



UDK: 621.1: 636.084.

Original scientific paper  
Originalni naučni rad  
doi:10.5937/POLJTEH20040290

## PHYSICAL PROPERTIES OF AFRICAN STAR APPLE FRUITS AND SEEDS

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**Abstract:** This research examines the physical properties of African star apple (*Chrysophyllum albidum*) fruits and seeds. The dimensions were measured with vernier calliper and the dimensional properties were computed using appropriate equations. The densities, porosity, angle of repose and coefficient of friction on three material surfaces were determined with standard methods from literature. The result of the study showed that the average major, intermediate and minor dimensions were 47.95 mm, 43.70 mm and 41.35 mm respectively for the fruits, and 26.05 mm, 15.12 mm and 6.07 mm respectively for the seeds. The volume, shape index and one thousand weight of fruits were obtained as 40.61 mm<sup>3</sup>, 0.95 and 48.34 kg respectively whereas those of the seeds were obtained as 1.69 mm<sup>3</sup>, 0.95 and 1.28 kg respectively. The true density, bulk density and porosity of the fruits were found to be 1710 kg/m<sup>3</sup>, 1550 kg/m<sup>3</sup> and 52.63 percent respectively, while that of the seeds were found to be 950 kg/m<sup>3</sup>, 570 kg/m<sup>3</sup> and 40.25 percent respectively. The sphericity obtained for the fruits and seeds were 0.94 and 0.55, respectively. Angle of repose was found to be 3.02° and 13.50° for the fruits and seeds, respectively. Coefficients of friction on plywood, mild steel and galvanized steel were 0.30, 0.24 and 0.20 respectively, for the fruits and 0.52, 0.46 and 0.39 respectively for the seeds. The empirical data from this study will aid researchers in the design and development of postharvest systems for the African star apple fruits and seeds postharvest operations.

**Key words:** African star apple fruits and seeds, bulk and true densities, dimensions, postharvest.

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## INTRODUCTION

The African star apple (*Chrysophyllum albidum*) is a tree crop that belongs to the family of *Sapotaceae*. The fruits and seeds are valued greatly in many African nations where the tree flourishes. The fruit contains higher quantity of ascorbic acid ( $446 \pm 2.5$  mg/100 g dry matter) compared to guava ( $201.1 \pm 0.7$ mg/100 g dry matter) or orange (28.89 mg/100 ml); and it also contains calcium, potassium, phosphorous, magnesium, tannins, flavonoids, terpenoids, and phytochemicals [1-4]. The nutritive value of the fruit makes it an excellent raw material for fruit jam, nectars, jelly and juice production [5-9]. According to [1], consumers of African star apple fruit have their blood sugar and cholesterol reduced. It was suggested that consumption of the fruit helps pregnant women for easy child delivery [10]. Some researchers [11] posit that the fruit is used to treat avitaminosis and dental decay in Benin republic. Each African star apple fruit has between 4-5 seeds [12]. The seed contains 10.71% oil, 18.34% crude protein, 6.48% fat and 4.63% crude fibre [13, 14]. The seed has potency in haemorrhoid and intestinal worm treatment [11].

Like many fruits, African star apple is a seasonal crop. The season spans between December and April [15]. The fruits are sold in markets and communities close to where they are grown. The fruit is yet to become an export commodity despite the potentials. The fruit suffers postharvest losses under ambient conditions [16, 17]. There is no standard storage and packaging systems for the fruits. This has further limited the commercialisation of the fruits. Therefore, there is need for the development of postharvest systems for the handling, processing and storage to guarantee availability of the fruits in and out of season. The design of such systems for postharvest operations of African star apple fruits and seed cannot be possible if their properties remain unknown. An attempt was made by [18] to investigate the properties of the seeds. However, their study failed to consider the properties of the fruits alongside.

The relevance of studying the physical properties of agricultural products cannot be overemphasized. As a result, many researchers have investigated the properties of various crops such as African breadfruit seed [19], yellow passion fruit seeds [20], kiwi fruits [21], *Cucurbita moschata* Duch. [22], date fruit varieties [23], groundnut pods and kernels [24], *Canarium schweinfurthii* Engl. fruits [25], Roselle calyxes [26], bottle gourd seeds [27], almond nut and kernel [28], wild mango fruit and nut [29], fluted pumpkin seed [30], African oil bean seed [31], *Prosopis Africana* seed [32], pistachio nuts and kernel [33], guan seed [34], among others. Apart from engineers, information on properties of biological materials is useful to scientists, processors and plant breeders [35].

Hence, the objective of this work was to determine the properties of the fruits and seeds of African star apple such as dimensions, densities, volume, porosity, angle of repose and coefficient of friction.

## MATERIAL AND METHODS

### Sample preparation

A bulk sample of freshly harvested African star apple fruits were obtained from Ngwa road market, Aba in Eastern Nigeria.

