Influence of moisture dependent physical properties of fluted pumpkin vital to development it’s processing equipments

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Abstract. Knowledge of physical and mechanical properties of seeds is an important factor for designing agricultural machines and equipment. A fluted pumpkin is a very important vegetable crop as well known for its high nutritional, medicinal and economic values, but the data on its physical and mechanical properties is still lacking. The aim of this study is to determine the effect of moisture content on the physical (basic dimensions, porosity, bulk and true densities, coefficient of friction, repose angle and sphericity) and mechanical properties of fluted pumpkin seed. These properties were evaluated as a function of moisture content at 45, 50, 55 and 60%. The results revealed that length, width and thickness increased with increasing moisture content. Similarly, an average mass of the seed, volume, surface area, sphericity, angle of repose all increased with increasing moisture content. Bulk density decreased as the moisture content increases. The parameters obtained from this study could be used as a reference data for the design of fluted pumpkin seed handling and processing equipment.

Keywords: fluted pumpkin, physical, mechanical, properties.

1. Introduction
The fluted pumpkin is cultivated in the rain forest zones of Nigeria and other western African countries [1]. As reported by [2] and [3], the economic value, health and nutritional benefits of fluted pumpkin have contributed in its more cultivation and consumption in Nigeria in many other parts of the world. The understanding of physical properties of agricultural materials among other engineering properties is essential to the development of various machine and equipment [4]. As it help in numerous design consideration such as size and capacity of the equipment, shape and angle of machine part and power requirement determination among others. In order to optimize the design of an Agricultural machine, basic engineering knowledge of the crops is important and it is needed by fabricators, engineers, food processors and scientists [5]. Among these engineering properties, physical and mechanical property data are essential for the design of a specific machine or for the analysis of product behaviour in under certain operational conditions [6]. For example, crop grading and packaging is dependent of physical characteristics such as size and shape of the crop. The axial dimensions of the agricultural product determine the size, while the diameter of the product determines the shape [5]. Bulk density is a major factor considered in the construction of storage, transport and separation facilities and machines, as well as in the determination of capacity of machines and equipment [5]. [7] suggested that the performance and efficiency of agricultural machine solemnly dependent on correlation between moisture and physical properties of the material to be processed by

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the machines. As the optimal efficiency of the machines could only be achieved with a specific range of moisture contents. In the prediction of seed pressure on walls of machines and equipment, frictional properties such as static angle and coefficient of friction are important. As well coefficient of friction is critical in the design of storage bins, hoppers, screw conveyors, forage harvesters and threshers [7].

Generally, the development of fluted pumpkin processing equipment is hindered by insufficient data available on its physical properties. Hence, the investigation on effects of change in moisture content level on physical properties of fluted pumpkin seed will help in developing various equipments for its processing. The aim of this study is to investigate the influence of moisture content level (45, 50, 55 and 60% wet basis) used in processing fluted pumpkin seed on a number of physical properties such as length, width, thickness, sphericity, surface area, volume, true and bulk densities, porosity, angle of repose and coefficient of friction that would aid in the design of numerous equipments for processing.

2. Methods

The fluted pumpkin seeds (Telforia occidentalis) varieties locally recognized as “Ugu” used in this study were purchased from farmer’s farm in Jima in Doko district area of Niger State. The seeds were cleaned and sorted before divided into samples [5]. The samples were then conditioned to obtain four different levels of moisture content of 45%, 50%, 55% and 60% wet basis by adding pre-determined volume clean water as reported by [2] and [5]. These moisture levels represent the processing and handling moisture content range of the seed. The moisture content of the seed was determined as reported by [1] by drying the ground seed samples in an vacuum oven set at 105 0C for average 18 hours.

To calculate the average size of the seed, 50 seeds were chosen at random from each of the four moisture contents. The three main longitudinal dimensions including length A, breadth B, and thickness C, were calculated using a micrometer screw gauge with an accuracy of 0.001 mm [6]; [8]. Seed sphericity and surface area were determined using the expression reported by [6]; [9] and are shown in equation (1) and (2) respectively

$$S_p = \frac{(A \times B \times C)^{0.333}}{A}$$  \hspace{1cm} (1)

$$S_{as} = \pi De^2$$  \hspace{1cm} (2)

Where $S_p$ is the sphericity of the seed; $A$ is the linear length of the seed (mm); $B$ is the breadth of the seed (mm); $C$ is the thickness of the seed (mm), $S_{as}$ is surface area of seed (cm$^2$); $De$ is the geometric mean diameter (cm)

