Current Journal of Applied Science and Technology

32(1): 1-8, 2019; Article no.CJAST.46137
ISSN: 2457-1024
(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843, NLM ID: 101664541)

Assessment of Some Physical Properties of Char (*Buchanania lanzan*) Seed

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CJAST/2019/46137
Editor(s):
(1) Dr. Ming-Chih Shih, Professor, Department of Health and Nutrition Science, Chinese Culture University, Taiwan.
Reviewers:
(1) Uguru Hilary, Delta State Polytechnic, Nigeria.
(2) P. S. Shelake, Indian Agricultural Research Institute (IARI), India.
Complete Peer review History: http://www.sciencedomain.org/review-history/27978

Original Research Article

Received 26 September 2018
Accepted 16 December 2018
Published 26 December 2018

ABSTRACT

Size, shape, volume, surface area, density, porosity are some physical characteristics, which are important in many problems associated with the design of a specific machine. The physical properties of wild variety of *Buchanania lanzan* seeds have been evaluated as a function of seed moisture content, varying from 10.1 to 20% (db). In the moisture range, seed length increased linearly from 7.28 to 12.98 mm, width from 5.97 to 11.2 mm, thickness from 5.36 to 10.34 mm and geometric mean diameter from 6.04 to 11.45 mm, respectively with an increase in moisture content. The sphericity, surface area, and volume increased nonlinearly from 0.850 to 0.881, 118.8 to 412.28 mm^2, and 121.9 to 787.37 mm^3, respectively. One thousand seed weight increased linearly from 0.211 to 0.433 kg. The bulk density and true density decreased linearly with moisture content from 639.01 to 521.36 kg/m^3 and 867.73 to 797.73 kg/m^3, respectively, while porosity values of seeds increased linearly from 26.45 to 33.36%. Static friction coefficients were found to increase as moisture content increases. Static friction coefficient was highest on rubber surface and lowest on glass surface ranging from 0.594 to 0.730 and 0.249 to 0.329, respectively, while the largest increase (34.71%) in static friction coefficient with moisture content was observed for plywood. The angle of repose increased linearly from 26.45 to 33.75º with the increase of moisture content.

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Keywords: Buchanania lanzan; moisture content; physical properties; frictional properties.

1. INTRODUCTION

Buchanania lanzan (char) fruit, the native of India, is extensively cultivated in Nepal, Burma, Vietnam, Laos, Cambodia, and Thailand. In India, it is found mostly in the states of Chhattisgarh, Jharkhand, Madhya Pradesh, Uttar Pradesh, Bihar, Orissa, Andhra Pradesh, Gujarat, Rajasthan, and Maharashtra [1]. Its kernels contain about 47-52% oil [2], which oil is used as a substitute for olive and almond oils, while the whole kernel is used in sweet-meats or as a substitute for almond kernels. The oil extracted from the kernels of *Buchanania lanzan* is used for treating skin diseases [3]. The kernel is the most important part of the fruit because of their nutritional quality and characteristics and economic importance in the present market. Gopalan et al. [4] reported that the one hundred gram of *Buchanania lanzan* fruits and kernels contain 74.3% and 3% moisture, 2.2% and 19% protein, 0.8% and 59.1% fat, 1.7% and 3% minerals, 1.5% and 3.8% crude fiber, 19.5 mg and 12.1 mg carbohydrate, 78 mg and 2.7 mg calcium, 28 mg and 5.3 mg phosphorus and 94 kcal and 650 kcal calorific values, respectively [4].

The knowledge of the engineering properties of *Buchanania lanzan* seeds is important and essential for the accurate designing of different components of processing machineries. In the process of drying, cracking, decorticating and in other allied processes, the *Buchanania lanzan* seeds undergo a series of changes and presently, limited information is available on engineering properties of *Buchanania lanzan* seed. Dried seeds are highly hygroscopic and affect handling and processing with the absorption of moisture. The objective of this study was to determine the physical and frictional properties of *Buchanania lanzan* seed in desired moisture range of 10.1 to 20% (db) so that the knowledge gained will be used in design and development of equipment for cleaning, separating, sorting, sizing, packaging and processing it into different food purposes.

