ORIGINAL CONTRIBUTION

Influence of Moisture Content and Compression Axis on Mechanical, Physical, and Phytochemicals Properties of Akuamma (*Picralima nitida*) Fruits and Seeds

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Abstract This research studied the effect of the moisture content and the three orthogonal axes on the physical, mechanical, and the phytochemical properties of *Picralima nitida* fruits and the seeds. The results showed that the compression force, the compression shear strength, the deformation, and the Poisson's ratio depend on the compression axis and the moisture content. Rupturing the fruit through the intermediate diameter showed higher strength than rupturing the fruit along the major and the minor diameter. The Poisson's ratio ranged from 0.468 to 0.432 at the moisture content range of 75–88.3% wb. Phytochemical screening of the seed showed that saponins, tannins, and flavonoid were present in the seeds. Losing moisture was associated with the loss of the phytochemicals, but flavonoid showed a higher susceptibility to the moisture loss. The frequency distribution of the axial dimensions showed that 85% of the seed major diameters fell within the median class of 27.5 mm. The surface area of the fruits ranged from 409.88 to 987.12 cm^2.

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Introduction

Herbs are becoming increasingly popular and they are receiving patronage from all over the globe. This is because of their affordability and the provision of a wide range of important biochemical actions. They are less toxic with fewer side effects compared to synthetic drugs. From many tropical rainforests in Africa, these herbs are primarily processed, packaged, and transported to other countries in Europe, the USA, China, etc. Among these plants is *Picralima nitida* staph that belongs to the family of Apocynaceae. The plant is used traditionally for the treatment of typhoid fever, malaria, trypanosomiasis, anemia, jaundice, hypertension, dysmenorrhea, and gastrointestinal disorders [1–3]. The plant can be found in Nigeria, Ghana, Gabon, Ivory Coast, Cameroon, Zaire, Cabinda, Central African Republic, Republic of Congo, and Uganda [4]. Olajide et al. [5] reported that the seed extracts inhibited the PGE 2 production by meddling with the various signaling corridors in the IL-1β-stimulated SK-N-SH neuronal cells and therefore could be useful in the treatment of Alzheimer's disease. Shittu et al. [6] reported the stimulation of glucose uptake by akuammicine from the chloroform seed extracts in the completely differentiated 3T3-L1 adipocytes. Several authors have reported the antimicrobial, anti-inflammatory, hypoglycemic, antihyperglycemic, and antiulcer effects of the seed, stem, and the extracts of the fruit [7–11]. The seed contains a blend of alkaloids, prominent among them, akuammine ($C_{22}H_{26}O_3N_2$), an indole alkaloid referred to as vincamajoridine [5, 12]. Other alkaloids isolated include picraphylline, picraline, picralicine, picracine, picratidine, burnamine, picranitine, and pericine [11]. The seed is sold around the world as drugs after drying, milling, and encapsulating [13, 14]. Most of the studies on *Picralima*

nitida focused on the effectiveness of the extract in medicine [11, 15, 16], but parameters that will help in the industrial processing are scarce in the open literature.

Li [17] reported that the physical properties of crops are part of the contact mechanics in post-harvest processing and a major determinant in intelligent harvesting. They help in the development of material handling equipment for sorting, separation, washing, conveying, drying, packaging, etc. [18–20]. The knowledge of the mechanical strength of biomaterial provides insight into the failure mechanics of the product biophysical body during the seed extraction process using impact force. They help in preventing body damage during transportation of the product over a long distance, while they are stacked or loaded in crates and sacks. Most biomaterials have unique characteristics because of the cultivar or environmental factors. Therefore, physical, thermal, and mechanical properties are separately studied for each crop [21–31].

Similar to the physical and mechanical properties in uniqueness for biomaterials is the phytochemical properties. Their knowledge with the moisture content will help in the choice of drying method and treatment points. Therefore, the study of moisture contents and its interactions with the physico-mechanical and the phytochemical properties is the first step in the design of effective processing operations for the dehulling, seed extraction, drying, and packaging of the desired high-quality products. Again, in many countries, the Department of Agriculture makes regulations for packaging and distribution besides pharmaceutical regulations for herbs that in most cases partly depend on the safe moisture contents. Moisture content can change the phytochemicals, size, weight, and shapes of these products, which affect the packaging and transportation.

However, for *Picralima nitida*, the interaction of saponin, tannins, and the flavonoids extracts with the moisture content is not available in the literature. Additionally, the characterization of the physical and the mechanical properties of the seed and the fruits is scarce in the literature. The embedding of the seed of *Picralima nitida* in the pulp enclosed in a hard ellipsoid-shaped fruit (Fig. 1) makes it difficult to break manually due to the fibrous nature. Yet, primary processing of the fruits by local farmers is by manual method and quantity processed is low when compared to the market demand that makes the seed expensive. Therefore, as part of our efforts in highlighting African medicinal and industrial plants and their potentials as a novel pathway to the discovery of therapeutic and other industrial solutions, the goal of the research is to fill the above gap to achieve their mass production.