The mass of the seed was calculated using an electronic balance with accuracy of 0.001g [8]. At each level of the moisture content, the true density is the ratio of mass of a single seed to the volume of that seed and was calculated using the water displacement method [5]. The bulk density was calculated as reported [5] filling a cylindrical container of 30 cm by 20 cm with the seeds. The container volume was determined, after the mass of the seed was weighed. The buck density was then calculated using the expression in equation (3)

$$\rho_s = \frac{M_{ps}}{V_{ct}}$$  \hspace{1cm} (3)

Where, $\rho_s$ is the bulk density of a given volume of the seed (kg/m$^3$), $M_{ps}$ is the mass of the given volume of the seed (kg), $V_{ct}$ is the volume of the container used (m$^3$)

The porosity was calculated in terms of true density and bulk density using the expression in equation (4) as stated by [5]

$$P = \frac{\rho_T - \rho_s}{\rho_T} \times 100$$  \hspace{1cm} (4)

Where the P is is the porosity of the seed in percentage, $\rho_T$ is the true density of the seed (kg/m$^3$), $\rho_s$ is the bulk density of a given volume of the seed (kg/m$^3$)

The seeds were poured into a hollow container of 30 cm and 20 cm height and diameter respectively. The container was filled and slowly raised until a conical pile of seeds was obtained free of the seeds. The angle of repose was determined by the expressing in equation [5] as reported by [9].
\[ \theta = \tan \frac{12H}{D} \]  

Where \( \theta \) the angle of repose (\(^\circ\)), \( H \) is the cone height (cm), \( D \) is the cone diameter (cm)

The coefficient of static friction of the seeds against glass, plywood and mild steel surfaces were determined. A hollow cylinder of height and diameter of 30 cm and 20 cm respectively was used to determine the coefficient. The cylinder was placed on the surface and then filled with the seeds. The material full of the seeds was slowly lifted with a screw tool until it began slipping. From a graduated scale the angle of tilt was read, and the slope of this angle was taken as the static friction coefficient [11].

3. Results and Discussion

3.1 Seed dimensions

The results obtained at the highest moisture level of the seed are similar to those reported by [11] and [12] for sweet maize and maize (Swam 1) respectively. All the dimensions of the seeds decreased with the decrease in moisture level. The seeds enlarge in length, breadth and thickness. The correlation between the axial dimensions and seed moisture level is shown in Table 1. The results point out that increase in size is dependant of moisture content. Within the range of analyzed moistures the seed increased in length by 2.45% (3.67-3.76 cm), likewise it breadth and thickness by 3.16% (3.16-3.26 cm) and 11.18% (1.61-1.79 cm) respectively. The interaction existing between axial dimensions and moisture levels for the seed were found to be linear and can be expressed as shown in Equation (6) to Equation (8) and Figure 1 to Figure 3:

\[
S_a = 0.062M + 33.87, R^2 = 0.896 \quad (6)
\]
\[
S_b = 0.066M + 28.76, R^2 = 0.985 \quad (7)
\]
\[
S_c = 0.112M + 11.22, R^2 = 0.933 \quad (8)
\]

where: \( S_a \) is the linear length of the seed, \( S_b \) is the linear breadth of the seed, \( S_c \) is the linear thickness of the seed, \( M \) is the moisture content (%)

The expansion is more linear in breadth of the seed coefficient of correlation value of 0.985. The seeds dimension is very vital feature regarded in determination of sieve apertures and other features in machine design [12]. This in lined with the report of [13], where grain size was found to be a significant factor considered in the design of sieve size in agricultural processing machine design. Also from Table 2, the results of Analysis of variance (ANOVA) of the seed linear dimensions at the study moisture ranged indicated that increased in moisture content have no significant effects on the linear dimension. Therefore this may not affect design data within the study moisture ranged.

