Determination of some engineering properties, proximate composition and phytochemical properties of African star apple (*chrysophyllum albidum*)

John Isa

(Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure, Nigeria)

ABSTRACT: African star apple (*Chrysophyllum albidum*) is a popular tree in tropical region with all the parts used for food and medicinal purposes. This study focused on the determination of some physical properties, mechanical properties, proximate composition, and phytochemical properties of the fruit. The experiment was conducted using standard procedures. Results for the physical properties of the fruits had values as follows: length per fruit 3.41–5.53 cm, width per fruit 3.31–5.08 cm, and thickness per fruit 2.93–4.73 cm, respectively. The density was found to be 1.07 g.cm^{-3}. The volume, angle of repose, geometric mean diameter, arithmetic mean diameter, spherical area was 47.55 cm^3, 4.74 °, 4.13 cm, 4.85 cm and 0.88 cm^2 respectively. The result for the mechanical properties for maximum compressive stress was 0.0519–0.1193 MPa and mean was 0.0908 MPa, while the standard deviation and coefficient of variation were 0.0252 MPa and 0.2775% respectively for the longitudinal orientation. And it was 0.062–0.0854 MPa and mean was 0.0739 with standard deviation and coefficient of variation were 0.0094 MPa and 0.1299% respectively for the transverse orientation. The coefficient of internal friction for the fruit was 0.083. The result of the proximate composition of the fruit showed that the juice component contained 76.20%–76.50 % moisture, 4.20%–4.40% fat, 3.4%–3.6% crude protein, 2.00%–2.20% ash, 10.00%–10.10% carbohydrate and 3.6%–3.9% crude fibre. The African star apple was also found to contain high nutrients and minerals such as calcium, 413.20 mg100g^{-1}, potassium, 654.21 mg 100g^{-1}, sodium, 53.61 mg 100g^{-1}, magnesium, 203 mg 100g^{-1}, iron, 2.160 mg 100 g^{-1}, and β -carotene content 367.92–368.11 mg 100g^{-1} with low anti nutrient such as tannin, alkaloid, flavoid, steroid *etc*.. This makes it safe for consumption as snacks by all.

Keywords: density, volume, angle of repose, geometric mean diameter, arithmetic mean diameter, sphericity

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1 Introduction

African star apple (*Chrysophyllum albidum*), is locally referred to as *agbalumo* by the Yorubas and *udaru* by Igbos in Nigeria. It belongs to the plant family *Sapotaceace* and is classified into the genus *chrysophyllum* (Oyelade et al., 2005). The trees are about 30 m tall and always produce green leaves throughout the year and seasonal fruit. The fruits are green and turn orange as they matures (Nzelu, 2009). African star apple fruit contains five large coffee-coloured seeds or sometimes fewer by abortion. It is common in both rural and urban center especially during the months of December to April. The fruits are not usually harvested from the trees but left to drop naturally to the floor (Amusa et al., 2003). The pulp is tart in taste and chewing the pulp will produce a significant quantity of gum

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***Corresponding author: J. Isa.** Ph.D, Department of Agricultural Engineering, Federal University of Technology, Akure, Nigeria, Tel: +2348034971788, Email: jisa@futa.edu.ng

residue (Nzelu, 2009).

African star apple fruit (*Chrysophyllum africanum*) serves as excellent source of vitamins, irons, flavours to diets and is of great economic value due to its diverse industrial, medicinal and food uses. The fruits are not only consumed fresh but also used to produce jam, jellies, stewed fruit, marmalade, syrup and several types of soft drinks in beverage industry (Oyelade et al., 2005). It is also used for medical purposes due to properties of stalk and fruits. The leaves and seeds are used in pharmaceuticals (Olufunmilola and Oladapo, 2011). Some of the trees are also valuable for ornamentation as an ever green broadleaf plant (Islam, 2002).

Several researchers (Adisa, 2000; Amusa et al., 2003; Egunyomi, et al., 2005; Akubugwo and Ugboku, 2007; Ugbogu and Akukwe, 2008; Duyilemi and Lawal, 2009; Adebayo et al., 2010; Adewoye et al., 2010) have reported the nutritional and medicinal importance of C*hrysophyllum albidum*. In spite of the wide consumption of this wild fruit and its great contribution to the nutritional intake of Nigerians, its seasonality limits and availability throughout the year couple with nutrients losing shortly after harvesting due to biochemical and microbial changing .

The study of food engineering focuses on the analysis of equipment and systems used to process food on a commercial production scale. Engineering of systems for food materials can be more thorough if there is an understanding of the changes that occur in food as it is processed by the system. Raw food materials are biological in nature and as have certain unique characteristics which distinguish them from other manufactured products. Because food materials are mainly biological origin, they have irregular shapes commonly found in natural raw materials, properties with a non-normal frequency distribution, heterogeneous composition, and composition varies with variety, growing conditions, maturity and other factors; as well as they are affected by chemical changes, moisture, respiration, and enzymatic activity. Dealing with materials that have these unique characteristics requires additional consideration, mostly indirect, in that there are additional sources or causes of variation. People unfamiliar with this natural variability of biological materials, so may overlook these factors or be frustrated by lack of control over the input parameters. This study aims to examine the engineering properties, proximate composition and phytochemical composition of African star apple fruit (C*hrysophyllum africanum*) after harvesting.

Therefore, the specific objectives of this research are to determine engineering properties of African star apple fruit, the proximate composition, mineral and vitamin content, the phytochemical properties, and nutritional composition of the fruit flesh.

2 Materials and methods

2.1 Sample collection

Ripe cherry fruits used in this study were procured from local market in Akure, Ondo State, Nigeria. The samples were sorted based on size, graded based on level of damage and the firmness. The undamaged samples were cleaned and kept in the refrigerator prior to its usage while the injured and damaged one were disposed. Other material used for this study included laboratory oven, vernier calliper, micrometer screw gauge, meter rule, weighing balance, and universal testing machine (UTM).

2.2 Determination of physical properties

All measurements were done on the cherry fruit as it was necessary for further processing of the product. The physical properties such as length (L), width (W), thickness (T), mass (M), volume (V), true density (T_d), bulk density (B_d), geometrical mean diameter (Dg), arithmetic mean diameter (Da), sphericity factor (ϕ), porosity (p), and surface area (S) were examined (Mammam et al., 2005). The experiment was carried out at the laboratory with 28 ^{o}C temperature and 70% relative humidity.

2.2.1 Dimensional measurement

The axial dimensions of the 100 cherry fruit were measured using digital vernier calliper with an accuracy of 0.01 mm. By using the three geometric dimensions, the geometrical mean diameter, sphericity factor and surface area(S) were obtained.