2. MATERIALS AND METHODS

2.1 Preparation of Samples

Buchanania lanzan seeds procured from the local market and the initial moisture content of seed was found to 11.3% (db). The seeds were manually cleaned to remove all foreign matter, broken and immature seeds. The experiments were conducted in the moisture content range of 10.1 to 20% (db). The initial moisture content of the samples was determined by drying the samples at 130±2°C for 1 h [5]. The sample of lower moisture content was obtained by drying in a mechanical dryer at 45°C with a 10 mm layer of seeds which was about two or three seeds deep. The sample of lower moisture content (10.1±0.5%, db) was prepared by drying to give a sample mass as calculated below [6,7]:

$$B = \frac{A(100-b)}{(100-b)} \quad (1)$$

The samples of higher moisture contents (12%, 14%, 17% and 20%, db) were obtained by adding predetermined quantity of distilled water as calculated from the following equation [6,7]:

$$Q = \frac{A(b-a)}{(100-b)} \quad (2)$$

where, *A* is initial mass of the sample (kg); *B* is final mass of the sample after drying (kg); *a* is initial moisture content of sample, (%, db); *b* is final (desired) moisture content of sample, (%, db) and *Q* is mass of water to be added (kg).

The prepared samples were stored in air tight containers and polyethylene bags respectively at 5°C in a refrigerator for a week to enable the moisture to distribute uniformly throughout the product. Before starting the experiment, the samples were taken out of the refrigerator and allowed to warm up to the room temperature for 2 hours. The experiments were replicated 10 times to avoid experimental error.

2.2 Physical Properties

2.2.1 Dimensions, mean diameter, sphericity, 1000 seed mass and surface area

The geometry and the relative sizes of the *Buchanania lanzan* seed is shown in Fig. 1. The three perpendicular dimensions *viz.,* length (*l*), width (*w*) and thickness (*t*) of each seed were measured by a digital caliper with least count of 0.001 mm. Hundred seeds were randomly selected for each moisture studied and the mean dimensions were recorded. The geometric mean diameter (D_g) of the seed was calculated by using the following equation [8]:

$$D_g = (lwt)^{\frac{1}{3}} \quad (3)$$

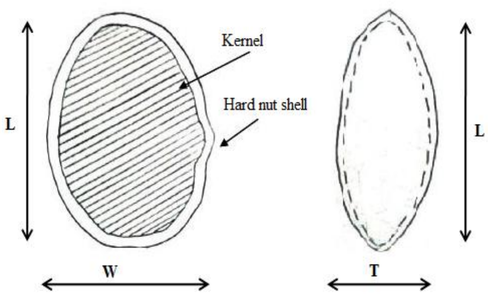


Fig. 1. Geometry of *Buchanania lanzan* seed, L, W and T are the length, width and thickness [3]

According to Mohsenin [8], the degree of sphericity (ϕ) can be expressed as follows:

$$\phi = \frac{geometric\ mean\ diameter}{major\ diameter}$$

$$\phi = \frac{(lwt)^{1/3}}{l} \quad (4)$$

This equation was used to calculate the sphericity of *Buchanania lanzan* seed in the present study.

To determined the thousand seed mass (M_{1000})., 10 samples, each of 1000 *Buchanania lanzan* seeds were picked at random and weighed by means of an electronic balance with 0.001 g graduations and the average was taken.

The surface area (S) of the *Buchanania lanzan* seed was calculated using the geometric mean diameter in the following formula [9]:

$$S = \pi D_g^2 \quad (5)$$

The volume (V) of the single *Buchanania lanzan* seed was calculated by using the following equations cited by Arslan and Vursavus [10]:

$$V = \frac{\pi B^2 L^2}{6(2L - B)} \quad (6)$$

Where

$$B = (WT)^{0.5} \quad (7)$$

2.2.2 Densities and porosity

The bulk density is the ratio of the mass sample of the seeds to its total volume. It was determined by filling the seeds in a circular container of known volume (5×10^{-4} m^3) with *Buchanania lanzan* seeds and weighing the contents in an electronic balance [9]. The true density (particle density) is defined as the ratio between the mass of the seeds to the solid volume occupied by the seed, was calculated using the toluene (C_7H_8) displacement method [11]. It is evident from the literature that the absorption of toluene by the seed is less as compared to water. The porosity is a physical property that reflects the number of air spaces in a bulk. It was calculated from the experimental values of bulk density and true density at corresponding moisture contents using the following equation [12]:

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

where, ε is porosity (%); ρ_b is bulk density (kg/m^3) and ρ_t is true density (kg/m^3)