**Table 1. The values of Physical Properties of Fluted Pumpkin Seeds at the Study Moisture Levels (wb)**

| S/N | Characteristics | Unit | 45% | 50% | 55% | 60% |
|-----|-----------------|------|-----|-----|-----|-----|
| 1   | Length of seed  | (mm) | 36.7±16.6 | 36.9±16.2 | 37.3±15.4 | 37.6±11.7 |
| 2   | Breadth of seed | (mm) | 31.6±12.87 | 32.2±11.0 | 32.5±9.2 | 32.6±11.7 |
| 3   | Thickness       | (mm) | 16.1±6.2 | 17.1±6.5 | 17.3±6.6 | 17.9±8.3 |
| 4   | Mass of seed    | (g)  | 12.004±7.2 | 16.6±10.9 | 16.34±15.1 | 16.97±11.5 |
| 5   | Bulk density    | (g/cm\(^3\)) | 0.5127 | 0.5066 | 0.5008 | 0.4594 |
| 6   | Surface area    | (cm\(^2\)) | 256±167 | 259±145 | 263±159 | 269±150 |
| 7   | Sphericity      |      | 0.730±0.135 | 0.739±0.151 | 0.739±0.239 | 0.742±0.151 |
| 8   | Angle of repose | (°)  | 29.55 | 30.07 | 32.28 | 41.08 |
| 9   | Static coefficient of friction | | | | | |
|     | Plywood         |      | 0.6249 | 0.7536 | 0.9325 | 1.1917 |
|     | Mild steel      |      | 0.5498 | 0.6249 | 0.7265 | 0.9325 |
|     | Glass           |      | 0.4500 | 0.5295 | 0.6249 | 0.7265 |
Table 2. Result of Analysis of variance of linear dimension

| Term          | DOF | Sum Sqr | Mean Sqr | F Value | Prob>F |
|---------------|-----|---------|----------|---------|--------|
| A-Moisture content | 3   | 1.049167 | 0.35     |         |        |
| B-Dimension   | 2   | 875.1517 | 437.58   |         |        |
| AB            | 6   | 1.288333 | 0.21     |         |        |
| Residuals     | 0   | 0       |          |         |        |

Figure 1. Relationship between linear length and moisture level

Figure 2. Relationship between linear breadth and moisture level

Figure 3. Relationship between linear thickness and moisture level

Figure 4. Relationship between sphericity and moisture level

From Figure 4, the sphericity of seeds decreased with decrease in moisture level and the relationship between moisture level and sphericity can be represented by the regression equation (9) and coefficient of correlation value of 0.965 indicated that the relationship is more of linear.

\[ S_{sp} = 0.0001M + 0.695, \quad R^2 = 0.965 \]  

where: \( S_{sp} \) is the sphericity of the seed, \( M \) is the moisture content (%)
From Figure 8, the surface area of seeds decreased with decrease in moisture level and the relationship between moisture content and surface area can be represented by the regression Equation (10) and coefficient of correlation value of 0.975 indicated that the relationship is more of linear.

\[ S_{as} = 4.3M + 251, \quad R^2 = 0.975 \]  

(10)

where: \( S_{as} \) is the surface area of the seed, \( M \) is the moisture content (%)

From Table 1 the mass of the fluted pumpkin seed varied from 12.0 g to 16.97 g. At the higher moisture level of 60 percent, the maximum values of 16.97 and 12.0 g were obtained from the higher moisture level of 60 percent and the lower level of 45 percent. It suggests an improvement in mass 41.42% with a rise in moisture level from 45 per cent to 60 per cent (wb). This factor is vital in designing sorting and grading equipment as well as in calculation of power requirement of an agricultural machine [11]. A linear relationship existed between the mass of the seed and moisture content level as shown in Equation (11) and Figure 5:

\[ S_M = 0.303M - 0.451, \quad R^2 = 0.704 \]  

(11)

where: \( S_M \) is the mass of the seed (kg), \( M \) is the moisture content (%)

As shown in Table 1 the bulk density values increased with decreased moisture level for all levels measured (Figure 6). The moisture content correlation was linear as shown in Equation (12). The finding is consistent with previous research by [11] on sweet maize seed. The increase in bulk density with decrease in moisture level could be because of lower rate of volume expansion is relative to weight gain. This is a vital variable which affects the efficiency and capacity of agricultural machine and its power requirement. For example to process five hundred grammes of this seed at the study moisture levels with equipment with a cylindrical chamber putting into considering the bulk density obtained at each of the level. As shown in Table 3, there are no any significant differences in volume of the seed and the dimension of the container at the various moisture levels. This is an indication that change in the study moisture level does not affect the volume of the seed to be process.

\[ S_{bd} = -0.003M + 0.668, \quad R^2 = 0.785 \]  

(12)

where: \( S_{bd} \) is the bulk density of the seed (kg/m³), \( M \) is the moisture content (%)