2.2.2 Fruit diameters and sphericity factor

The method reported by Dutta et al. (1999) was used for determining the diameters and sphericity factor from three principal dimensions namely length, width, and thickness which were measured using a vernier caliper. The geometric mean diameter (D_g) in cm, arithmetic mean diameter (D_a) in cm and sphericity factor (ϕ) was calculated as the Equations 1–3.

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

$$D_a = \frac{L+W+T}{3} \quad (2)$$

$$\phi = \frac{(LWT)^{\frac{1}{3}}}{L} \times 100\% \quad (3)$$

2.2.3 Surface area

The surface area of the kernels was determined using the relationship described by Mccabe et al. (1986) as shown in Equation 4.

$$S = \pi Dg^2 \quad (4)$$

2.2.4 Coefficient of static friction

The coefficient of static friction of the cherry fruit was determined using sliding box. The fruit was placed on an adjustable tilting plate. The structural surface with the fruit on it was gradually raised with a screw component of the device until the fruit sample just started to slide down and the angle of tilt was read from a graduated scale on the device. The coefficient of static friction was calculated as follow.

$$\mu = \tan \phi \quad (5)$$

Where μ was coefficient of static friction and ϕ was angle of tilt.

2.2.5 Weight determination

The weight of each fruit was measured using a precision digital weighing balance (accuracy was 0.01 g) and the average was computed. To determine 100 unit mass (M_{100}), 50 fruits were selected randomly and weighed.

2.2.6 Volume determination

The volume of each fruit was obtained using water displacement method. A measuring cylinder of 500 mL was used. The water was dropped in the measuring cylinder which was equal to the cylinder volume following Archimedes principle, and the weighed fruit was carefully dropped into the cylinder filled with water. The volume of the overflowed water was measured as it was equivalent to that of the fruit. This procedure was also used for the determination of bulk volume by using 50 samples of the cherry fruit.

2.2.7 Density determination

The density of each fruit (ρ) was calculated as unit mass (m) per unit volume (v), while the bulk density (γ) was calculated as bulk mass (m_b) per bulk volume (v_b). They were mathematically expressed as follows.

$$\rho = \frac{m}{v} \quad (6)$$

$$\gamma = \frac{mb}{vb} \quad (7)$$

2.3 Determination of mechanical properties

African star apples were subjected to compression up to failure in order to determine the force-deformation behaviour at both longitudinal and transverse orientation of loading. The dimensions of each seed were determined prior to loading. The three principal dimensions namely length, width, and thickness were measured using a vernier caliper (Accuracy was 0.01 mm). These measurements were used to calculate the volume of the individual seeds by assuming the seeds were ellipsoid in shape. Seeds were further visually examined, discarding those with visible cracks in the hull. A universal testing machine (Shimadzu Autograph DSS-10T-S) equipped with a 1 kN load cell was used for the compression of the egusi melon seeds. The seeds were compressed between two flat parallel plates, at a crosshead speed of 1 mm/min.

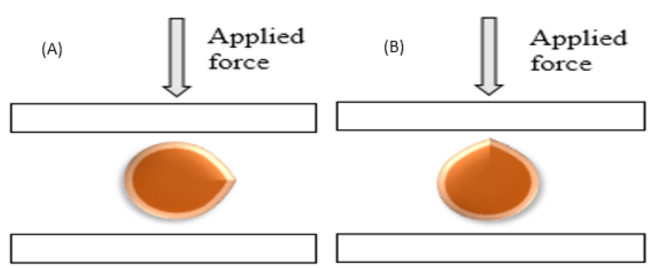

Figure 1 Compression test of African star apple under transverse orientation
(A) and longitudinal orientation (B)

The force-deformation curves were recorded with an analog recorder and stored for further processing using a high-speed data acquisition system. The measurement accuracy was ±0.5 N in force and 0.001 mm in deformation (Erica, 2006). To determine the effect of loading orientations on rupture, the samples were tested in transverse and longitudinal orientations as shown in Figure 1.

2.4 Procedure for evaluating chemical properties

A proximate analysis of the cherry was carried out with 73 fruits following different laboratory methods as follows:

2.4.1 Moisture content

Moisture content of the material was determined using the standard oven drying method described by AOAC (1990, 2000) which was generally adopted as an efficient method of determining moisture content and the procedure was as follows: Sampling dishes were taken and measured empty to get their weight on an electronic weighing balance. A carefully diced firm cherry fruit (5 g) were weighed on the electronic balance to get initial weight of the samples and recorded as W_1. Measured samples were taken into the aluminum dishes into the electronic oven for drying at a temperature of 105°C till the weight of the samples were not changing (about 8 h) (Kane, et al., 2008) and at this point the samples were removed from the oven and reweighed to get the final weight and recorded as W_2 (Norimi, et al., 2012). The Equation 8 was used in determining the moisture content.

$$MC_{db} = \frac{W_1 - W_2}{W_2} \quad (8)$$

Where MC_{db} was the moisture content.

2.4.2 Determination of ash content

This was determined by the dry-ashing method using muffle furnace. The organic compounds were heated with a flame in an open dish or crucible at 550–600 °C before put in the furnace. The residue remaining after the destruction of the organic matter sample used was weighed as total ash (AOAC, 1995).

2.4.3 Determination of crude fibre content

Crude fibre is the insoluble and combustible organic residue remains after the sample has been treated under prescribed conditions. The method employed for the sample is the procedure laid down in the fertilizers and feeding stuff (Amendment) Regulations 1976 SI NO 840 (Egan et al., 1981).

2.4.4 Determination of protein content

Crude protein was determined by the Micro Kjeldhal method (AOAC, 1995). 5 g of the sample was digested with conc. H_2SO_4 and Kjeldahl catalyst in a Kjeldahl flask for 3 h. The digest was made up to 100mL and 5 mL portion was then pipetted to Kjeldahl apparatus as well as 5 mL of 40% (w v^{-1}) NaOH solution was added. The mixture was distilled, and the liberated ammonia was collected in 10 mL of 2% boric acid and titrated against 0.01 M HCl solution. The amount of crude protein was then calculated by multiplying percentage nitrogen in the digest by 6.25 (AOAC, 1995).