Fig. 1 *Picralima nitida* fruit

Materials and Method

Material Collection

Fresh matured *Picralima nitida* fruits of an unknown variety were obtained from eleven different forests in the southeastern region of Nigeria. Fruits devoid of any external injury were manually sorted for each forest and separately stored under room condition. The fruits were grouped according to the forest where they were obtained and labeled 1–11. Fifty fruits were selected randomly from each group for the physical and compressive test.

Physical Properties Analysis

The initial moisture content (% wb) of the Picralima seed was determined with an oven (DHG-9053A Ocean med$^+$, England) at a temperature of 105 °C for 24 h [32]. The seed mass (m) was determined with a digital weighing balance (Scout Pro SPU 405, China) with a sensitivity of 0.01 g [33]. Moisture variation of the seed is obtained by sun-drying. Spatial dimensions, geometric mean, surface area, bulk, true, and apparent densities, porosity, sphericity, elongation, aspect ratios, projected surface area, and 1000 kernel mass were determined using standard methods [34–41]. In determining the physical properties of the seeds and fruits, the experiments were replicated on 50 fruits and 100 seeds.

Density and Porosity

The bulk density (σ_b) of the seed and the fruits was determined by filling a known mass (M) in a calibrated container of known volume (V) [34, 35]. The cylinder was shaking gently to obtain a uniform filling and reduce wall effects [36]. The true density (σ_T), and apparent density

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(σ_a) were determined by toluene (C_7H_8) displacement method and digital weighing balance (Scout Pro SPU 405, China) [37]. The bulk, true, and apparent densities were computed as follows

$$\sigma_T = m/v \tag{1}$$

$$\sigma_b = M/V \tag{2}$$

$$\sigma_a = \sigma_l \frac{W_{air}}{W_l} \tag{3}$$

where σ_I is the density of the liquid (g/cm^3), W_{air} is the weight of the seed or fruit in the air (g), W_I is the weight when in liquid (g), and m and v are the mass and volume of the seed or fruit.

The porosity (ε) of the seeds or the fruits was calculated based on the bulk and true density as follows

$$\varepsilon = (1 - \sigma_B/\sigma_T) \tag{4}$$

Dimensional Properties

To determine the principal axial dimensions of the fruits and the seed, 50 fruits and 100 seeds were selected randomly from the bulk sample. The three major dimensions, which include the major (length), intermediate (breath), and the minor diameter (thickness), were determined using a digital caliper [37]. These dimensions were used in computing the geometric mean (d_g), projected area (P) and the aspect ratio (A_r) as follows

$$d_g = (d_1 d_2 d_3)^{1/3} \tag{5}$$

$$P = \pi d_1 d_2 / 4 \tag{6}$$

$$A_r = d_2/d_1 \tag{7}$$

Shape Parameters

The shape parameters determined include the sphericity and elongations ratios. The sphericity relates the shapes of a solid to a sphere of equivalent volume [37]. For non-spherical solids, sphericity is defined as the ratio of the geometric mean diameter to the major axial diameter [35]. Therefore the sphericicity and elongation ratios are computed with Eqs. 8 and 9 as follows

$$\emptyset = d_g/d_1 \tag{8}$$

$$E = d_1/d_2 \tag{9}$$

Surface Area of the Fruit

The surface area of the fruits and the seed was determined using Legendre explicit formula for the area of a general ellipsoid, in terms of incomplete elliptic integrals of the first and second order. Initial comparison of the shapes with other shapes of biomaterials presented in Mohsenin [42]

showed that they are approximately a triaxial ellipsoid with the major, intermediate, and the minor diameters representing the principal axis. The initial measurement of the diameters showed that d_1, d_2, d_3, where d_1, d_2, and d_3 are the major, intermediate, and the minor diameter of the fruit or the seed, respectively. The surface area was therefore deduced in terms of incomplete elliptic integrals of the first and second order presented [43, 44] as follows

$$S_a = 2\pi z_3^2 + \frac{2\pi z_1 z_2}{\sin\varphi}\left(E(\varphi,k)\sin^2(\varphi) + F(\varphi,k)\cos^2(\varphi)\right) \tag{10}$$

z_1, z_2, and z_3 were the major, intermediate, and the minor radius of the fruits and seed equivalent to the semi-axis of the triaxial ellipsoid.