2.3 Frictional Properties

2.3.1 Angle of repose

An experimental apparatus (Fig. 2), developed by Visvanathan et al. [6] was used to determine the angle of repose of *Buchanania lanzan* seed. The apparatus consists of a cylinder pipe of 50 mm diameter and 100 mm height. A cylinder was filled up to the top with the sample and was placed at the center of a raised circular plate having a 150 mm of diameter. The cylinder was raised gradually until the material formed a cone on the plate. The angle of repose was estimated from the height and diameter of the naturally formed heap of seed/seed on a circular plate and the average value was taken from ten replications for each moisture contents. The angle of repose (θ) was calculated based on the equation [13,14]:

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

where; H is height of cone (mm) and D is diameter of cone (mm)

2.3.2 Coefficient of static friction

The experimental setup used in the friction studies was made according to Saracoglu and

Ozarslan [15] consisted of a fixed plate, adjustable plate, reading scale, a bottomless sample box (50 mm × 50 mm × 50 mm) and test surfaces (Fig. 3). The container placed on the test surface (glass, plywood, mild steel and rubber) was filled with *Buchanania lanzan* seed. The test surface with the cylinder resting on it was raised gradually with a screw device until the cylinder just started to slide down and the angle of tilt was read from a graduated scale. The experiment was performed at different moisture contents of seed using test surfaces with ten replications. For each replication, the sample in the container was emptied and refilled with a different sample. The coefficient of static friction (μ_s) was calculated using the following relation [15]:

$$\mu_s = \tan \alpha \tag{10}$$

where α is the tilt angle in degrees.

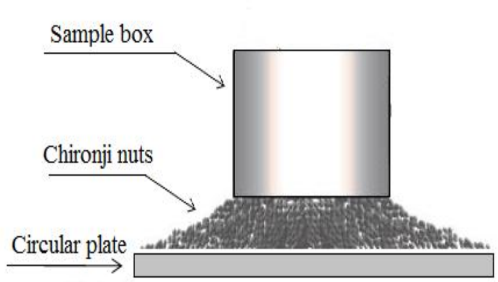


Fig. 2. Experimental setup for measurement of angle of repose

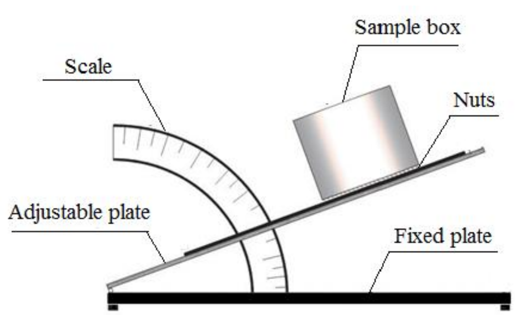


Fig. 3. Experimental setup for measurement of coefficient of static friction

2.4 Statistical Analysis

All the physical and frictional properties mentioned above were determined with randomly selected *Buchanania lanzan* seeds at different desired moisture content. The tools used in computation and comparison of data are mean and standard deviation using MS-Excel software.

3. RESULTS AND DISCUSSIONS

3.1 Seed dimensions

The axial dimensions of *Buchanania lanzan* seed, including length, width, thickness and geometric mean diameter determined in this study at the moisture contents range of 10.1 to 20% (db) are presented in Table 1 and regression equation shown in Table 2. All the dimensions of seed (length, width, thickness and geometric mean diameter) were increased linearly with the moisture content increased from 10.1 to 20% (db). The seed length increased from 7.28 to 12.98 mm (78.29% increase), width from 5.97 to 11.21 mm (87.77% increase) thickness from 5.39 to 10.34 mm (92.91% increase) and geometric mean diameter from 6.04 to 11.45 mm (89.58 % increase) with the same moisture ranges. The increase in the dimensions was due to the expansion of seeds because of moisture absorption in the porous spaces of *Buchanania lanzan* seed. The increase in thickness was relatively higher than other two dimensions *i.e.* length and width. The geometric mean diameter values were higher than width and thickness and lower than the length. The average expansion from the l/w, l/t and l/D_g ratios are given in Table 1. All ratios decreased when the moisture content increases. l/t ratio exhibited the highest value, followed by l/w and l/D_g. The l/w and l/D_g ratios found very similar. This indicates that the thickness of the seed is closely related to its length. Similar findings were reported for pearl millet [12], millet [16] and coriander seeds [17].

