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ASSESSMENT OF PHYSICAL, FRICTIONAL AND AERODYNAMIC PROPERTIES OF CHAROLI (*Buchanania Lanzan Spreng*) NUT AS POTENTIALS FOR DEVELOPMENT OF PROCESSING MACHINES

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ABSTRACT

Charoli (*BuchananialanzanSpreng*) has a sustainable economic potential due to its nutritional and medicinal values. The moisture dependent physical, frictional, and aerodynamic properties play a key role while processing food and designing a processing machine. This study determined various physical, frictional, and aerodynamic properties of Charoli (*BuchananialanzanSpreng*) nut at increasing moisture content, and the importance of processing, machine designing were discussed. Different properties of Charoli nut were examined at 9.06, 10.92, 12.51, 15.29, and 17.86 % (d.b) moisture content. Various axial dimensions as length, width, and thickness revealed a linear increment by nut moisture content. The value of true and bulk density reduced as of 657.23 to 578.32 kg m^{-3} and 917.94 to 851.21 kg m^{-3}, respectively, while sphericity and porosity increased from 86.42 to 88.64 %, and 28.40 to 32.06 %, respectively. The coefficient of static friction increases linearly and found highest for rubber. The value of static and dynamic angle of repose increased significantly as of 16.52° to 22.31° and 27.91° to 33.23° respectively. Also, the linear increment was noted in terminal velocity from 13.21 to 14.94 m/s by increasing moisture content. Data obtained by this study will be very much helpful for the development of novel equipment, which will be valuable for operations like separation, grading, cleaning, sorting, deshelling, packaging, and storage structures for Charoli (*BuchananialanzanSpreng*) nut.

1.Introduction

Charoli has a place with the family Anacardiaceae and mostly found in deciduous forests throughout India (Hiwale 2015). The plant expands on yellow sandy–topsoil and is regularly located inside the western, northern, and central India, notably inside the forest zone of Andhra Pradesh(AP), Bihar(BR), Chhattisgarh(CG), Gujarat(GJ), Jharkhand(JH), Maharashtra(MS), Madhya Pradesh(MP), and Uttar Pradesh(UP) (Pandey 1985). Along with India, this plant also observed globally, like in Burma and Nepal (Hemavathy and Prabhakar 1988).

The Charoli fruits grown–up in four to five months and are manually harvested in the summer season, generally in April / May(Shelare et al. 2020). Fig. 1 (a) shows the freshly harvested Charoli fruits and Fig. 1 (b) shows the Charoli nuts after expelling the skin. Fully matured Charoli fruits become blackish after storage. This blackish skin must be expelled prior to deshelling. For expelling, fruits are kept in water for a night and scrubbed within palms or by a jute sack. Again this is washed with fresh water to get cleaned nuts. These nuts are then dried in solar light and put away for further processing, i.e., deshelling (Kumar et al. 2012).

It is a medicinally valuable tropical tree species and an essential cause of living for the bounded tribal community (Dhande et al. 2020). Practically all the parts of this plant are used for the therapy of numerous disorders (Jawalekar and Shelare, 2020). The Charoli kernel has a high amount of protein(19.0 – 28.19 %) which is exceptionally nutritious. The kernel yields sweet oil (33.50 %), of which 1.90 % is unsaponifiable. The 20.00 % of linolenic acid found in the saponifiable part. Charoli oil is healthy and fit for the consumption of humans (Banerjee and Jain 1988). Table 1 shows the proximate composition of Charoli, Sesame, Almond, Cashew, and Walnut kernals. Compared to other dried fruits, Charolikernals have significant fat, protein, ash, fiber, starch, and carbohydrate that is very significant for human health.