$$\cos(\varphi) = \frac{z_3}{z_1} \tag{11}$$

$$\sin(\varphi) = \sqrt{1 - \frac{z_3^2}{z_1^2}} \tag{12}$$

Garry [43] and Olver et al. [44] gave the two incomplete elliptic integrals of the first and second order in Eqs. 13 and 14

$$E(\varphi,k) = \int_0^\varphi \frac{d\theta}{\sqrt{1 - k^2\sin^2\theta}} = \int_0^{\sin(\varphi)} \frac{dt}{\sqrt{(1-t^2)(1-k^2t^2)}} \tag{13}$$

$$F(\varphi,k) = \int_0^\varphi \frac{d\theta}{\sqrt{1 - k^2\sin^2\theta}d\theta} = \int_0^{\sin(\varphi)} \sqrt{\frac{(1-k^2t^2)}{(1-t^2)}}dt \tag{14}$$

$$k^2 = \frac{z_1^2\left(z_2^2 - z_3^2\right)}{z_2^2\left(z_1^2 - z_3^2\right)} \tag{15}$$

t is given as $\sin\theta$ where θ is the polar angle ($^\circ$) and φ is the azimuth angle ($^\circ$) of points on the ellipsoid surface where the ellipsoid axis coincides with coordinate axis.

Substituting Eqs. 11–15 into Eq. 10 and resolving the integrals, Keller [45] (1979) approximated the surface area as follows

$$S_f \approx 2\pi z_3^2 + \frac{2\pi z_1 z_2}{\sqrt{1 - \frac{z_3^2}{z_1^2}}} \ln \frac{1 + \left(1 - z_2^2/z_1^2\right)^{1/2}}{1 - \left(1 - z_2^2/z_1^2\right)^{1/2}} \tag{16}$$

Axial Compression Test

The axial compression tests on the three major axial diameters were carried out at room temperature and at five different moisture contents using the digital universal tester (Okhard Machine Tools Ltd). The axis was defined as

loading through the major diameter, intermediate diameter, and minor diameters. The fruits were quasi-statically compressed at a constant speed of 50 mm/min until it ruptures. The values of the axial and lateral extensions and the compression force (F) were recorded, while deformations were calculated. Equation 17 was used to calculate the compression shear strength (CS) in N/cm^2 as follows

$$C.S = \frac{F}{2\pi z_3^2 + \frac{2\pi z_1 z_2}{\sqrt{1-\frac{z_2^2}{z_1^2}}}\ln\frac{1+\left(1-z_2^2/z_1^2\right)^{1/2}}{1-\left(1-z_2^2/z_1^2\right)^{1/2}}} \qquad (17)$$

Sitkei [46] gave the Poisson's ratio of the fruits as follows

$$\mu = \frac{\left(\frac{\Delta d_2}{2}\right)}{(\Delta d_1/d_1)} \qquad (18)$$

where Δd_2 is the change in intermediate diameter after deformation and Δd_1 is the change in major diameter after deformation.

Regression Model and Statistical Analysis

Multiple regression equations relating the descriptor (moisture content) to dependent variables (other parameters) were deduced using Origin Pro 9.0 software (Origin Lab, USA). The physico-mechanical property data were fitted using linear, exponential, quadratic, power, and logarithmic functions, and the best fit of the data was chosen based on the high R^2, the lowest root means square error (RMSE), and Chi-square [34, 47]. Statistical parameters such as standard deviation, skewness, and kurtosis were used to analyze the distribution of the physical properties [37].

Phytochemical Analysis of Seed Extracts

The seed extracts were evaluated for saponins, tannin, and flavonoid at various moisture contents using the standard methods presented by Trease and Evans [48] and Giuseppina Negri et al. [49]. The standard samples of the sodium chloride, ethanol, petroleum ether, sodium carbonate, and hydrochloric acid were purchased from local suppliers for the biochemical evaluation. The seed was milled into a powder form and the powdered sample sieved with the 30 mesh screen and kept in a transparent vial for the subsequent tests. To extract the saponin, 5 g portion of the powdered sample was extracted twice with 20% (v/v) ethanol over the water bath (HH-S, Search Tech Instruments) for 1 h and then filtered using Whatman No. 1 filter paper. The filtrate was defatted with 20 ml of petroleum ether and the mixture separated. The pH of the dense liquid

collected was adjusted with 10 ml of butanol before further addition of 20 ml of NaCl and separated. The less dense liquid obtained was evaporated to dryness to obtain the total saponin content (TSE).