3.2 Sphericity

The values of the sphericity for different moisture levels varied from 0.850 to 0.881. The nonlinear relationship between sphericity and moisture content of *Buchanania lanzan* seed is shown in Fig. 4(a). This relationship can be represented by the regression equation (Table 2). Previous researchers reported the sphericity linearly increased with moisture content [18,19]. However, it was found nonlinear relationship between sphericity and moisture content for *Buchanania lanzan* seeds in our study.

Table 1. Axial dimensions and geometric mean diameter of *Buchanania lanzan* seeds at different moisture content

Moisture content, % (db)	Length (mm)	Width (mm)	Thickness (mm)	Geometric mean diameter (mm)	*l/w*	*l/t*	l/D_g
10.1	7.28[e] (0.53)	5.97[e] (0.47)	5.36[e] (0.43)	6.04[e] (0.41)	1.22	1.36	1.21
12	8.69[d] (0.47)	7.16[d] (0.52)	6.51[d] (0.48)	7.46[d] (0.45)	1.21	1.33	1.17
14	9.48[c] (0.49)	8.05[c] (0.42)	7.23[c] (0.34)	8.15[c] (0.36)	1.18	1.31	1.16
17	11.47[b] (0.42)	9.86[b] (0.46)	8.93[b] (0.45)	10.00[b] (0.31)	1.16	1.28	1.15
20	12.98[a] (0.50)	11.21[a] (0.49)	10.34[a] (0.37)	11.45[a] (0.39)	1.15	1.26	1.13

Note: a, b, c, d and e: The values within same column for seed are significantly different. Standard deviation in parentheses

3.3 1000 Seed Mass

As can be seen in Fig. 4(b), the 1000 seed mass was found to increase linearly from 0.211 to 0.433 kg as the moisture content increased from 10.1 to 20% (db). The relationship between the mass of 1000 seed mass and the moisture content can be represented by the regression equation (Table 2). The same trend has been observed for neem seeds [6], pomegranet seed [20] and pigeon pea [21], respectively.

3.4 Surface Area and Volume

The moisture dependence of surface area and volume for the moisture content ranging from 10.1 to 20% (db) is shown in Fig. 4(c). These relationships were best fitted using a second order polynomial equation is presented in Table 2. The surface area of seed ranged from 118.88 to 412.28 mm^2 and volume from 121.91 to 787.37 mm^3 with the moisture increase from 10.1 to 20% (db). The second order polynomial relationship might be due to the wide range of moisture used, which was selected to find the adequate moisture content for shelling of *Buchanania lanzan* seed. Some of those studies were reported for green wheat [22], millet [16] and coriander seed [17].

3.5 Bulk Density and True Density

The bulk and true density of *Buchanania lanzan* seed and its relation with moisture content is shown in Fig. 4(d). The bulk density and true density decreased significantly (at 5% level of significance) and linearly from 639.01 to 521.36 kg/m^3 and 867.73 to 797.73 kg/m^3 as moisture content increased from 10.1 to 20% (db). The decrease in bulk density may be due to the increase in size due to absorption of moisture, which results in decrease in quantity of seeds occupying the same bulk volume. The decrease in true density was mainly due to the larger increase in seed volume as compared to their masses. The decrease in true density (8.06%) was about twice time less than the decrease in bulk density (18.41%) with moisture content increase. Similar results reported for sunflower seeds [9], soybean [18], rapeseed [23], popcorn [24] and karingda seed [25], respectively.

3.6 Porosity

The porosity value of the *Buchanania lanzan* seed is calculating from the bulk density and true density of the seed. The variation of the porosity with moisture content is plotted in Fig. 4(e). The porosity starts at 26.45% and increases linearly up to 33.36% at 20% (db) moisture content. A fist order linear relationship between the porosity and moisture content was obtained (Table 2). This relationship showed a slightly increase of porosity with moisture content increase. Higher porosity provides better aeration and water vapor diffusion during deep bed drying. Similar increasing trend was reported for millet [16], soybean [18], chickpea [26], amaranth and fenugreek [27] and rapeseed [23]. However, porosity was reported to decrease with moisture increase for gram [13] and sunflower [9]:

