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Original Research Article

Engineering Properties of Gbafilo (*Chrysobalanus icaco*) Fruits and Kernels Preparatory to Primary Processing

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Abstract

The aim of the study was to determine the physical properties of gbafilo fruit and kernel, namely, axial dimension, geometrical and arithmetic mean diameter, sphericity, aspect ratio, 1000 unit mass, surface area, true and bulk density, porosity angle of repose and coefficient of static friction. Investigation of physical properties of gbafilo (*Chrysobalanus icaco*) is important for the design of appropriate equipment for processing, transporting, cleaning, sorting, packaging and storage processes. The mean length, width and thickness of gbafilo fruit (*Chrysobalanus icaco*) were determined at 8.3% moisture content (d.b.). The analysis of variance showed that variations in the values obtained for fruit and kernel for axial dimensions were significantly different at 5% probability level. The arithmetic and geometric mean diameter for gbafilo fruit were 24.95 mm and 24.74 mm. The sphericity, surface area and as well as 1 000 unit mass of gbafilo kernel were 0.82, 1 056.70 mm^2 and 2 804.64 g. True and bulk densities were 989.19 kg/m^{-3} and 652.53 kg/m^{-3} for kernel. Angle of static friction of gbafilo fruit and kernel were 19.34° and 17.61°. Data obtained were subjected to analysis of variance (ANOVA) and Duncan Multiple Range (DMR) using Statistical Analysis System. The static coefficient of friction of plywood structural surface was observed to be the highest followed by galvanized steel sheet and glass. This is an indication that plywood interior lining would not be suitable material for chute design. All the gbafilo fruit and kernel parameters investigated were significantly different ($P < 0.05$). This finding could therefore be useful in the design and fabrication of gbafilo processing machines.

Keywords: gbafilo; sphericity; surface area; true density; bulk density.

INTRODUCTION

Gbafilo (*Chrysobalanus icaco*) is a medicinal herb. It has different purposes such as therapeutic way to treat undesirable clinical conditions. It is recommended in the treatment of diabetes (Hart, 2005). It is commercially grown in tropical rain forest of some western central African countries such as Nigeria, Ghana, Congo and Senegal. The seeds are economically and medically important and have been traditionally utilized for preparation of a special soup, control blood pressure, malaria fever and treatment of stomach disorder.

The physical and mechanical properties of gbafilo (*Chrysobalanus icaco*) are essential for the design of machines for harvesting, transporting, sorting, cleaning, separation, sizing, packaging and processing it into different foods. Presently, the machines used for harvesting and processing were designed without considering the physical and mechanical properties; the resulting designs lead to inappropriate equipment. The physical properties have been studied for various agricultural products by other researchers such as soybean (Manuwa and Afuye, 2004), arigo seed (Davies, 2010), bambara groundnut (Adejumo et al., 2005), caper fruit, *Capparis* spp. (Sessiz et al., 2005) cocoa bean (Bart-plange and Baryeh, 2002), pigeon pea (Shepherd and Bhardwaj, 1986), locust bean seed (Ogunjimi et al., 2002), wheat (Tabatabaefa, 2003), pistachio nut and its kernel (Razari et al., 2007), groundnut (Davies, 2009), *Irvingia garbonensis* (ogbono) nuts (Zibokere, 2001) cowpea (Davies and Zibokere, 2011) and water hyacinth parts (Davies and Mohammed, 2011).

There is paucity of information on physical and mechanical properties of the gbafilo (*Chrysobalanus icaco*) that will assist in the development of appropriate machines. In order to achieve this objective some important physical and mechanical properties of gbafilo (*Chrysobalanus icaco*) fruit and kernel such as axial dimensions, thousand unit mass fruit and kernel, true density, bulk density, porosity, sphericity, static coefficient friction and angle of repose were determined.