2.4.5 Determination of carbohydrate content

Carbohydrates content was determined according to FAO (1982) as follows:

$$C = 100 - (m + p + a + l + f) \quad (9)$$

Where C is the Carbohydrate (%), m is moisture (%), p is the protein (%), a is the ash (%), l is the lipid (%)and f is the crude fiber (%)

2.4.6 Determination of mineral composition

Mineral composition was determined according AOAC methods (AOAC, 1990; AOAC, 2000) using atomic absorption spectrophotometry (AAS). 2 g of fruit pulp was dried in an air oven at 105 °C for 3 h. The dried sample was next charred until it ceased to smoke. The charred sample was then ashed in a muffle furnace at 550°C until a whitish or greyish ash was obtained. The ash was treated with concentrated hydrochloric acid transferred to a volumetric flask and made up to 100 mL before submission to atomic absorption spectrophotometry (AAS).

For AAS, a SHIMADZU atomic absorption flame emission spectrophotometer model AA-670 IF with an air-acetylene flame was used, and wavelength was set to 422.7 nm for calcium, 279.5 nm for manganese, 248.3 nm for iron and 213.9 nm for zinc determination respectively. Stock solutions (1000 ppm) of calcium, manganese, iron and zinc were used to prepare working standard solutions with at least 4 concentrations within the analytical range. To eliminate phosphorus interference, lanthanum chloride was added to working standard solutions of calcium and to the test ash solution destined to calcium determination so that the final solutions contained 1% La. Concentration of each mineral contained in test solutions was calculated from the standard curve prepared (Ureigho and Ekeke, 2010).

2.4.7 Determination of phytochemical content

The phytochemical content of the African star apple which included the Lycopene (mg $100g^{-1}$), VC (mg $100g^{-1}$), Terpenoid (%), Saponins (%), Alkaloid (%), Tannin (mg $100g^{-1}$), Steroid (mg $100g^{-1}$), and Flavoid (mg $100g^{-1}$) were carried out on the flesh of the fruit using the standard method described by AOAC (1990, 2000)

3 Results and discussion

3.1 Physical properties

3.1.1 Size and shape

The statistical results of the tests were presented below with the mean, SD and CV. The 100 sample measurements taken for the axial dimensions of the African star apple were presented in Table 1 and Figures 2-4. Arithmetic and geometric mean diameter, sphericity and surface area with their respective frequency distribution were presented in Table 2 and Figures 5-8. The results showed that the length, width, and thickness of the fruit ranged between 3.41–5.53 cm, 3.31–5.08 cm and 2.93–4.73 cm, respectively, while the arithmetic mean diameter, geometric mean diameter, and sphericity ranged between 3.55–4.95 cm, 3.53–4.94 cm, 0.74–1.05 and 39.08–76.68, respectively. The sphericity values of the African cherry fruit fall within the range of 0.32–1.00 reported by Mohsenin (1986) for most agricultural particles.

Table 1 Descriptive statistics of the axial dimensions

Statistical parameters	Length (cm)	Width (cm)	Thickness (cm)
Mean	4.69	3.90	3.87
Median	4.68	3.90	3.91
Mode	4.61	3.91	3.91
Standard Error	0.04	0.03	0.03
Standard Deviation	0.39	0.32	0.27
Sample Variance	0.16	0.09	0.07
Kurtosis	0.13	4.05	1.94
Skewness	-0.16	1.59	-0.14
Range	2.12	1.77	1.80
Minimum	3.41	3.31	2.93
Maximum	5.53	5.08	4.73
Sum	468.70	390.51	387.10
Confidence Level (95.0%)	0.08	0.06	0.05