Table 1. Proximate composition of some dried fruit kernals

Reference	Nut	Moisture (%)	Fat (%)	Protein (%)	Ash (%)	Fiber (%)	Starch / Carbohydrate (%)
(Sahu et al. 2018), (Hiwale 2015), (Banerjee and Jain 1988), (Dwivedi et al. 2012).	Charoli	2.86 – 3.12	50.72 – 61.91	19.0 – 28.19	5.63 – 6.59	3.8	10.87 – 12.25
(Onsaard 2012) (Badifu and Akpagher 1996)	Sesame	4.50 –11.00	48.20– 56.30	19.10– 26.90	2.0–5.59	2.5–3.90	5.59–17.90
(Ahrens et al. 2005), (Sze–Tao and Sathe 2000)	Almond	2.84 – 5.86	43.3 – 56.05	16.42 – 23.30	2.69 – 4.56	1.98	23.6 – 27.0
(Arogba 1999) (Alobo et al. 2009)	Cashew	9.30 – 12.40	45.17 – 51.0	20.23 – 36.0	0.3 – 6.96	4.54 – 4.56	3.4 – 11.39
(Dogan and Akgul 2005) (Sze–Tao and Sathe 2000)	Walnut	3.00 – 3.62	66.75 – 67.15	16.23 – 17.47	1.81 – 2.26	——	65.0 – 70.0

(a) (b)

Figure 1. (a) Freshly harvested Charoli Fruits, (b) Charoli nuts after expelling the skin.

The delicate piece of Charoli nut is the kernel that could be influenced by deshelling, its removal from a shell is the critical most practice (Kumar et al. 2012). Damaging the kernels in de-shelling process decreases the demand cost of nuts (Güner et al. 2003). Preserving the quality and decreasing the losses of this kind of items is an important subject and has pulled numerous researchers in the field. In the past, minimal research has been done on some physical properties of Charoli nut and the work was carried out on the samples from the specified local region (Deshmukh et al. 2017; Kumar et al. 2016; Nishad et al. 2019). Also, it is essential to expand knowledge of the Charoli nut properties globally to produce an effective, efficient, and safe machine for kernel extraction followed by separation and grading because these processes on Charoli nuts are still carried out manually in India (Sahu et al. 2018). This investigation aimed to determine the physical, frictional, and aerodynamic properties of harvested nuts that will be valuable for researchers/scientists in designing and developing equipment for various postharvest treatments and processing.

2. Materials and methods

2.1.Sample preparation

Charoli nuts used in the study were procured from the nearby markets of various states/districts of India like Maharashtra, Madhya Pradesh, Chhattisgarh, Jharkhand, and Gujarat during April 2019 for randomization. The Charoli nuts were typically soaked overnight in plain water and scoured against the rough surface of the jute bag to remove the skin. Then the nuts were rewashed with clean water and dried in sunlight (Kumar et al. 2012). These dried, cleaned nuts were used for further experimentation.

2.2.Moisture content

Primarily experiments were conducted for moisture content determination of dried Charoli nut. The experiments were performed at the Metallurgical lab of the Mechanical Engineering Department, Priyadarshani College of Engineering, Nagpur, Maharashtra, India. The drying in the oven (hot air oven; Universal, New Delhi, India) method was adopted to find the moisture content of Charoli nuts. The nuts are kept in an oven at 105°C for 6 hrs as per the ASAE standard (ASAE 1982). The moisture content of dried Charoli nut was observed as 9.06 % (db) and was considered base moisture level to other examination. The moisture content was varied from 09.06 to 17.86 % (d.b) for an examination. The required moisture level of Charoli nuts was obtained by the addition of a specific amount (Equation 1) of distilled water and packing into the isolated polyethylene packets. For consistency of moisture, Charoli nut samples were stored at 5° C in the fridge around 15 days. Prior to each test of nuts, the required Charoli nut samples were brought out of the fridge and kept in room temperature (Bajpai et al. 2019). The distilled water amount to be added to achieve the required moisture content was computed using relation (1) (Galus and Lenart 2019; Aghbashlo 2013).

$$Q = \frac{W_i\,(M_f - M_i)}{(100 - M_f)} \qquad (1)$$

Where, W_i– initial sample mass (g); M_i– initial moisture content of the sample (% d.b.); M_f– final moisture content of the sample (% d.b.); and Q– amount of distilled water added (g).