MATERIALS AND METHODS

Gbafilo (*Chrysobalanus icaco*) is a large, egg-shaped fruit with rough sandpaper-like surface. The kernel, which shakes freely inside, is removed and ground for inclusion in pepper soups. The fruits are sold in the markets by traders from the Niger-Delta areas. The gbafilo fruits were procured for the study from Yenegoa market in Bayelsa State, Niger Delta, Nigeria on 19th April, 2011. The samples were selected and cleaned manually. It was ensured that the fruits were free of dirt, any broken ones and other foreign materials. The moisture content of the sample was determined using ASAE (1998) standard S 352.2 involving the use oven-drying method. Three samples, each weighing 15 g, were placed in an oven set at 105 °C for 72 hours. The samples were cooled in a dessicator, reweighed and the moisture content of the sample was calculated. Physical properties were determined at the moisture of 8.3% dry basis.

For this experiment, 100 gbafilo (*Chrysobalanus icaco*) were randomly selected; the length (x), width (y) and thickness (z) and mass of gbafilo were measured using a micrometer screw gauge with a reading of 0.01 mm. The arithmetic mean diameter, D_a, and geometric mean diameter, D_g, of the gbafilo were calculated by using the following relationships (Galedar et al., 2008; Mohsenin, 1980).

$$D_a = \frac{(x + y + z)}{3} \quad (1)$$

$$D_g = (x\,y\,z)^{1/3} \quad (2)$$

where D_a – arithmetic mean diameter (mm), D_g – geometric mean diameter (mm),

The sphericity (φ) (%) was calculated by using the following relationship (Koocheki et al., 2007; Milani, 2007).

$$\Phi = \frac{(x\ y\ z)^{1/3}}{L} \quad (3)$$

The surface area S (mm^2) was found by the following relationship given by McCabe et al. (1986)

$$S = \pi\ D_g^{\ 2} \quad (4)$$

For the determination of aspect ratio, 30 gbafilo fruits and kernel were randomly selected. The aspect ratio, R_a was calculated by applying the following relationships given by (Maduako and Faborode, 1990):

$$R = (y/x)\ 100 \quad (5)$$

The 1 000 unit mass of gbafilo fruit and kernel were determined using precision electronic balance to an accuracy of 0.01 g. To evaluate the 1 000 unit mass, 50 randomly selected samples were weighed and multiplied by 20. The reported value was a mean of 20 replications.

The grain volume, V_s and true density, ρ_t were determined by water displacement method (Adejumo et al., 2005). A bunch of 100 grains of known average weight was dropped into a container filled with water. The weight of displaced water was used to calculate the equivalent volume of water and thus the volume of the grain. The grains were not coated to prevent water adsorption due to the short duration of experiment since it did not result in a significant increase in mass as reported by Davies (2009). The net volumetric water displacement by each fruit was recorded. The true density ρ_t was determined using the unit volume and unit mass of individual fruit and kernel. The true density was calculated using the following relationship by Burubai et al. (2007). The net volumetric water displacement by each fruit was recorded. The true density was then calculated using Eq. (6) below:

$$\rho_t = M/\ V_s \quad (6)$$

where ρ_t – true density (kg/m^{-3}), M – mass of individual fruit or kernel (kg), V_s - volume (m^3).

The bulk density of gbafilo fruit and kernel were determined by using the standard test weight procedure (Garnayak et al., 2008). This was achieved by filling a container of 500 ml with grain from the height 0.15 m striking the top level and then weighing the contents and the bulk density was determined from the measured mass and volume. The experiment was replicated ten times and the average was taken. Bulk was evaluated according to the relationship established by Garnayak et al. (2008):

$$\rho_b = M_b/\ V_b \quad (7)$$

where: ρ_b - bulk density (kgm^{-3}), M_b – mass of fruit or kernel (kg) V_b – volume of container (m^3).

The porosity (ε) of the bulk gbafilo was computed from the values of the true density and bulk density of the gbafilo by using the relationship given by Mohsenin (1980).