The fruits were manually cleaned and sorted to ensure that only good quality fruits are used for the experiment. Two-third of the bulk fruit sample were ripped open to extract the seeds. The moisture content of the fruits and seeds were determined using oven drying method at 105°C for 24 hours. One hundred samples of fruits and seeds were randomly selected from the bulk sample for the measurement of axial dimensions. The dimensions were measured at moisture contents of 61.89 percent and 37.62 percent respectively for the fruits and seeds.

### Determination of the dimensions of the fruits and seeds

The three principal axes, major (a), intermediate (b) and minor (c) dimensions of each fruit and seed were measured using digital vernier calliper (Mitutoyo, Japan) with an accuracy of 0.01 mm. The geometric mean dimension ( $D_g$ ), arithmetic mean dimension ( $D_a$ ), sphericity ( $\varphi$ ) and square mean dimension ( $D_s$ ) were computed using Equations (1), (2), (3) and (4) thus [18, 32, 34]:

$$D_g = (abc)^{1/3} \quad (1)$$

$$D_a = \frac{(a+b+c)}{3} \quad (2)$$

$$\varphi = \frac{(abc)^{1/3}}{a} \quad (3)$$

$$D_s = \left( \frac{ab+bc+ac}{3} \right)^{1/2} \quad (4)$$

The shape index of the fruits and seeds was determined using the following Equation [36]:

$$\text{Shape index} = \frac{a}{\sqrt{bc}} \quad (5)$$

### Determination of the gravimetric properties

One thousand weight of both the fruit and seed was determined using the method described by [37, 38] where 100 fruits and seeds were weighed separately with an electronic balance and multiplied by ten. The average mass of five replications was taken as the mean.

The bulk density ( $\rho_b$ ) of the fruits and seeds was measured with the method used by [39]. The method involves weighing separately the fruits and seeds packed in containers of known volume. The sample was densely packed by gently tapping the container to allow the settling. Then the bulk density was computed as:

$$\rho_b = \frac{\text{weight of material packed}}{\text{known volume}} \quad (6)$$

The true densities ( $\rho_t$ ) of the fruits and seeds were determined using water displacement method. A sample was measured and the weight ( $W_s$ ) and number of samples ( $n_s$ ) in each experiment carefully noted. The sample was poured into a measuring cylinder of known volume, and the volume of water displaced was recorded. The true density was then computed thus:

$$\rho_t = \frac{W_s}{V_s} \quad (7)$$

The individual weight and volume of samples were determined from the measurements taken for true density. The porosity was calculated using the relationship between bulk and true densities [35]:

$$p = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \quad (8)$$

#### Determination of the frictional properties

The frictional properties which consist of the angle of repose and coefficient of frictions were studied for the seeds and fruits using the following methods.

##### Angle of repose

This was determined using a topless and bottomless cylinder as reported by [32, 40, 41]. The cylinder was placed over a smooth circular plate and filled with the fruits to a reasonable level. Then the cylinder was raised slowly allowing the fruits to flow down and form a natural cone. The height of the cone ( $H$ ) and the diameter ( $D$ ) were measured and the angle of repose calculated using the following Equation:

$$\theta_r = \tan^{-1} \left( \frac{2H}{D} \right) \quad (9)$$

##### Coefficient of friction

The static coefficient of friction was determined using an inclined plane [42]. The inclination of the test surface was gradually increased until the box just started to slide down and the angle of tilt ( $\alpha$ ) was read from the graduated scale attached to instrument. Three different material surfaces, namely, plywood, mild steel and galvanized steel were used to measure the friction coefficient of fruits and seeds on them. Five replications were taken for each test surface.

For each replication, the sample in the container was emptied and refilled with new sample. The static coefficient of friction ( $\mu_s$ ) was then calculated from Equation (10) given by [40]:

$$\mu_s = \tan \alpha \quad (10)$$

## RESULTS AND DISCUSSION

### Dimensional properties

The average values for the major, intermediate, minor, arithmetic mean, geometric mean and square mean dimensions of African star apple fruit are 47.95 mm, 43.70 mm, 41.35 mm, 42.82 mm, 42.80 mm, and 12.08 mm respectively, as shown in Table 1.

The arithmetic and geometric mean dimensions are higher than the minor dimension but lower than the major and intermediate dimensions (Table 1). This follows the same trend for bottle gourd seeds [27].