### Table 3. Relationship between moisture level and some design parameter

| Parameter                  | 45% | 50% | 55% | 60% |
|----------------------------|-----|-----|-----|-----|
| Mass of the seed (g)       | 500 | 500 | 500 | 500 |
| Bulk density (g/cm³)       | 0.5127 | 0.5066 | 0.5008 | 0.4594 |
| Volume of the seed (cm³)   | 975 | 986.97 | 998.4 | 1088 |
| Height of the container (cm) | 10 | 10 | 10 | 10 |
| Radius of the container (cm) | 5.567 | 5.607 | 5.63 | 5.88 |

The angle of repose of the seed decreased linearly with decrease in moisture content from 41.08° to 29.55°. Figure 7 suggests an decrease -39 % in angle of repose with decrease in moisture level from 60 per cent to 45 per cent (wet basis). This is because as the seed absorbed more moisture it becomes heavier and therefore sticks to surface of the material. [9] reported similar finding. This parameter is a vital factor that affects flow of material in processing machines. The relationship can be expressed by the Equation (13) and Figure 7:

\[ S_{ag} = 0.303M - 0.451, \quad R^2 = 0.704 \]  

(13)

where: \( S_{ag} \) is the angle of repose of the seed (kg/m³), \( M \) is the moisture content (%)
3.2 Static coefficient of friction
The static friction coefficient of the seeds on glass, mild steel and plywood surfaces decreased linearly with decreasing moisture level. Concrete has the highest static friction coefficient followed by plastic. From all the levels of moisture content, the values were lowest on glass surfaces followed by mild steel and then the highest value from plywood. This is because the glass surface was smoother than the other material under the analysis. Similar trends have been published [5]; [9] on sweet corn. This aspect is crucial in the design of hopper and discharge outlets for the processing machine [5]. The moisture content correlation was linear as shown in Equation (14) to Equation (16) and Figure 8. Also from Table 4, the results of Analysis of variance (ANOVA) of the static coefficient at the study moisture ranged indicated that increased in moisture level of the seed and material surfaces have significant effects on the static coefficient of friction of the seed with moisture level having more effects than the material surface. The moisture level of 45% had coefficient of estimate of -0.18, 50% had value of -0.086 and 55% had value of 0.040. The material surfaces of plywood and mild steel have coefficient of estimate of 0.3 and 0.013 respectively. Therefore, if a machine part that is being influenced by this factor is constructed considering a particular level of moisture content say 45% that part of machine may not function well processing the seed with higher or lower level of moisture compared to the design moisture. Also, if an angle of the machine part was constructed considering particular material surface say plywood, this part may not work well if the surface is replaced with different material. Consequently, the level of moisture and the material surface are very vital factors to consider in the fabrication of equipment for processing fluted pumpkin seed.
\[ S_{PW} = 0.187M + 0.405, \quad R^2 = 0.976 \]  
(14)

\[ S_M = 0.125M + 0.396, \quad R^2 = 0.944 \]  
(15)

\[ S_G = 0.092M + 0.351, \quad R^2 = 0.997 \]  
(16)

where: \( S_{PW} \) is the static coefficient of the seed on plywood, \( S_M \) is the static coefficient of the seed on mild steel, \( S_G \) is the static coefficient of the seed on glass, \( M \) is the moisture content (%) 

Figure 9. Relationship between static coefficient of friction and moisture level

Table 4. Result of Analysis of static coefficient of friction

| Source               | Sum of Squares | Df | Mean Square | F Value | p-value       |
|----------------------|----------------|----|-------------|---------|---------------|
| Model                | 0.40223        | 5  | 0.080446    | 68.82366| < 0.0001      |
| A-Moisture content   | 0.277039       | 3  | 0.092346    | 79.00456| < 0.0001      |
| B-Type of Surface    | 0.125192       | 2  | 0.062596    | 53.5523 | 0.0001        |
| Residual             | 0.007013       | 6  | 0.001169    |         |               |
| Cor Total            | 0.409244       | 11 |             |         |               |

4. Conclusion
Within the study moisture level of 45-60% (w.b), the linear dimensions of the seeds insignificantly increased with the increase in moisture. The mass, volume, sphericity, angle of repose and the static coefficient of friction all decreased with a decrease in the seed moisture level. While the bulk density increased with decrease in moisture level. The implication of the findings is that for any characteristics that is been influenced significantly by the moisture change, the data obtained from one level of moisture of the seed with respect to that characteristic cannot be used to fabricate a machine that will process seed at different moisture level. This also applies to the type of material surface. But for characteristics that is not been influenced significantly by the moisture change, data obtained from one level of moisture of the seed with respect to that characteristic can be used to fabricate a machine that will process seed at different moisture level within the study range of moisture.
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