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t}\ 100 \quad (8)$$

Where ε – porosity (%)
ρ_b - bulk density (kgm^{-3})
ρ_t - true density (kgm^{-3})

The static coefficient of friction for gbafilo was determined with respect to four test surfaces, namely: plywood, galvanized steel sheet and glass using Joshi et al. (1993). The static coefficient of friction (μ_s) was calculated based on this equation (Mohsenin, 1980).

$$\mu_s = \tan\theta \quad (9)$$

The static angle of repose with the horizontal at which the material will stand when piled. This was determined using topless and bottomless cylinder of 0.15 m diameter and 0.25 m height. The cylinder was placed at the centre of a raise circular plate having a diameter of 0.35 m and was filled with gbafilo fruit. The cylinder was raised slowly until it formed a cone on a circular plane. The height of the cone was measured and the filling angle of repose θ_f was calculated by the following relationship (Karababa, 2006 and Kaleemullah and Gunasekar, 2002)

$$\theta_f = \tan^{-1} \left(\frac{2d}{h} \right) \quad (10)$$

where h and d are the height and diameter of the cone respectively

Statistical analysis

The result obtained from the study conducted on gbafilo fruit and kernel was subjected to analysis of variance (ANOVA) and Duncan multiple range test using Statistical Analysis System.

RESULTS AND DISCUSSION

The summary of the results of the physical properties of gbafilo fruit and kernel (*Chrysobalanus icaco*) is in Table 1. The analysis of variance showed that variations in the values obtained for fruit and kernel for axial dimensions were significantly different at 5% probability level. The mean corresponding axial dimension of simarouba fruit as reported by Dash et al. (2008) were 21.26 mm, 13.81 mm and 11.03 mm, respectively. Sirisombaron et al. (2007) reported the corresponding values of axial dimensions for jatropha seeds as 18.65 – 21.02 mm, 11.34 – 11.9 mm and 8.91 – 9.58 mm, respectively. A critical view at the axial dimensions of gbafilo, simorouba fruit and jatropha seed revealed that there is significant difference at 0.05%. The axial dimensions play important roles in the design of aperture size of the equipment. It can be deduced from the above data that processing machine designed based on physical properties of gbafilo fruit and kernel may not be suitable for simorouba fruit as well as for jatropha (Mohsenin, 1980; Dash et al., 2008). The calculated geometric mean diameter for gbafilo fruit and kernel were 24.74 and 18.34 mm. The analysis of variance results revealed that the differences were statistically significant at the level of 5% for these parameters. The 1 000 unit mass of gbafilo fruit and kernel were 3 916.21 and 3 040.57 ($P < 0.05$). The mean sphericity of gbafilo fruit and kernel were 0.84 and 0.82. This result is an indication that the shape of gbafilo is very close to sphere. The corresponding values for nutmeg, simarouba fruit and kernel and jatropha seed and kernel were 0.74, 0.69, 065, 0.64 and 0.68, respectively, as reported by Dash et al. (2008) and Burubai et al. (2007). The above results indicate that the sphericity values of gbafilo fruit and kernel were higher than nutmeg, simarouba (fruit and kernel) and jatropha whereas the sphericity values obtained in simarouba and jatropha were almost similar. Furthermore, the values of sphericity as reported by Jayan and Kuman (2004) for maize, red gram and cotton were 0.621 (± 0.065), 0.750 (± 0.016) and 0.677 (± 0.016). The aspect ratio of fruit was 0.750 and that of kernel was 0.676 ($P < 0.05$). This is an indication that gbafilo will experience sliding and rolling movement. This behaviour is essential for the design and development of hopper.

According to the obtained results, the average bulk density value of gbafilo fruit was lower than its kernel. The corresponding true and bulk density of nutmeg and simarouba fruit and kernel, were 836.54 kg/m^3, 488.76 kg/m^3, 622.27 kg/m^3 and 727.27kg/m^3. The analysis of variance result showed that the difference among true and bulk density values of gbafilo fruit and kernel, nutmeg and simarouba were statistically significant at 0.05 probability level. The mean porosity of gbafilo of fruit and kernel were found to be significantly different ($P < 0.05$). The corresponding values of simarouba fruit and kernel were 33.23% (± 2.03)

Table 1 : Physical properties of gbafilo fruit and kernel (*Chrysobalanus icaco*) at moisture 8.3% dry basis

Physical properties	Fruit(Mean ± SD)	Kernel (Mean ± SD)
Length (mm)	29.64 ± 0.67a	22.48 ± 1.13b
Width (mm)	22.22 ± 0.84a	15.20 ± 0.51b
Thickness	23.00 ± 1.98	18.06 ± 0.92
Arithmetic mean diameterDa (mm)	24.95 ± 0.39a	18.58 ± 0.56b
Geometric mean diameter (Dg) (mm)	24.74 ± 1.37a	18.85 ± 0.54b
Sphericity	0.84 ± 0.02a	0.82 ± 0.03b
Surface area (mm^2)	1922.90 ± 21.79a	1056.70 ± 20.23b
Aspect ratio (%)	74.97 ± 1.98a	67.62 ± 1.52b
1 000-unit Mass (g)	3916.21 ± 28.91a	2804.64 ± 18.75b