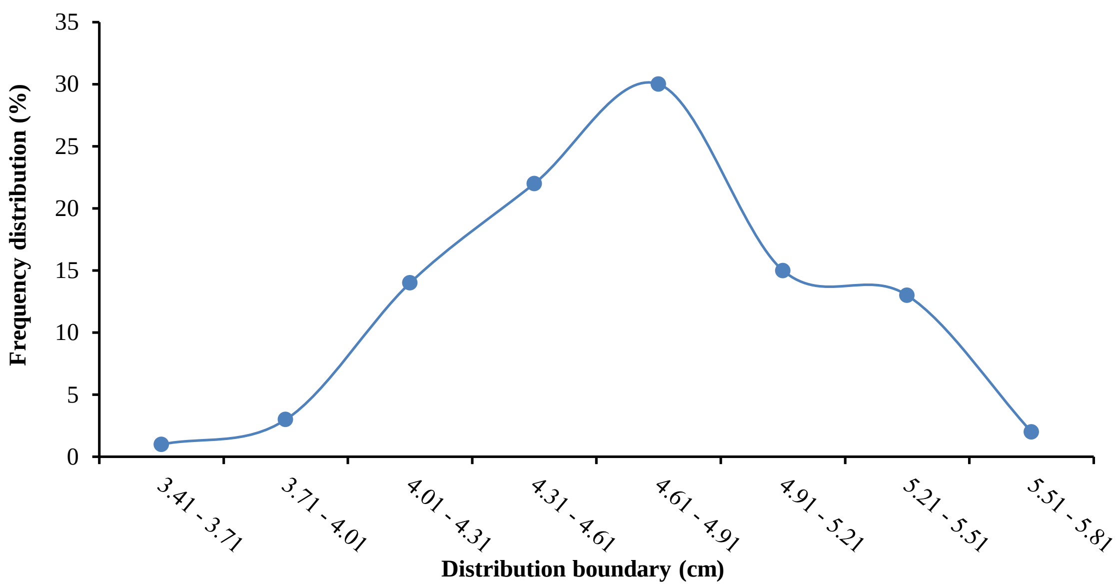

Figure 2 Frequency distribution of length

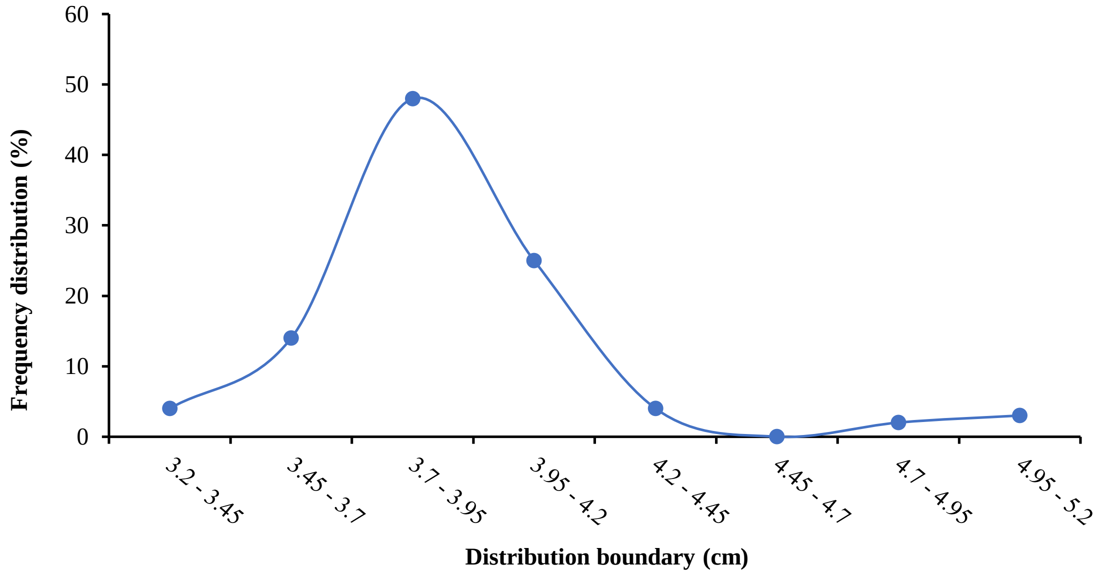

Figure 3 Frequency distribution of width

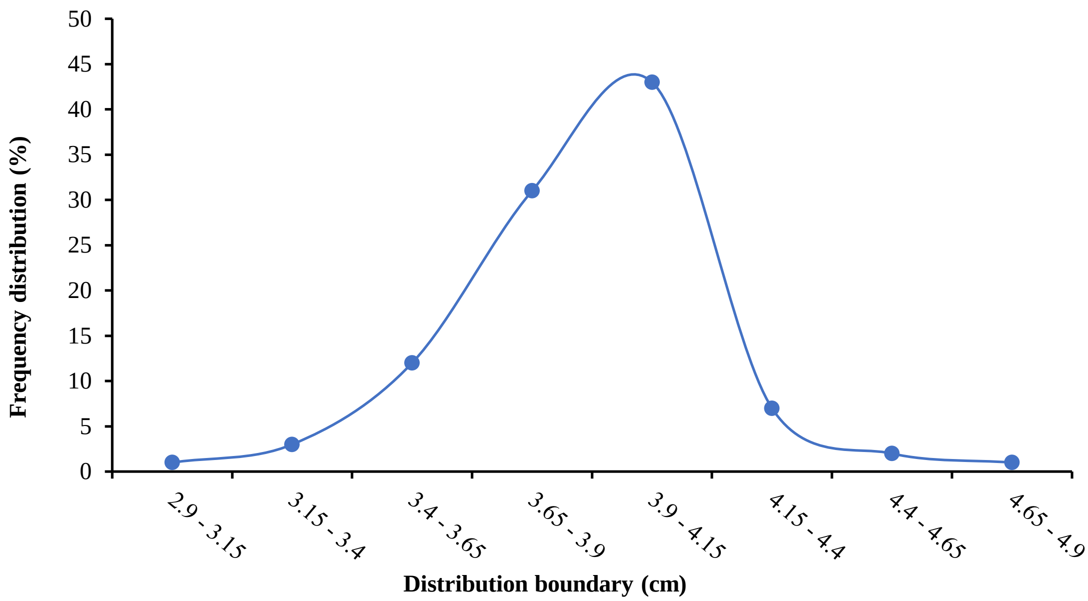

Figure 4 Frequency distribution of thickness

The little difference in the axial dimensions of the fruit with the relatively high sphericity (>0.65) showed that the seed would rotate easily during handling. The closer the sphericity to 1.0, the higher the tendency to roll about any of the three axes. The ratio of thickness to width of the fruit was closer to 1.0 and this showed its high tendency to rotate about the major axis. The skewness and kurtosis analysis of the frequency distribution curves for the 100 readings taken for each dimension was presented in Table 2. The curves showed the distribution for all the parameters with the peaks being around the means which agreed with earlier results by Ige (1977) for five varieties of cowpea, Irtwange and Igbeka (2002) for two African yam bean accessions and Taser et al. (2005) for vetch seed. This was an indication that the axial dimensions were relatively uniform and these were useful information in the design of separation and size reduction systems. Positive skewness indicates a distribution with an asymmetric tail extending towards more positive values (skewed to the right) and vice versa for negative. Kurtosis characterizes the relative peakedness or flatness of a distribution compared to the normal distribution, therefore, the positive skewness and kurtosis characterizes of all the physical properties distribution shows that most of the properties of the fruit are greater than the mean value.

Table 2 Descriptive statistics of some physical properties (shape) gotten from dimensions

Statistical parameters	Arithmetic mean (cm)	Geometric mean (cm)	Sphericity	Surface area (cm^2)
Mean	4.15	4.13	0.88	53.94
Median	4.16	4.14	0.88	53.95
Standard Error	0.03	0.03	0.01	0.719
Standard Deviation	0.28	0.28	0.04	7.19
Sample Variance	0.08	0.08	0.01	51.82
Kurtosis	0.09	0.17	2.59	0.41
Skewness	0.17	0.18	0.25	0.39
Range	1.39	1.41	0.30	37.59
Minimum	3.55	3.53	0.74	39.08
Maximum	4.95	4.94	1.05	76.68
Sum	415.44	413.44	88.44	5393.67
Confidence Level (95.0%)	0.06	0.05	0.01	1.43