Table 1. Physical properties of African star apple fruit

Properties	Minimum	Mean	Maximum	SD
Major axis, mm	40.83	47.95	58.80	4.19
Intermediate axis, mm	36.11	43.70	56.12	4.05
Minor axis, mm	37.86	41.35	46.31	2.73
Arithmetic mean dimension, mm	39.09	42.82	48.31	2.86
Geometric mean dimension, mm	39.06	42.80	48.23	2.86
Square mean dimension, mm	11.35	12.08	13.26	0.55
Shape index, dimensionless	0.92	0.95	0.96	0.01
Sphericity, dimensionless	0.92	0.94	0.95	0.01
Unit volume, mm <sup>3</sup>	30.3	40.61	50.1	6.81
Unit weight, g	38.5	48.92	60.4	6.72
One thousand weight, kg	47.14	48.34	49.11	0.69

SD is the standard deviation

The relationship between the dimension ratio  $a/b$ ,  $a/c$ ,  $a/D_g$  and  $a/D_a$  can be expressed as:

$$a = 1.10b = 1.16c = 1.12D_g = 1.12D_a$$

This indicates that the intermediate, minor, geometric mean and arithmetic mean dimensions have positive relation with the major axis.

The mean values of African star apple shape index and sphericity are 0.95 and 0.94 respectively.

The sphericity value falls within the range of 0.32 – 1.00 for most agricultural materials [35]. The value of the sphericity that is closer to 1.00 shows that the fruit has high tendency to roll than slide [29, 41].

### Dimensions of the African star apple seed

The average values for the major, intermediate, minor, arithmetic mean, geometric mean and square mean dimensions of African star apple seeds were 26.05 mm, 15.12 mm, 6.07 mm, 15.63 mm, 14.91 mm, and 6.06 mm respectively, as shown in Table 2. The shape index and sphericity were obtained as 0.95 and 0.55, respectively. Unlike the fruit, the African star apple seed will not roll easily because of its relative low sphericity value of 0.55.

Table 2. Physical properties of African star apple seed

Properties	Minimum	Mean	Maximum	SD
Major axis, mm	21.81	26.05	31.64	1.81
Intermediate axis, mm	12.55	15.12	17.78	1.09
Minor axis, mm	8.49	6.07	10.69	0.59
Arithmetic mean dimension, mm	17.49	15.63	18.83	0.93
Geometric mean dimension, mm	15.81	14.91	17.03	0.68
Square mean dimension, mm	6.50	6.06	6.84	0.23
Shape index, dimensionless	1.02	0.95	1.12	0.05
Sphericity, dimensionless	0.58	0.55	0.63	0.02
Unit volume, mm <sup>3</sup>	1.85	1.69	1.99	0.09
Unit weight, g	1.33	0.70	1.70	0.21
One thousand weight, kg	1.30	1.28	1.32	11.35

SD is the standard deviation

### Gravimetric and frictional properties of the fruits and seeds

The average values of the bulk and true densities of African star apple fruits were found to be 1550 kg/m<sup>3</sup> and 1710 kg/m<sup>3</sup>, respectively (Table 3). The bulk and true densities of the fruit are higher than that of the seeds average values found to be 570 kg/m<sup>3</sup> and 950 kg/m<sup>3</sup> respectively (Table 4). The densities are in the range obtained for the seeds at 8.49 percent moisture content dry basis [18]. The true density of the fruit is higher than that of Pistachio kernel (1082.73 – 1087.98 kg/m<sup>3</sup>) and Pistachio nuts (1180.75 – 1210.50 kg/m<sup>3</sup>) as reported by [33].

The bulk density of the seed is close to the values of Pistachio bulk density, 465.38-576.20 kg/m<sup>3</sup> [33] and higher than that of groundnut, 479.28 kg/m<sup>3</sup> [43].

The porosity of the fruit, which is dependent on the bulk and density densities, was higher than that of the seed. The average value of the fruit porosity was obtained as 52.63 percent (Table 3) whereas that of the seed is 40.25 percent (Table 4).

The porosities of both the fruit and the seed are within the range of porosity of karingda seed, 40.7 – 57.6 percent, reported by [42]. The porosity is important in designing drying, packaging and storage systems for the product. The angle of repose, which is the angle at which the product will stand when piled, was obtained as 3.02° and 13.50° respectively, for the fruit and the seed (Tables 3 and 4). These values are below the highest possible angle of repose of 45° for most agricultural products [35].

The fruit's coefficient of friction was found to be 0.30, 0.24 and 0.20 on plywood, mild steel and galvanized steel surfaces, respectively (Table 3).

The coefficient of friction of the fruit on galvanized steel is similar to that of *Garcinia kola* seeds (0.20) on galvanized steel surface [41] and the value on plywood compares well with the value obtained for oilseed bean on glass (0.29) as reported by [44].