Means with different letter in the same row are significantly different ($P < 0.05$).
SD – standard deviation

Table 2: Gravimetric and frictional properties gbafilo fruit and kernel (*Chrysobalanus icaco*) at moisture 8.3% dry basis (mean ± SD)

Properties	Fruit	Kernel
True density kg/m^3	813.39 ± 9.43a	986.19 ± 10.43b
Bulk density kg/m^{-3}	497.43 ± 9.43a	652.53 ± 12.43B
Porosity (%)	38.85 ± 1.50a	33.83 ± 1.19b
Angle of repose	19.34 ± 0.98a$^\circ$	17.61 ± 0.83b$^\circ$
Glass	0.48 ± 0.09a	0.27 ± 0.05b
Galvanized steel sheet	0.59 ± 0.03a	0.31 ± 0.02b
Plywood	0.63 ± 0.02a	0.33 ± 0.01b

Means with different letter in the same row are significantly different ($P < 0.05$)
SD – standard deviation

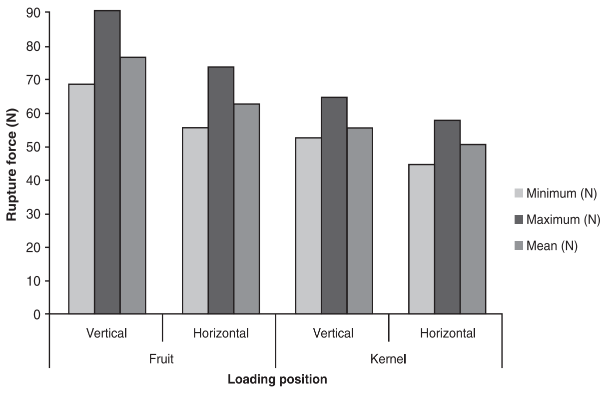
and 28.6% (±2.861). Burubai et al. (2007) reported porosity of 41% (± 4.20) for nutmeg. The angle of repose of gbafilo fruit was higher than its kernel. The corresponding angle of repose of simarouba fruit and kernel were higher than gbafilo. The corresponding values of angle of repose for maize, red gram and cotton were 22.1˚, 28.48˚ and 21.48˚, respectively.

The static coefficient of friction of gbafilo fruit and kernel against three different structural surfaces was experimented. The results shown in Table 2 indicated that plywood structural surface had the highest value of static coefficient of friction for gbafilo fruit and kernel ($P < 0.05$). Glass as structural surface had the least static coefficient friction for gbafilo fruit and kernel ($P < 0.05$). Tabatabaeefar (2007) observed a similar trend in the static coefficient of friction of wheat. It was also reported that static coefficient of friction of glass surface was lowest, followed by galvanized iron and lastly plywood. There was no significant difference in the coefficient of static friction of wheat in all the surfaces tested while gbafilo experience significant difference in all the tested surfaces. The variation in the value of compressive force required to cause gbafilo fruit to rupture at two orientation positions revealed a significant difference ($P < 0.05$). In view of this observation, attention should be given to the manner in which gbafilo fruit and kernel are loaded since loading position had significant effect on the rupture force as shown in Figure 1.

CONCLUSIONS

The results of the physical and mechanical properties of gbafilo fruit and kernel (*Chrysobalanus icaco*) revealed significant difference ($P < 0.05$). Thus, the behaviour of gbafilo fruit and kernel towards harvesting, transporting, sorting, cleaning, separation, sizing, packaging and processing will be different. This finding could therefore be useful in the design and fabrication of appropriate processing machines. The static coefficient of friction of plywood structural surface was observed to be the highest followed by galvanized steel sheet and glass. This is an indication that plywood interior lining would not be suitable material for chute design.

Figure 1: Mechanical property of gbafilo at rupture force at two loading positions



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