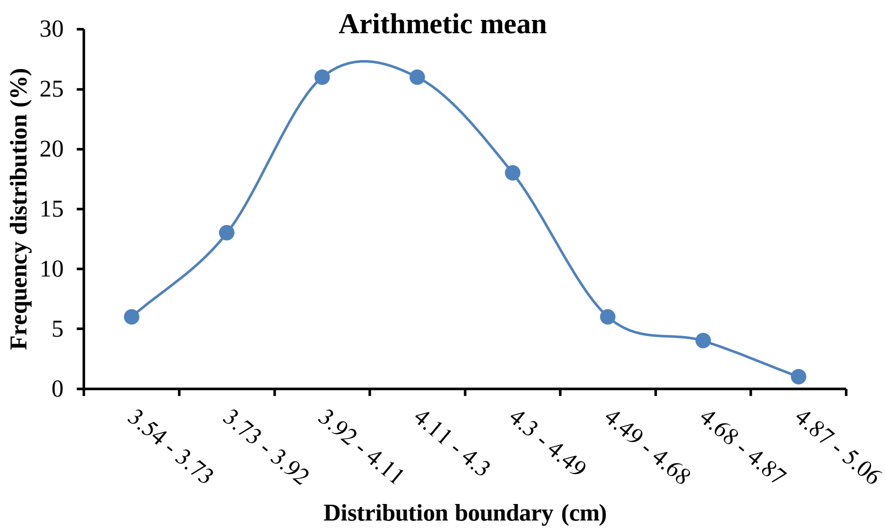

Figure 5 Frequency distribution of arithmetic mean diameter

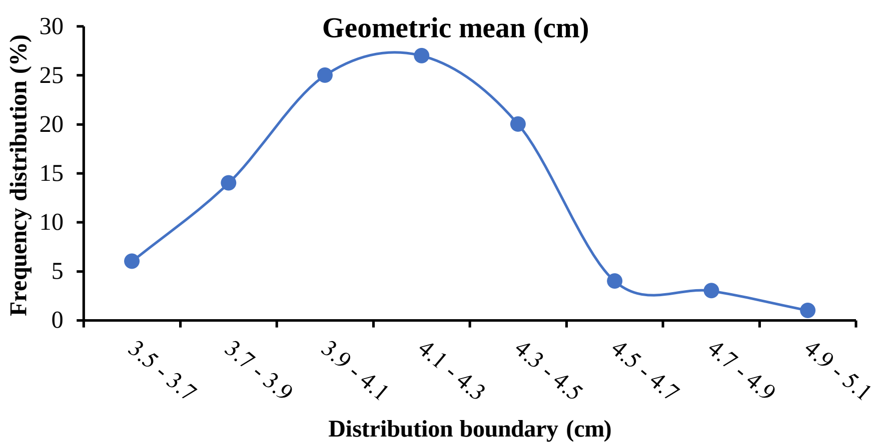

Figure 6 Frequency distribution of geometric mean diameter

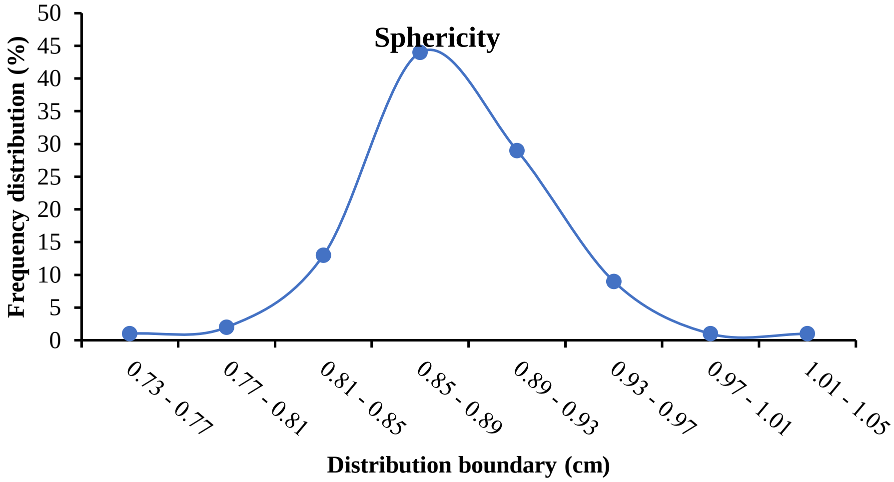

Figure 7 Frequency distribution of the sphericity

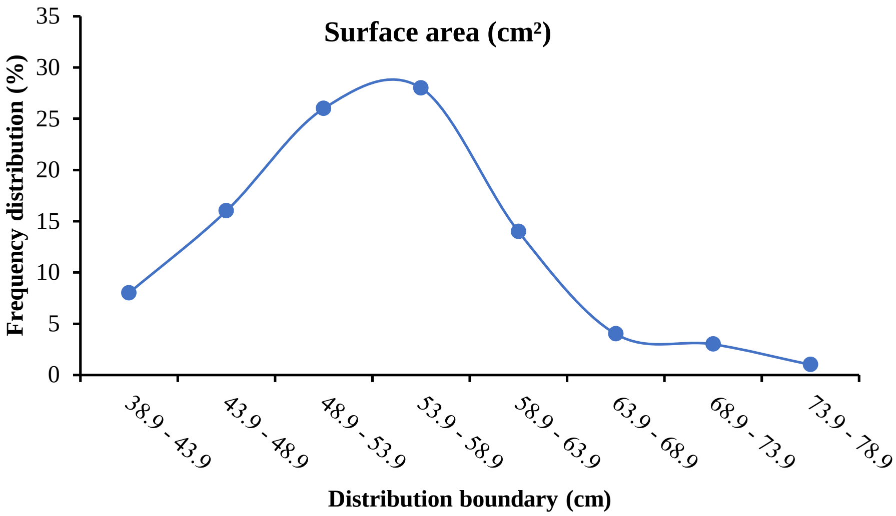

Figure 8 Frequency distribution of surface area

Table 3 Statistical summary of some basic physical properties (size)

Statistical parameters	Mass (g)	Volume (cm^3)	Density ($g.cm^{-3}$)	Angle of repose	Coefficient of friction
Mean	50.72	47.55	1.07	4.74	0.08
Standard Error	0.84	0.88	0.01	0.16	0.01
Median	51.03	47.50	1.07	4.00	0.07
Mode	47.65	50.00	1.19	4.00	0.07
Standard Deviation	8.39	8.78	0.07	1.59	0.03
Sample Variance	70.35	77.05	0.01	2.52	0.01
Kurtosis	2.58	1.26	-0.39	0.25	0.28
Skewness	0.68	0.41	0.02	0.88	0.89
Range	54.27	55.00	0.39	7.00	0.12
Minimum	31.52	25.00	0.87	2.00	0.03
Maximum	85.79	80.00	1.26	9.00	0.16
Sum	5071.70	4755.00	107.29	474.00	8.29
Count	100.00	100.00	100.00	100.00	100.00
Confidence Level (95.0%)	1.66	1.74	0.01	0.31	0.01

The weight and volume obtained of the fruit were 50.72 g and 47.55 cm^3 with SD of 8.39 and 8.78 respectively. The summary of the properties of the fruit is presented in Table 3. The mean of the fruit density, angle of repose and coefficient of friction were 1.07 g cm^{-3}, 4.47°, and 0.83 with SD of 0.0704, 1.5867, and 0.028 respectively (Table 3). The density falls within the range for most seeds as reported by Mohsenin (1986) for agricultural material such as soya bean (840 kg m^{-3}), cocoa bean (1124 kg m^{-3}), shelled maize (756 kg m^{-3}), millet (673 kg m^{-3}), Irtwange and Igbeka (2002) for African yam bean TSs 137 (760–741 kg m^{-3}) and Taser et al. (2005) for vetch seed (785 kg m^{-3}).

Figures 9–13 shows the frequency distribution of the mass, volume, angle of repose and coefficient of internal friction respectively.