To another filtrate, 1 ml of falling reagent, 2 ml of Na_2CO_3, and 45 ml of distilled water were added and stirred with a high-speed mixer. Identification and quantification of the amount of tannin were by UV–visible spectrophotometer (UV 1800pc, Mapada) at 750 nm and reported in mg/g of dried mater. Also to obtain the total flavonoid, another powdered sample (5 g) was added a 50 ml of 2 M hydrochloric acid solution and boiled over a water bath for 1 h and filtered. After allowing the filtrate to cool, 30 ml of ethyl acetate was added to the filtrate and allowed to settle. The organic extract was collected by separation with filter paper and evaporated in an oven, and the quantity of flavonoid was calculated and presented in mg/g.

Results and Discussions

Variation in Moisture Content with the Physical Properties

Spatial Dimensions and Surface Area

The frequency distribution curve for the major, intermediate, and minor diameters of the seed at a moisture content of 47.19% wb is plotted in Fig. 2. This showed that 85% of the seed major diameters fall within the median class of 27.5 mm, while the least was 1.67% that represents the median class of 33.5 mm diameter with maximum and minimum values of 32.18 mm and 21.17 mm as shown in Table 1. The intermediate diameter falls majorly within the 18.5 mm median range, while the minor diameter falls within 6.5 mm median range.
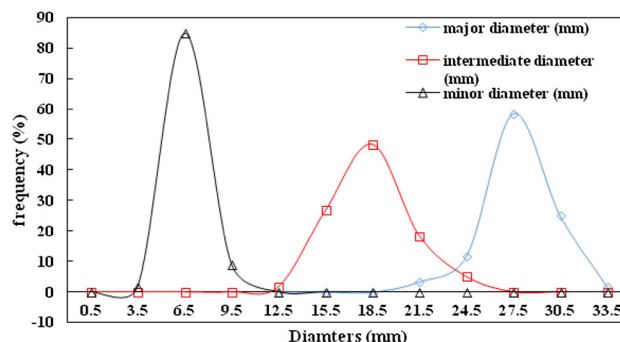

Fig. 2 Frequency distribution curves of the axial dimensions for the seed

Table 1 Statistical data for physical properties of the seed at 47.19% wb average moisture content

Parameter	Unit	Max. value	Min. value	Average value	SD	Skewness	Kurtosis
Major diameter	mm	32.18	21.17	27.80	2.26	− 0.73	0.91
Intermediate diameter	mm	25.53	13.30	18.47	2.36	0.22	0.01
Minor diameter	mm	8.70	6.33	7.30	0.61	0.27	− 0.77
Geometric mean	mm	17.15	13.57	15.47	0.78	− 0.22	0.04
Sphericity	–	0.69	0.48	0.56	0.05	0.52	− 0.42
Surface area	mm^2	924.70	578.75	741.88	75.39	− 0.08	− 0.003
Aspect ratio	–	0.92	0.50	0.67	0.11	0.47	− 0.60
Elongation	–	1.99	1.08	1.53	0.24	0.07	− 0.82
Projected area	mm^2	526.79	229.94	396.02	55.79	− 0.30	0.75
Mass	g	2.67	1.71	2.26	0.24	− 0.28	− 0.48
1000 seed mass	g	2258.86	1446.68	1709.14	239	–	–
Moisture content	% wb	47.74	46.41	47.19	1.57	–	–