Table 3. Gravimetric and frictional properties of African star apple fruit

Properties	Minimum	Mean	Maximum	SD
Bulk density, kg/m <sup>3</sup>	1200	1550	1800	0.20
True density, kg/m <sup>3</sup>	1380	1710	1940	0.18
Angle of repose, degree	2.87	3.02	3.20	0.12
Porosity, %	51.04	52.63	53.12	0.61
Coefficient of friction on:				
Plywood	0.28	0.30	0.31	0.004
Mild steel	0.23	0.24	0.26	0.007
Galvanized steel	0.19	0.20	0.22	0.008

SD = standard deviation

Table 4. Gravimetric and frictional properties of African star apple seed

Properties	Minimum	Mean	Maximum	SD
Unit weight, g	1.33	0.70	1.70	0.21
One thousand weight, kg	1.30	1.28	1.32	11.35
Bulk density, kg/m <sup>3</sup>	560	570	590	0.01
True density, kg/m <sup>3</sup>	970	950	990	0.01
Angle of repose, degree	15.15	13.50	17.10	1.02
Porosity, %	42.71	40.25	44.83	0.43
Coefficient of friction on:				
Plywood	0.52	0.50	0.54	0.02
Mild steel	0.46	0.44	0.48	0.01
Galvanized steel	0.39	0.34	0.42	0.03

SD = Standard deviation

The coefficient of friction of the African star apple seed was found to be 0.50, 0.44 and 0.34 on plywood, mild steel and galvanised steel surfaces, respectively (Table 4). It was observed that these values are higher than that of the fruit on the same material surfaces. These data are valuable for the design of hoppers, conveying systems, and storage systems for the product.

### CONCLUSIONS

The following conclusions were drawn from the investigation on the physical properties of African star apple fruits at moisture content of 61.89 percent (wet basis) and African star apple seeds at moisture content of 37.62 percent (wet basis). The average characteristic dimensions - major, intermediate and minor axes - of the fruit were 47.95 mm, 43.70 mm and 41.35 mm, respectively, whereas those of the seed were 26.05 mm, 15.12 mm and 6.07 mm, respectively. The bulk and true densities were found to be 1550 kg/m<sup>3</sup> and 1710 kg/m<sup>3</sup> for the fruits, and 570 kg/m<sup>3</sup> and 950 kg/m<sup>3</sup> for the seeds, respectively. The porosity was found to be 52.63 percent for the fruit and 40.25 percent for the seed. Angle of repose was obtained as 3.02° for the fruit and 13.50° for the seed. These empirical data for the various properties of African star apple fruit and seed will be useful in designing postharvest systems that will add value to the African star apple fruits and seeds.

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## FIZIČKE OSOBINE PLODA I SEMENA JABUKE AFRIČKA ZVEZDA

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**Sažetak:** Ovo istraživanje prikazuje fizičke osobine plodova i semena jabuke Afrička zvezda (*Chrisophillum albidum*). Dimenzije su merene preciznim pomičnim merilom (nonijus-mikrometar). Karakteristične dimenzije izračunate pomoću odgovarajućih relacija i jednačina.

Zapremina, poroznost, ugao nagiba i koeficijent trenja po podlozi za tri površine različitih materijala utvrđeni su standardnim metodama iz literature. Rezultat studije je pokazao da su prosečne velike, srednje i male dimenzije jabuke bile: 47,95 mm, 43,70 mm i 41,35 mm za plodove, odnosno 26,05 mm, 15,12 mm i 6,07 mm za seme jabuke.

Gustina, indeks oblika i težina hiljadu plodova, dobijeni su kao 40,61 mm<sup>3</sup>, 0,95 i 48,34 kg, dok su semena dobijena kao 1,69 mm<sup>3</sup>, 0,95 i 1,28 kg, retrospektivno. Utvrđeno je da su stvarna gustina, zapreminska težina i poroznost plodova 1710 kg/m<sup>3</sup>, 1550 kg/m<sup>3</sup>, odnosno 52,63 %, dok je određeno da je gustina semena 950 kg/m<sup>3</sup>, 570 kg/m<sup>3</sup> i 40,25 % retrospektivno.

Dobijena sferičnost plodova i semena jabuke iznosila je 0,94, odnosno 0,55. Utvrđeno da je ugao mirovanja (nema kotrljanja) za plodove 3,02°, odnosno za seme 13,50°. Koeficijenti trenja po šper ploči, mekanom čeliku i pocinkovanom čeliku su vrednosti 0,30; 0,24, i 0,20 za plodove, odnosno 0,52; 0,46 i 0,39 za semena jabuke.

Empirijski podaci iz ove studije pomoći će istraživačima u dizajnu i razvoju sistema čuvanja za plodove i semena jabuke Afrička zvezda (*Chrisophillum albidum*) posle berbe.

**Ključne reči:** *Plodovi i semena jabuke Afrička zvezda, zapremina i stvarna gustina, dimenzije, naknadna berba.*

Prijavljen:	02.10.2020.
<i>Submitted</i>	
Ispravljen	15.10.2020.
<i>Revised:</i>	
Prihvaćen	26.10.2020.
<i>Accepted:</i>	