2.3.Measurement of dimensional properties

Dimensional properties of samples were assessed on five levels of moisture content, namely 9.06, 10.92, 12.51, 15.29, and 17.86 % d.b. To determine the dimensions of the Charoli nut, 100 nuts of five moisture content levels were picked randomly from the sample (Igbozulike and Amamgbo 2019). The axial dimensions like length (L), width (W) and thickness (T) of a nuts, as shown in Fig. 2 were measured by loading between two parallel jaws and applying equal pressure using digital micrometer screw guage (Mitutoyo, Japan) having accuracy of ± 0.001 mm (Kacal and Koyuncu 2017; Aydin 2003).

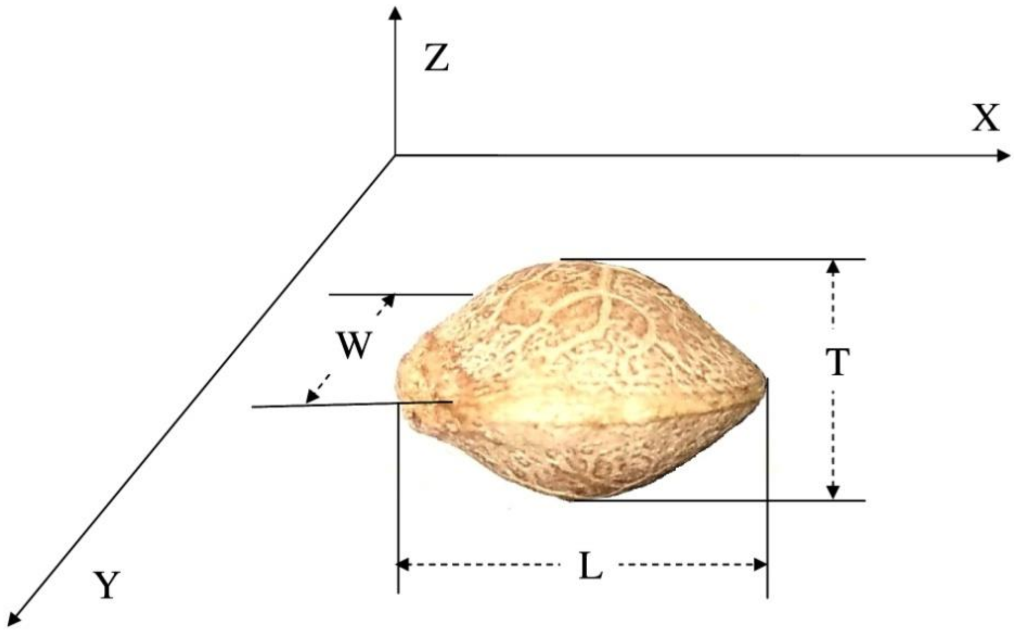


Figure 2. Axis and dimensions of Charoli Nut.

Geometric (D_g) and arithmetic (D_a) mean diameter were calculated through relations (2)–(3) (Moradi et al. 2019; Galedar et al. 2010; Celli 2015).

$$D_g = (L+W+T)^{1/3} \qquad (2)$$

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

The sphericity (φ) and surface area (S) of the Charoli nut were found through the relationship as in equation (4)–(5) (Jahanbakhshi et al. 2019).

$$\varphi = \frac{D_g}{L} \qquad (4)$$

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

2.4.Measurement of gravimetric properties

2.4.1.Thousand nut mass (M_{1000}):

Thousand unit masses were obtained by an electronic balance (Model FA-2204B) of 0.001g accuracy. 100 nuts of the cleaned sample were randomly picked and weighed in the balance. Output was multiplied with 10 to get 1000 nuts mass. The measurements were replicated ten times for individual moisture content (Coskuner and Karababa 2007; Mohsenin 1980)

2.4.2.Bulk density

The bulk density (ρ_b) was calculated by pouring nuts from 15 cm height into an empty 50 ml graduated cylinder (Mohsenin 1980). For achieving the throughout consistency, the cylinder was stabbed ten times to consolidate the nuts. A similar process was performed ten times individually for five moisture content level, and the bulk density was computed using the formula (6) (Sonawane et al. 2020)

$$\rho_b = \frac{W_s}{V_s} \qquad (6)$$

Where, W_s– nut weight (kg); and V_s– Occupied Volume by nuts (m^3)