The physical characteristics of the seed at varying moisture contents achieved through initial moisture treatments were established. This is necessary because the properties are required in industrial dehulling of the seeds. Figure 3a shows the influence of the moisture content on the geometric mean, mass, and the volume of the individual seed, while Fig. 3b shows the effect of moisture content on surface area. Generally, physical properties increased with moisture content. Jha and Kachuru [35] have reported similar behavior on the physical properties of makhana. The values ranged from 1.84 to 2.89 g for seed mass and 1.71 to 2.91 cm^3 for seed volume over a moisture range of 38.31–62.44% wb with a geometric mean diameter of 15.41–15.56 mm. In addition, the surface area of the seed ranged from 745.82 to 761.13 mm^2 as shown in Fig. 3b. The ANOVA test showed that the moisture content
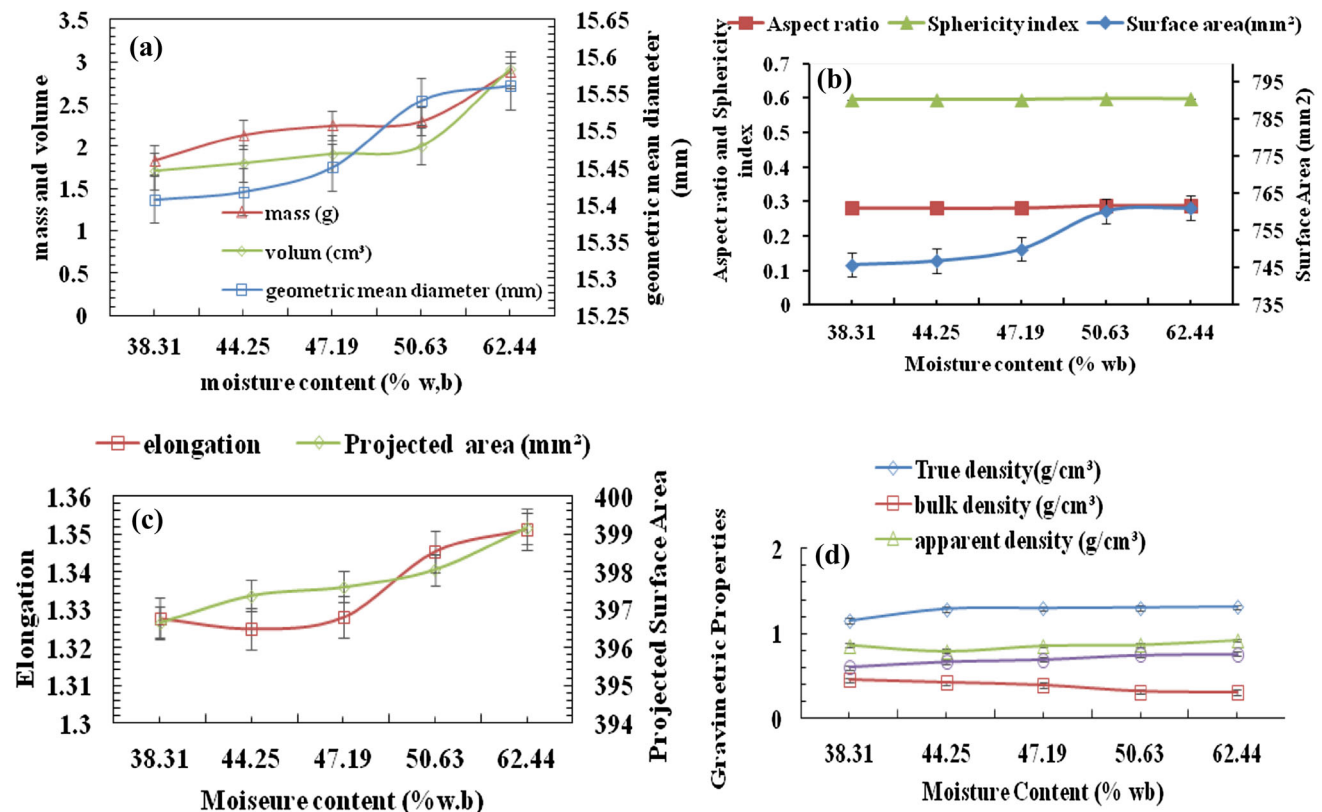

Fig. 3 Variation in physical properties of the seed with moisture content

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Table 2 Physical properties of the fruits

Groups	m (g)	d_1 (cm)	d_2 (cm)	d_3 (cm)	V (cm³)	dg (cm)	S_{af} (cm²)	Ar	Ø	ρ_T (g/cm³)	ρ_b (g/cm³)	ε	E	P (cm²)	ρ_a (g/cm³)
1	546.3	11.34	9.78	8.54	460	9.82	409.88	0.75	0.87	1.19	0.72	0.39	1.16	87.12	1.12
2	710.4	15	10.02	8.74	540	10.95	677.68	0.58	0.73	1.32	0.72	0.45	1.50	118.06	1.23
3	782.9	12.3	11.25	9.81	615	11.07	460.21	0.80	0.90	1.27	0.72	0.43	1.09	108.69	1.27
4	870.3	15.5	10.83	9.48	720	11.67	739.96	0.61	0.75	1.21	0.72	0.40	1.43	131.85	1.2
5	877.4	14.3	11.09	9.69	780	11.54	651.34	0.68	0.81	1.12	0.72	0.36	1.29	124.57	1.11
6	955.7	18.5	10.72	9.76	790	12.46	987.12	0.53	0.67	1.21	0.72	0.40	1.73	155.78	1.20
7	1009.7	15	11.08	9.77	785	11.75	713.02	0.65	0.78	1.29	0.72	0.44	1.35	130.55	1.21
8	1012.2	15	10.94	10.08	815	11.82	742.30	0.67	0.79	1.24	0.72	0.42	1.37	128.90	1.22
9	1016.5	18.1	10.44	9.91	870	12.32	968.38	0.55	0.68	1.17	0.72	0.38	1.73	148.43	1.13
10	1017.6	16.2	11.37	10.3	860	12.38	835.41	0.65	0.76	1.18	0.72	0.39	1.42	144.68	1.16
11	1121.5	16	11.91	10.5	1050	12.60	813.32	0.66	0.79	1.07	0.72	0.32	1.34	149.68	1.04