3.7 Angle of Repose

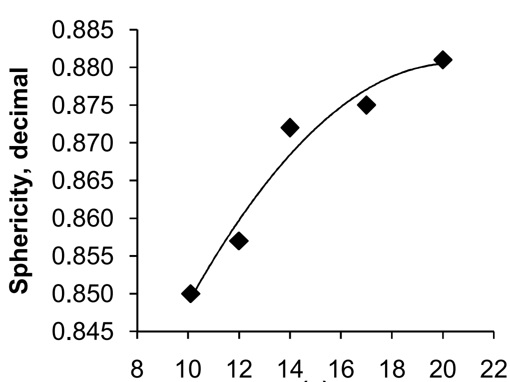
The angle of repose of *Buchanania lanzan* seed increased linearly from 26.45° to 33.75° with the increase of moisture content from 10.1 to 20% (db) (Fig. 4e). The increasing trend of the angle of repose could also be attributed to the surface tension caused by the layer of moisture surrounding the seeds. A linear increase in angle of repose when the moisture content increases have also been observed Kingsly et al. [20], Altuntas and Ozgoz [27], and Singh and Goswami [11] for pomegranate seeds, fenugreek seeds and cumin seeds.

3.8 Coefficient of Static Friction

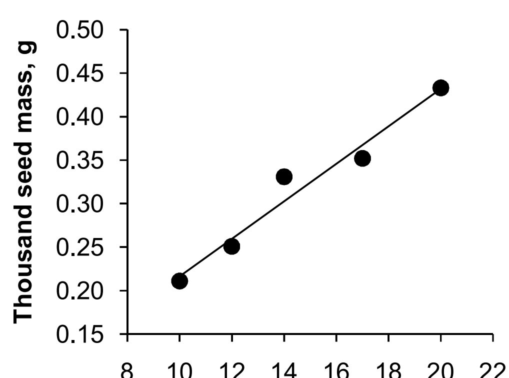
Fig. 4(f) shows the static coefficient of friction of *Buchanania lanzan* seed for four surfaces (rubber, mild steel, plastic and glass). It was observed that the static coefficient of friction increased linearly and significantly (at 5% level of significance) with increase in moisture content on all surfaces. The coefficient of static friction increased from 0.249 to 0.329, 0.291 to 0.392, 0.608 to 0.698 and 0.594 to 0.729 with increasing moisture content for glass, plywood, mild steel and rubber, respectively. Glass, plywood, mild steel, and rubber increase respectively by 32.13%, 34.71%, 14.80% and 22.72%. At all moisture contents, the static coefficient of friction of rubber was higher followed by mild steel, plywood and glass, respectively. This can be attributed to the surface roughness which is largest on rubber. The relationship between moisture content and the coefficient of static friction as different surface can be expressed by the regression equations is presented in Table 2. A similar observation was reported for pumpkin seeds [14], rapeseed [23], and karingda seed [25], respectively.

Table 2. Best fit equations of the physical properties for *Buchanania lanzan* seed

Sl. No.	Property	Notation	Regression equation	Order	R^2
1.	Length of seed, mm	L	$0.538M_c + 2.121$	1	0.969
2.	Width of seed, mm	W	$0.483M_c + 1.463$	1	0.982
3.	Thickness of seed, mm	T	$0.466M_c + 0.967$	1	0.967
4.	Geometric mean diameter, mm	D_g	$0.538M_c + 0.749$	1	0.994
5.	Sphericity, decimal	ϕ	$-0.0002M^2_c + 0.011M_c + 0.758$	2	0.962
6.	Thousand seed mass	M_{1000}	$0.021M_c – 0.001$	1	0.961
7.	Surface area, mm^3	S	$0.981M^2_c + 9.15M_c – 41.94$	2	0.997
8.	Volume , mm^3	V	$3.435M^2_c – 36.12M_c + 138.7$	2	0.998
9.	Bulk density, kg/m3	ρ_b	$-11.60M_c + 749.7$	1	0.989
10.	True density, kg/m3	ρ_t	$-7.061M_c + 934.5$	1	0.976
11.	Porosity, %	ε	$0.852M_c + 17.75$	1	0.975
12.	Angle of repose, °	θ	$0.699M_c + 19.77$	1	0.950
13.	Coefficient of friction, decimal				
	Rubber	μ_r	$0.013M_c + 0.472$	1	0.928
	Mild steel	μ_{ms}	$0.008M_c + 0.518$	1	0.976
	Plywood	μ_p	$0.010M_c + 0.186$	1	0.989
	Glass	μ_g	$0.007M_c + 0.179$	1	0.955