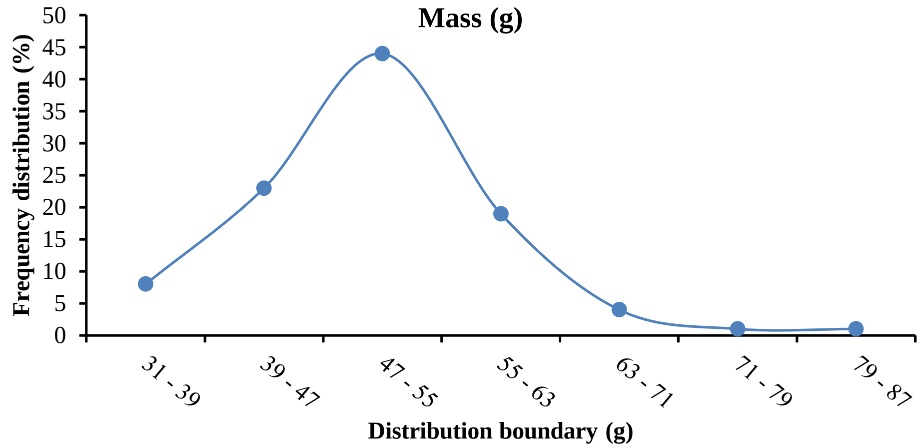

Figure 9 Frequency distribution of mass

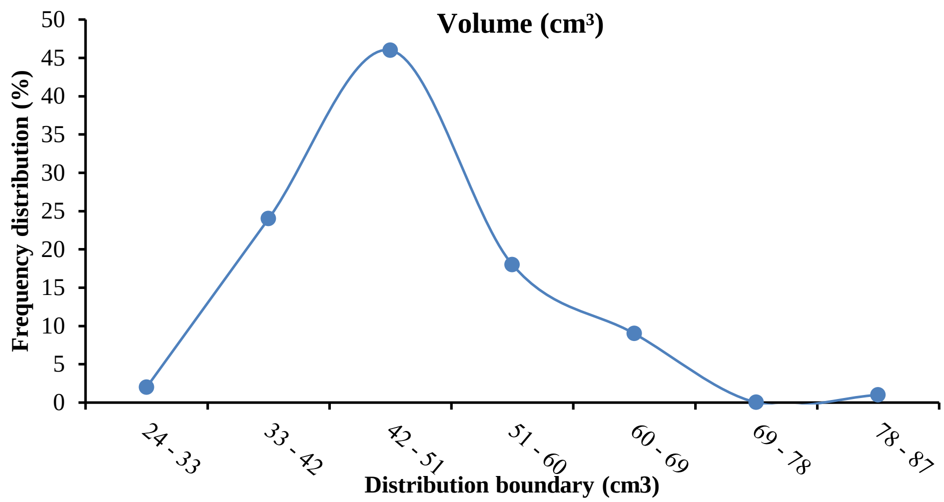

Figure 10 Frequency distribution of volume

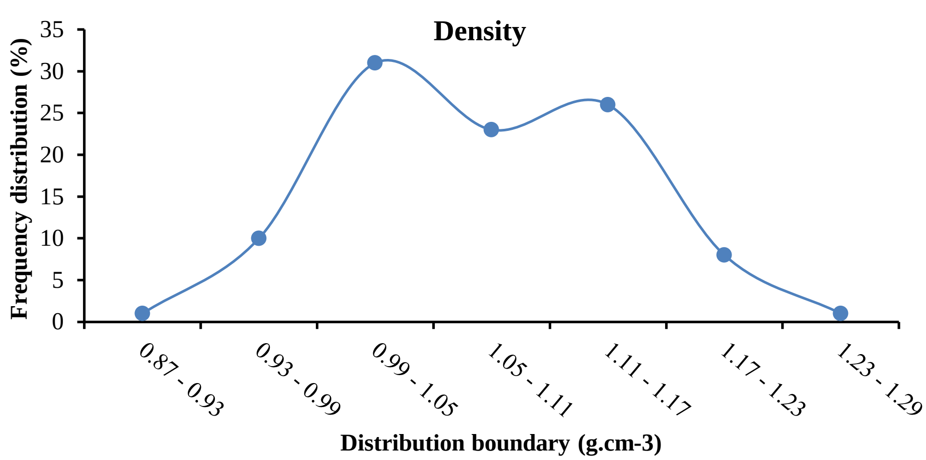

Figure 11 Frequency distribution of density

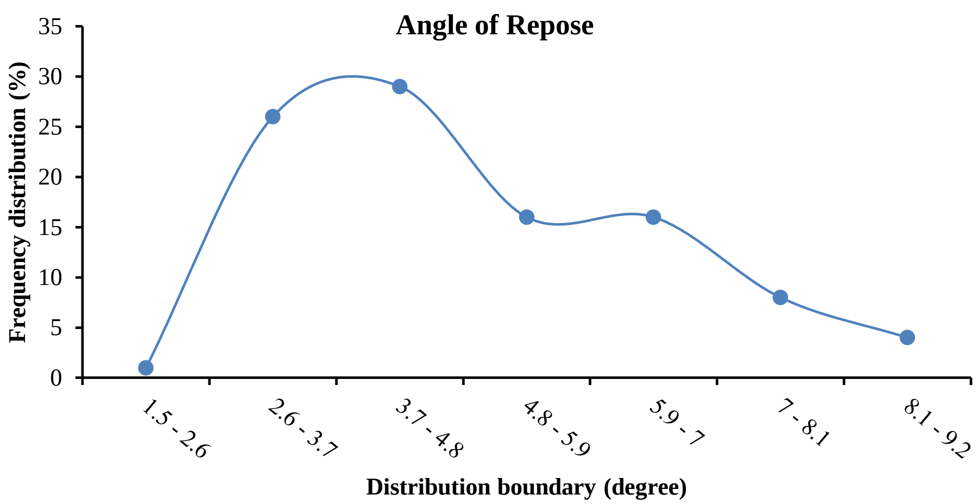

Figure 12 Frequency distribution of angle of repose

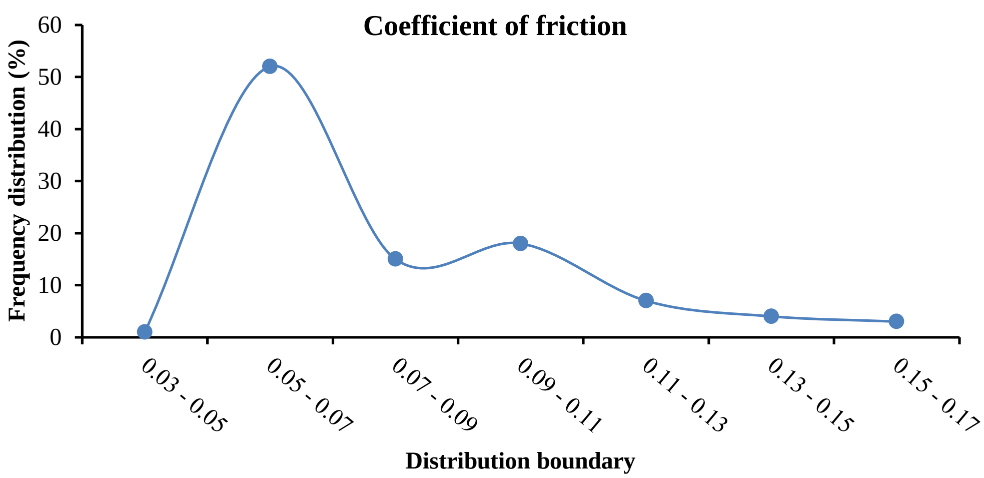

Figure 13 Frequency distribution of coefficient of friction

3.2 Mechanical properties

Tables 4–5 showed the results of the maximum compressive stress of African star apple fruits.

Table 4 Maximum compressive stress for the longitudinal orientation

Properties	Max	Min	Mean	SD	CV (%)
Anvil height (mm)	34.45	34.45	34.45	0.00	0.00
Diameter (mm)	44.05	44.05	44.05	0.00	0.00
Maximum Compressive stress (MPa)	0.12	0.05	0.09	0.02	0.28

Note: CV is coefficient of variation, the same below.

The test was carried out in replicate for both longitudinal and transverse orientation of the fruit. It was found that the maximum compressive stress (MPa) ranged between 0.0519–0.1193 and mean of 0.0908 with standard deviation and coefficient of variation of 0.0252 and 0.2775% respectively for the longitudinal orientation (Table 4) and ranged between 0.062–0.0854 and mean of 0.0739 with standard deviation and coefficient of variation of 0.0094 and 0.1299% respectively for the transverse orientation (Table 5)

Table 5 Maximum compressive stress for the transverse orientation

Parameters	Max	Min	Mean	SD	CV (%)
Anvil height (mm)	34.45	34.45	34.45	0.00	0.00
Diameter (mm)	44.05	44.05	44.05	0.00	0.00
Maximum Compressive stress (MPa)	0.09	0.06	0.08	0.01	0.13

The compressive load (N), compressive extension (mm), compressive strain (mm/mm) and energy at maximum compressive stress for the longitudinal and transverse orientation were shown in Table 6 and Table 7 respectively for the African star apple fruits.

Table 6 Compressive property at maximum compressive stress for the longitudinal orientation

at maximum compressive stress	Max	Min	Mean	SD	CV(%)
Compressive load (N)	181.84	79.01	138.38	38.40	0.28
Compressive extension (mm)	13.09	9.11	12.09	1.68	0.14
Compressive strain (mm mm^{-1})	0.38	0.26	0.35	0.05	0.14
Energy (J)	1.09	0.36	0.83	0.28	0.34

Table 7 Compressive property at maximum compressive stress for the transverse orientation

at maximum compressive stress	Max	Min	Mean	SD	CV(%)
Compressive load (N)	130.26	94.57	111.15	14.44	0.13
Compressive extension (mm)	10.19	8.30	9.26	0.69	0.08
Compressive strain (mm mm^{-1})	0.29	0.24	0.27	0.02	0.08
Energy(J)	0.73	0.48	0.57	0.10	0.18