significantly ($p < 0.05$) affected the mass, volume, and the geometric mean diameter. Equations 19–22 show the effect of the moisture content (M) on the mass (m), volume (V), geometric mean diameter, and the surface area of the seed as follows

$$m = 0.68572 + 0.48491e^{M/41.26} \quad R^2 = 0.9935, \quad (19)$$

$$V = 1.85708 + 3.18 \times 10^{-7}e^{M/4.16} \quad R^2 = 0.9114 \quad (20)$$

$$d_g = 0.0169M^2 - 0.0673M + 15.46 \quad R^2 = 0.9756 \quad (21)$$

$$S_a = 777.4 - 112.42e^{-M/31.28} \quad R^2 = 0.7846, \quad (22)$$

where M is the moisture content (decimal)

Table 2 shows the physical properties of the fruit grouped into 1–11 based on the forest where they were collected. The trend of representation of the mass and the axial dimensions showed that the mass of the fruit increased with the geometric mean diameter except for groups 4 and 6 due to disproportionate higher major diameters compared to the other two diameters. This makes it easy to sort the fruits based on the geometric diameters that will increase the esthetics of the selection of fruits. Equation 23 shows the fitting of the mass and the geometric mean of the fruits. The surface area of the fruits ranged from 409.88 to 968.38 mm² as shown in Table 2 although the trend is not represented by any of the axial dimensions.

$$d_g = 316m^{0.186} \quad R^2 = 0.897 \quad (23)$$

where m is the mass (g)

Shape Parameters

The shape factor includes elongation ratio, projected surface area, aspect ratio, and sphericity index. From Fig. 3c, the seed elongation ratio and projected surface area increased with moisture content. The mean values were 1.33–1.35 and 394–399.15 mm² for the elongation ratios and projected surface area, respectively. The values of the projected area are higher than that of Somsori variety of melon seed, while it has the elongation is lower [37]. The increase in projected area is because of the increase in the spatial dimension of the seed and fruit due to increase in moisture content. Additionally, the increase in elongation ratios showed that the major diameter projected more than the intermediate diameter. Similar results have been found on the influence of moisture content on the physical properties of shelled and kernel walnuts [50]. However, these values are not statistically ($p < 0.05$) significant. In addition, the aspect ratio and spherical index ranged from 0.28 to 0.29 and 59.5 to 59.88% as shown in Fig. 3b. The value of the sphericity showed that the seed is not spherical and therefore cannot roll.

On the fruits, the aspect ratio ranged from 0.53 to 0.80, while the sphericity index ranged from 0.67 to 0.90 as shown in Table 3. These values showed the resemblance of the fruits to a sphere, but closer observations showed that it is not a perfect sphere but a triaxial ellipsoid. The elongation and the projected area of the fruits ranged from 1.09 to 1.73 and 87.11 to 149.68 cm², respectively, as shown in Table 1.

Gravimetric Properties

Figure 3d shows the gravimetric properties of the seed, which includes true density, bulk density, apparent density, and porosity. The true density, apparent density, and porosity of the seeds increased with the increase in the moisture content, while the bulk density decreased. A similar trend was also reported for bulk and true density of makhana [34, 35]. However, Jha and Kachuru [35] noted that the increase in densities with moisture content might be because of proportional weight increase with a moisture content not being proportional to an increase in the volume

Table 3 Specific deformation and Poisson's ratio at the different moisture contents of the fruits

Moisture content (%)	Mass (g)	Surface area (cm^2)	Deformation at rupture (mm)			Poisson's ratio
			d_1	d_2	d_3	
75.00	955.70	987.12	8.40	4.70	5.40	0.468 (0.031)
79.46	955.70	987.12	7.50	4.70	6.10	0.453 (0.008)
82.00	968.80	987.52	9.80	5.10	7.80	0.442 (0.056)
85.36	974.50	987.62	10.00	4.40	5.90	0.448 (0.004)
88.10	980.20	987.69	11.10	5.70	8.20	0.432 (0.011)

of the product. Their values ranged from 0.994 to 1.311 g/cm^3, 0.511 to 0.3201 g/cm^3, 0.86 to 0.92 g/cm^3, and 46.5 to 76.34%, respectively. The apparent density is less than the density of water; therefore, the seed will float in water. The data observed from the above study for the gravimetric properties are in line with the range found in the literature by Teotia and Ramakrishna [51] for similar seeds like the watermelon, long melon, and muskmelon seeds. The fittings of porosity (ε), bulk density (σ_B), and true density (σ_T) are shown in Eqs. 24–26 as follows

$$\varepsilon = 0.65169 - 3.73 \times 10^{-5} e^{M/6.83} \quad R^2 = 0.936 \quad (24)$$

$$\sigma_B = 0.25869 - 1.45 \times 10^{-2} e^{M/17.71} \quad R^2 = 0.9868 \quad (25)$$

$$\sigma_T = 1.24777 - 0.329 e^{M/30.59} + 0.328 e^{M/30.6}$$
$$R^2 = 0.9945, \quad (26)$$

where M is the moisture content (decimal)

