skewness). Figure 3 reveals that the skewed distribution was towards the right side which indicates that the mean, mode and median of the data collected were slightly different. Hence, larger % of the data was between the medium and large size ranges (45.0 mm ≤ $D_E$ ≤ 55.0 mm). However, the observed axial dimensions, $D_G$ and $D_E$ could be used in the design of sieve aperture of a grading and screening system; peeling and cleaning system for taro cocoyam.

Shape of Taro Cocoyam Samples

The average values of aspect ratio (AR) and sphericity ($\psi$) were 0.55 ± 0.13 (decimal) and 65.46 ± 10.26%, respectively. Their C.V. values were low (i.e., 23.20% and 15.68%, respectively). The observed value of AR means that the samples may not roll on a plane surface if there is a resistance, while the sphericity value attests that the samples are a sphere, but not perfect, and may likely to roll on any surface. This data could be employed in the design of Taro Cocoyam hopper for separating and conveying systems.
**Surface Area of Taro Cocoyam Samples**

The average surface area of Taro Cocoyam samples was found to be 5384.85 ± 1646.64 mm$^2$. The C.V. value (30.58%) got was low. This parameter could be used in designing peeling machine, heat and mass transfer equipment for heat treatment processes.

**Volume and Solid Density of Taro Cocoyam Samples**

The average volume and density of Taro Cocoyam samples were 38449.40 ± 16926.30 mm$^3$ and 0.0014 ± 0.0003 g/mm$^3$, with their corresponding C.V. as 44.00% and 19.53%, respectively. The volume obtained could find application in designing sorting equipment, storage systems (e.g., silos and bins) and in screening solids. The observed estimated value of solid density of Taro Cocoyam samples (0.0014 g/mm$^3$ = 1400 kg/m$^3$) is higher than density of water (1000 kg/m$^3$). This implies that the samples can sink in water, and as such lighter foreign particles can be separated easily. The calculated density value could aid in product characterization and process calculation. Besides, its true volume can be found by water displacement method.

**Bulk Density of Taro Cocoyam Samples**

The average values of bulk density of Taro Cocoyam samples were 0.00085 ± 0.00015 g/mm$^3$ with C.V. of 12.11%. The C.V. determined was low. The observed value is lesser that the solid density. Hence, more spores (void spaces) are expected in the container when packaged with the samples. This value is useful in the design of system for transportation, containerization and packaging or storage system.

**Porosity of Taro Cocoyam Samples**

The average value of porosity of Taro Cocoyam samples was 60.7 ± 8.4% with C.V. of 10.33%. This means that the samples would generate more air-spaces among their particles when loaded in a container. Therefore, the observed value is useful in storage system design.

**Angle of Repose of Taro Cocoyam Samples**

The mean value of angle of repose of Taro Cocoyam samples was determined as 32.15 ± 4.51$^\circ$ with its C.V. of 14.02%. The calculated angle of repose can find application in efficient design of hopper, conveyor belt system, silos and bins.

**Coefficient of Static Friction of Taro Cocoyam Samples**

The mean values of coefficients of static friction of Taro Cocoyam samples were 0.22 ± 0.045, 0.15 ± 0.045 and 0.19 ± 0.046 for plywood, glass and galvanized iron surfaces, respectively. Their respective C.V. values were 20.40%, 30.20% and 23.74%.

These values were low. Glass surface had the least static frictional coefficient compared to other surfaces. This was followed by galvanized iron surface.
This shows that glass and galvanized iron surfaces are better surfaces to be used in fabricating hopper and conveyor belt system. However, the glass surface is expensive and delicate. Hence, galvanized iron surface is preferable.

CONCLUSION

In this work, some physical properties of Taro Cocoyam samples were studied at the moisture content of 70.50 ± 3.80%. The data acquired are vital information for the lucid design of Taro Cocoyam processing systems for proficient unit processes.

CONFLICT OF INTEREST

There is no conflict of interest.

REFERENCES

NEKE FIZIČKE OSOBINE TARO COCOYAM (Colocassia esculenta) RELEVANTNE ZA DIZAJN MAŠINA ZA PRERADU

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Apstrakt: Podaci o fizičkim osobinama Taro Cocoyam (Colocassia esculenta) su neophodni za efikasan razvoj opreme/mašina za njegovu preradu. U ovom radu, neke fizičke osobine su istraživane primenom standardnih inženjerskih principa. Rezultati su otkrili da su prosečna dužina, širina, debljina i masa dobijene pri sadržaju vlage vrednosti od 70,50 ± 3,8% (w.b.), i dimenzija uzorka: 63,67 ± 12,91 mm, 31,88 ± 5,99 mm, 34,27 ± 6,12 mm i 52,25 ± 52,65 g, respektivno. Vrednosti izračunate geometrijske i aritmetičke sredine, sume kvadrata, sredine ekvivalentnih prečnika, bile su: 40,88 ± 6,55 mm, 43,27 ± 6,79 mm, 41,88 ± 6,62 mm i 42,01 ± 6,65 mm, respektivno. Vrednost asimetrije distribucije uzorka bila je 0,29. Odnos širine i visine, sferičnosti, dodirne površine, ukupne zapreminе, nasipne zapremine, poroznosti i ugla trenja bili su: 0,59 ± 0,15 (dec.), 65,46 ± 10,26%, 5384,85 ± 1646,64 mm³, 38449,90 ± 16926,30 mm³, 0,0014 ± 0,0003 g/mm³, 0,00085 ± 0,00015 g / mm³, 60,7 ± 8,40% i 32,15 ± 4,510, respektivno. Vrednost koeficijenta statičkog trenja na šper ploči, staklu i pocinkovanoj čeličnoj površini, bile su: 0,22 ± 0,045, 0,15 ± 0,045 i 0,19 ± 0,046, respektivno. Vrednosti koeficijenta varijacije za sve parametre, osim jedinične mase, bile su niske. Ovo implicira da su podaci ravnomerno raspoređeni oko svojih prosečnih vrednosti.

Ključne reči: Fizičke osobine, Taro Cocoyam, dizajn, mašine za obradu.

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