The maximum compressive load were 181.84 N and 130 N for longitudinal and transverse orientation and these were close to the result gotten by Singh and Reddy (2006) for orange which was 153 N for longitudinal and 134 N for transverse orientation.

Table 8 and Table 9 showed the compressive property at yield and breaking point of African star apple fruits for longitudinal and transverse orientation respectively. The result showed that the maximum force required to break an African star apple ranged between 72.4247–144.9055 N, average of 94.1407 N with standard deviation and coefficient of variation of 31.5858 and 0.3355% respectively for the longitudinal orientation (Table 8), and ranged between 56.1797–85.4130 N, mean of 67.1913 N, standard deviation and coefficient of variation of 11.7736 and 0.1752% respectively for the transverse orientation (Table 9). This was higher than the result of Nader et al. (2011) for pomegranate and lesser than the result of Owolarafe et al. (2007) for palm kernel. Figures 14 and 15 showed the stress-strain graph of all the samples for longitudinal and transverse orientation respectively.

Table 8 Compressive property at yield and breakpoint for the longitudinal orientation

Compressive property	Max	Min	Mean	SD	CV (%)
Compressive stress at Yield (Zero Slope) (MPa)	0.1193	0.0519	0.0908	0.0252	0.2775
Compressive load at Yield (Zero Slope) (N)	181.8433	79.0130	138.3788	38.4040	0.2775
Compressive extension at Break (Standard) (mm)	13.3336	10.5501	12.7612	1.2362	0.0969
Compressive load at Break (Standard) (N)	144.9055	72.4247	94.1407	31.5858	0.3355
Compressive stress at Break (Standard) (MPa)	0.0951	0.0475	0.0618	0.0207	0.3355
Compressive strain at Break (Standard) (mm mm^{-1})	0.3870	0.3062	0.3704	0.0359	0.0969
Energy at Break (Standard) (J)	1.1361	0.4635	0.8899	0.2587	0.2907

Table 9 Compressive property at yield and breakpoint for the transverse orientation

Compressive property	Max	Min	Mean	SD	CV (%)
Compressive stress at Yield (Zero Slope) (MPa)	0.0855	0.0621	0.0701	0.0093	0.1328
Compressive load at Yield (Zero Slope) (N)	130.2586	94.5680	106.8557	14.1920	0.1328
Compressive load at Break (Standard) (N)	85.4130	56.1797	67.1913	11.7736	0.1752
Compressive extension at Break (Standard) (mm)	11.8670	8.9081	10.2083	1.1067	0.1084
Compressive strain at Break (Standard) (mm mm^{-1})	0.3445	0.2586	0.2963	0.0321	0.1084
Compressive stress at Break (Standard) (MPa)	0.0561	0.0369	0.0441	0.0077	0.1753
Energy at Break (Standard) (J)	0.9355	0.5641	0.6631	0.1561	0.2355

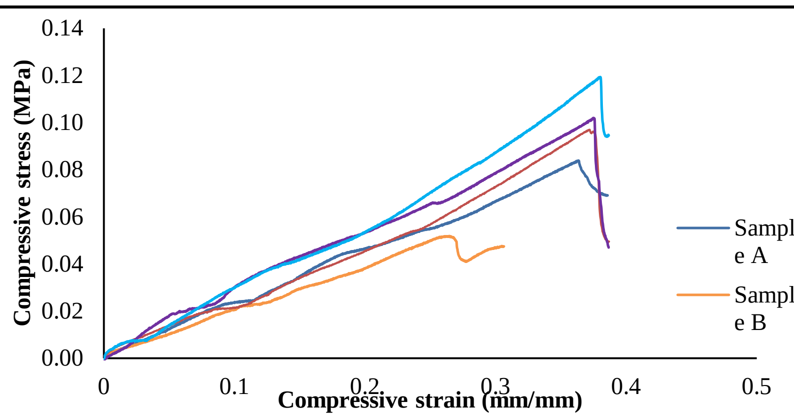

Figure 14 Stress–strain curves for longitudinal orientation under compression test (Sample A-E represent the 5 replicates).