The bulk density of the fruits collected did not vary and was determined as 0.7217 g/cm^3; however, the true density and apparent density values ranged from 1.068 to 1.316 g/cm^3 and 1.044 to 1.268 g/cm^3, respectively, as presented in Table 2. This shows how dense this fruit is and therefore cannot float in water.

Effect of Moisture Content and Compression Axis on Compression Shear Strength

The compression force and the compressive shear strength at different orthogonal diameters and moisture contents of the fruits are shown in Figs. 4 and 5. The compression force and compressive shear strength decreased with moisture content; however, constant values between two successive moisture contents were observed for compressing at the major diameter and intermediate diameters. The compressive shear strength ranged from 0.141 to 0.253 N/cm^2, 0.354 to 0.557 N/cm^2, and 0.354 to 0.43 N/cm^2 for compressing at the major, intermediate, and minor diameters, respectively, with a compression force of 140–550 N for the three diameters. On average, the force required to break the fruit along the intermediate diameter
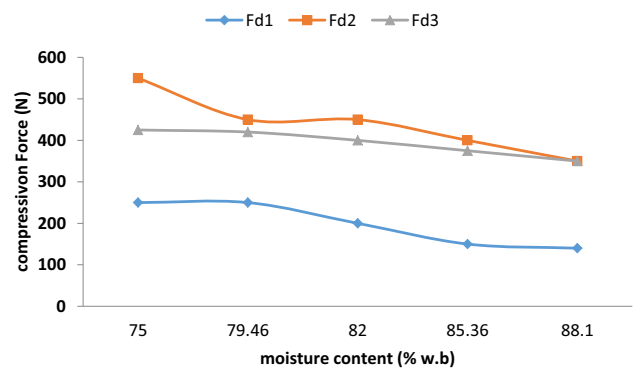

Fig. 4 Effect of moisture content and compression axis on compressive force (*Fd1* force at major diameter, *Fd2* intermediate, *Fd3* minor diameter)
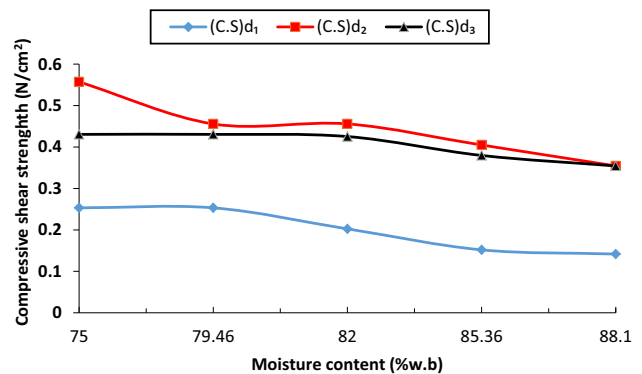

Fig. 5 Effect of moisture content and compression axis on compressive strength

is 80–167% higher than that required to break it along the major diameter, while it is 70–150% higher along the minor diameter. Equations 27–29 show the relationship between compression shear strength and the moisture content (M) when compressed through the major, intermediate, and the minor diameter axis, respectively.

$$C.S = 0.2878 - 0.0014M^2 + 0.0238M \quad R^2 = 0.9267, \quad (27)$$

$$\text{C.S} = 0.5552 - 0.114\ln(M) \quad R^2 = 0.9357, \tag{28}$$

$$\text{C.S} = 0.187 - 0.0065M^2 - 0.0002M \quad R^2 = 0.960, \tag{29}$$

where M is the moisture content (decimal)

A closer examination of the failed fruits shows that the fruits contain tough fiber in the flesh tissues, which covers the seed. Fruits like this with tough fibers show uneven force–deformation curves during the rupture and compression tests [17]. However, because of the partial ripeness of the fruit, the resultant mechanical response from the structure of the fruit or cells was weak and therefore dominated by the mechanical response from the solid tissues or cell constituents [52], so the deformation was localized along the direction of compression. Various plots in Figs. 4 and 5 show that this fruit is relatively hard to break when compared to other fruits like orange, plum fruits, and apples [53, 54]. However, breaking it along the intermediate diameters axis requires more force, while compressing it through the major diameters fails the fruit more easily around the neck and the base. This shows that the fruit is thicker along the intermediate diameters, while the underneath neck has a thinner skin.