(a)



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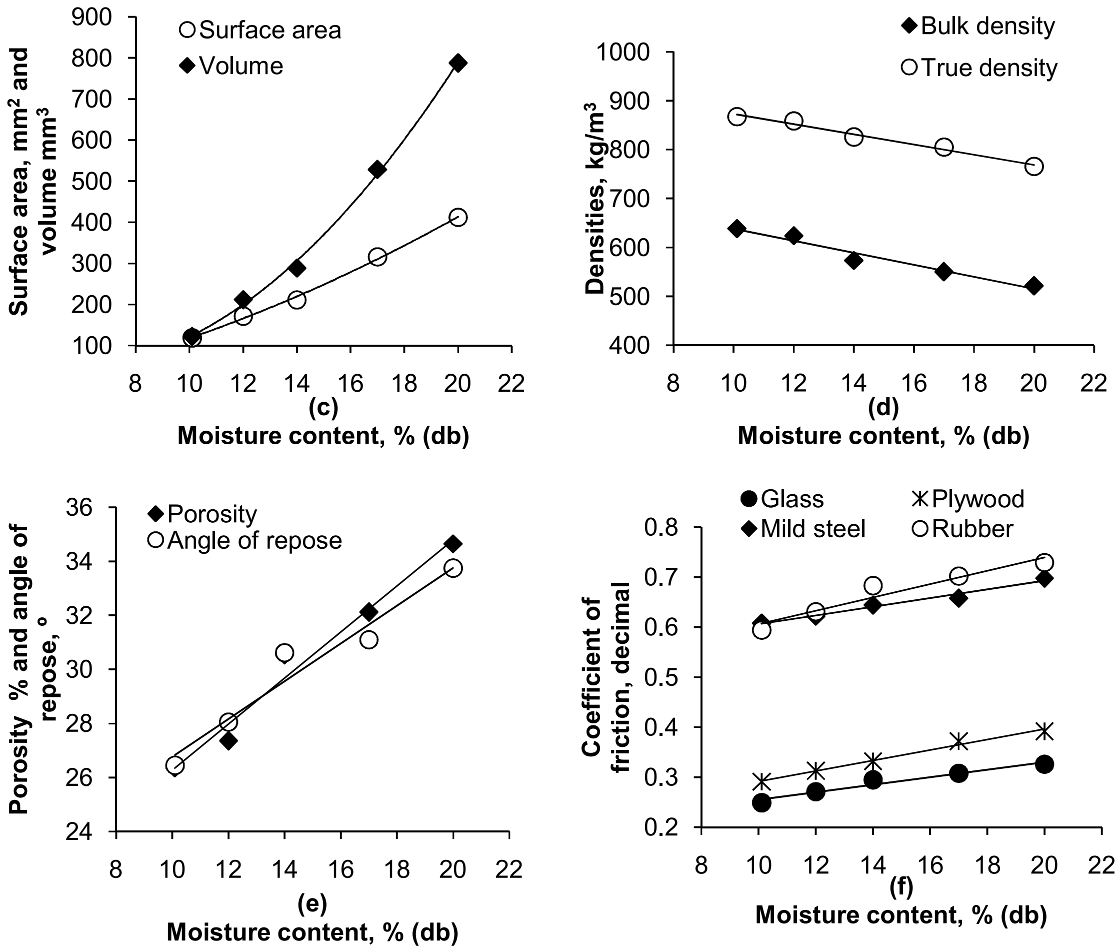

Fig. 4. Effect of moisture content on sphericity (a), thousand seed mass (b), surface area and volume (c), true density and bulk density (d), porosity and angle of repose (e), coefficient of friction on different surfaces (f) of *Buchanania lanzan* seed

4. CONCLUSION

It may be concluded that, the axial dimensions (length, width and thickness), geometric mean diameter and 1000 seed mass, porosity, angle of repose and the static coefficient of friction increased linearly with increase in moisture content from 10.1 to 20% (db). While the sphericity, surface area and volume was found to increased polynomial in same moisture content. The bulk density and true density was found to decrease linearly with moisture content increase. The decrease in true density was about five times greater than the decrease in bulk density were found in this study.

COMPETING INTERESTS

Authors have declared that no competing interests exist

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The peer review history for this paper can be accessed here:
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