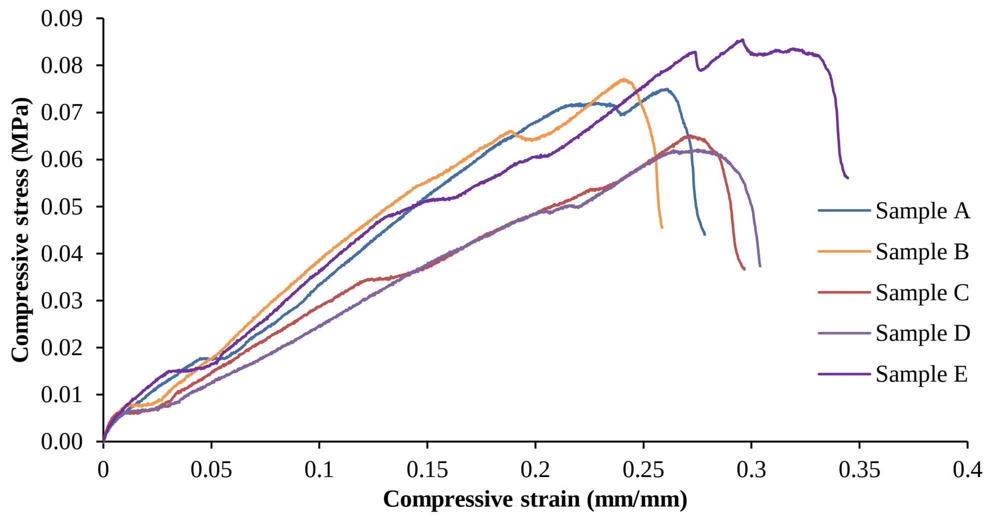

Figure 15 Stress–strain curves for transverse orientation under compression test (Sample A-E represent the 5 replicates).

3.3 Chemical composition

3.3.1 Proximate and mineral composition

Table 10 showed the proximate composition of African star apple fruit. The star apple fruit contained 76.20%–76.50% moisture, 4.20%–4.40% fat, 3.4%–3.6% crude protein, 2.00%– 2.20% ash, 10.00%–10.10% carbohydrate and 3.6%–3.9% crude fibre.

Table 10 Proximate composition of African star apple fruit

Moisture (%)	Ash (%)	Fat (%)	Fibre (%)	Protein (%)	CHO (%)
76.20	2.20	4.20	3.90	3.60	10.00
76.50	2.00	4.40	3.60	3.40	10.10
76.35	2.10	4.30	3.75	3.50	10.05

The African star apple contained minerals namely calcium 413.20 mg $100g^{-1}$; potassium 654.21 mg $100g^{-1}$; sodium 53.61 mg $100g^{-1}$; magnesium 203 mg $100g^{-1}$; iron 2.160 mg $100g^{-1}$; and β -carotene content 368.11 mg $100g^{-1}$ as shown in Table 11.

Table 11 Mineral composition of African star apple fruit

Minerals	Content (mg $100g^{-1}$)
Na	53.61
K	654.21
Ca	413.20
Fe	2.160
Mg	203.0
β –carotene	368.11

3.3.2 Phytochemical composition

Table 12 showed the phytochemical contents of African star apple which included lycopene content 0.02–0.03 mg $100g^{-1}$, VC content 94.56–94.62 mg $100g^{-1}$, tannin content 1.643–1.651 mg $100g^{-1}$, steroid content 2.07–2.09 mg $100g^{-1}$, flavoid content 7.265–7.311 mg $100g^{-1}$, saponnins 3.42%–3.44%. The fruit contained low amount of anti-nutrients such as terpenoid 0.00019%–0.00021% and alkaloid 0.0001% but had no anthraquinone which was similar to the result reported by Odo et al. (2005).

Table 12 Phytochemical composition of African star apple

Composition	Sample A	Sample B
Lycopene (mg $100g^{-1}$)	0.03000	0.02000
VC (mg $100g^{-1}$)	94.5600	94.6200
Terpenoid (%)	0.00019	0.00021
Saponins (%)	3.42000	3.44000
Alkaloid (%)	0.00010	0.00010
Tannin (mg $100g^{-1}$)	1.64300	1.65100
Steroid (mg $100g^{-1}$)	2.07000	2.09000
Flavoid (mg $100g^{-1}$)	7.26500	7.31100

Note: Sample A and B are the replicates

4 Conclusion

Having carried out investigations on some physical and mechanical properties of African star apple fruit (*Chrysophyllum albidum*), the results of the test has shown good agreement with some of the general trends and ranges obtained for other similar fruit such as orange. The dimensions of the fruit are relatively uniform hence this will make the process of mechanization in size reduction, separation and cleaning very easy.

The results of chemical composition of African star apple fruit (*Chrysophyllum albidum*) studied showed that the fruit was high in micronutrient content, low in gross energy and anti-nutrients, hence they can be good snack or fruit for all. Its low carbohydrate content underscore its low value of simple sugar, hence it can be consumed by diabetic patients. Its low calorie, sugar, and high vitamin content qualified the fruit as suitable for the obese, while its very low sodium content qualified it as good fruit for the hypertensive. Its high value of nutrients composition makes it suitable for all. The fruit is also believed to be a good source of antioxidants (β-carotene, and ascorbic acid) needed by the body to prevent or combat the activities of free radicals. Its high ascorbic acid content can be a limitation for peptic ulcer.

The physical and mechanical properties is a good data source, that could be useful for the design and development of the necessary processing machines for the fruit. This will help in using appropriate data rather than using properties of similar fruit in the machine and process design for African star apple fruit (*Chrysophyllum albidum*). Based on the high nutrients and minerals composition with a low anti-nutrient such as tannin, alkaloid, flavoid, steroid etc. the fruit is advisable to be consumed as a snack by all.

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