Effect of Moisture Content on Poisson's Ratio and Deformation

Table 3 presents the Poisson's ratios of the fruit at different moisture contents, masses, and surface areas. The data in brackets are the standard deviation for the experimentation in triplicate. The trend of Poisson's ratios showed a decrease with an increase in moisture content. The Poisson's ratios ranged from 0.468 to 0.432. The high Poisson's ratio obtained might be due to the large size of the fruits and high loading rate, which Burubai et al. [55] observed on African nutmeg. However, these values are similar to the value obtained for similar biomaterial, which ranges from 0 to 0.5 [42]. Equation 30 shows the trend of the Poisson's ratios with the moisture content as follows

$$\mu = 0.4674 - 0.02\ln M \quad R^2 = 0.8725 \tag{30}$$

where M is the moisture content (decimal)

Table 3 also shows the mean values of deformation at rupture when compressed along the three diameters. The results show that the fruit is more deformable along the major diameters and higher moisture content. The relationships between deformation (D) and moisture content (M) are given in Eqs. 31–33 for compressing at d_1, d_2, and d_3, respectively, as follows

$$D = 7.94 + 0.1357M^2 - 0.0243M \quad R^2 = 0.8111 \tag{31}$$

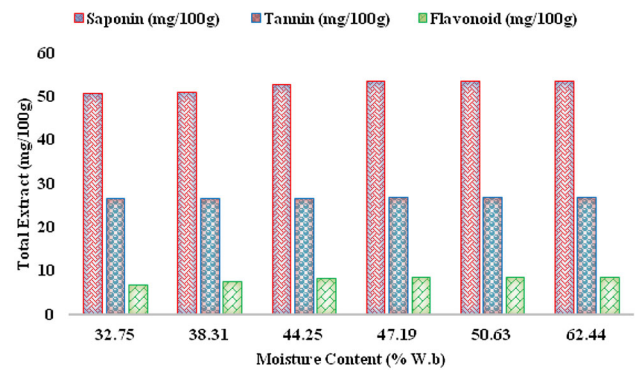$$D = 5.4195M^{0.2043} \quad R^2 = 0.5028 \tag{32}$$

Fig. 6 Variations in saponin, tannin, and flavonoids from *Picralima nitida* seeds at different moisture levels

$$D = 5.16 + 0.1071M^2 - 0.4729M \quad R^2 = 0.4461 \tag{33}$$

where M is the moisture content (decimal)

Variations in Total Flavonoids, Saponin, and Tannin with Seed Moisture Content

The initial analysis of extracts from *Picralima nitida* seed at a moisture content of 62.44% wb revealed the predominance of saponin among the constituents screened with 53.4 mg/g followed by tannin with 26.8 mg/g and flavonoids with 8.6 mg/g of the extracts as shown in the plot in Fig. 6. This reveals a rich presence of saponin from this seed which previously might not have been studied and classified. This is because several researchers have classified saponins found in other plant families [49], but little information is available on the only known Apocynaceae, which is *Picralima nitida*. This analysis, therefore, revealed the usefulness of this seed as natural raw material for saponin, tannin, and flavonoid extraction which has found applications in the pharmaceutical, chemical, leather, food, and cosmetic industries [56–62]. The plots in Fig. 6 list the level of various compounds at different moisture contents which showed that the loss of moisture is associated with the loss of compounds, though the values are not significant ($p < 0.05$). It is evident that the flavonoids though with a minor content are the most vulnerable as shown by the percentage decrease at low moisture content. This shows that if drying treatment is to be applied in the processing and storage of this seed, it will be more at the expense of the flavonoid content.

Conclusions

In this research, the effect of moisture content and the three orthogonal axes on the physical, mechanical, and the phytochemical, properties of *Picralima nitida* fruits and the seeds were established. The seeds show the presence of

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saponins, tannins, and flavonoid. The loss of moisture was
associated with the loss of these phytochemicals, but fla-
vonoid showed a higher susceptibility to the moisture loss.
The frequency distribution of the axial dimensions showed
that 85% of the seed major diameters fall within the
median class of 27.5 mm. The surface area of the fruits
ranged from 409.88 to 987.12 cm^2. The results showed that
the compression force, compressive shear strength, defor-
mation, and Poisson's ratio depend on the compression axis
and moisture content. Rupturing the fruit along the inter-
mediate diameter showed greater strength than rupturing
the fruit along the major diameter. The Poisson's ratios
ranged 0.432–0.468

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