2.4.3.True density

True density (ρ_t) can be calculated by toluene displacement method. Toluene (C_7H_8) has low absorptivity compared to water; hence it was used (Singh et al. 2019). Due to the property of low surface tension, it occupies the fills shallow dips of the nuts. A sample of nuts was immersed in toluene of a measuring cylinder with 0.1 ml accuracy. The graduated scale of the cylinder shows the amount of displaced toluene. A similar process was performed ten times (Thakur and Nanda 2018). The true density was computed using the formula (7)

$$\rho_t = \frac{M}{V} \qquad (7)$$

Where, M– mass of each nut (kg); and V– volume displaced (m^3)

2.4.4.Porosity

Porosity (ε) indicates a number of pores into sample at given moisture content. It was computed by true and bulk density values and appears into the percentage. The porosity was determined by the use of the given formula (8). (Garnayak et al. 2008).

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

Where, ρ_t– true density of nut (kg m^{-3}); and ρ_b– bulk density (kg m^{-3}).

2.5.Measurement of frictional properties

2.5.1.Coefficients of static friction

Coefficients of static friction (μ) of Charoli nut at five moisture contents were estimated for distinct frictional surfaces, specifically aluminium, plywood, and rubber (Obi et al. 2018). The samples were kept in an open-ended wooden container of 150 × 150 × 50 mm size, and the container was kept on the adjustable friction material tilting surface (Mansouri et al. 2017). The schematic of the arrangement is as shown in Fig. 3. A friction material surface was inclined slowly until a container began sliding on the surface. The tilting angle was recorded with the help of a graduated scale provided near surface. A coefficient of static friction (μ) was determined with equation (9).

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

Where μ– coefficient of static friction and θ– tilt angle (degree).

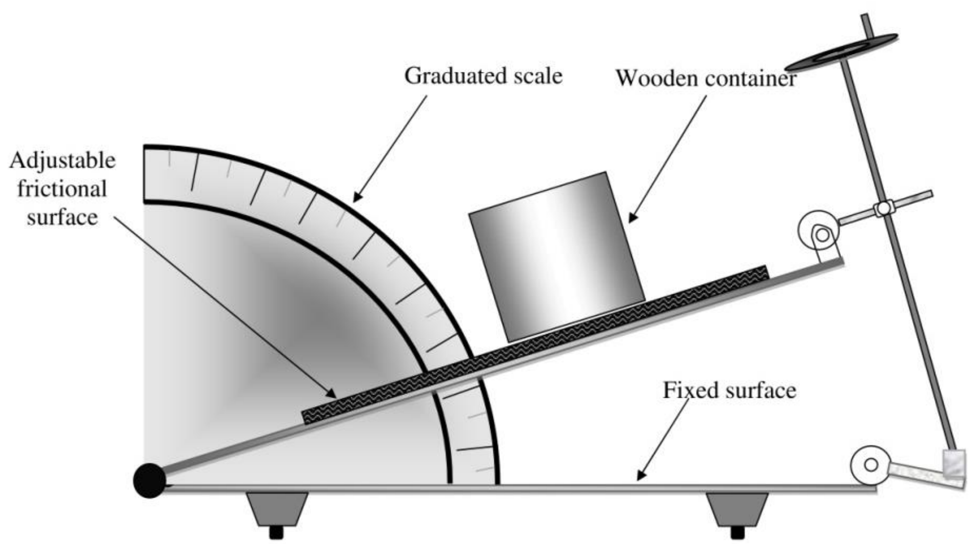


Figure 3. Schematic of the arrangement for measurement of coefficient of static friction of Charoli nut.

2.5.2.Static and dynamic angle of repose

A cylinder having 150 mm diameter and 250 mm height was used to find a static or filling angle of repose. The cylinder was filled by Charoli nut kept on the middle portion of the circular plate. Then the cylinder was then removed gradually until nut sample formed of the cone shape on the circular plane (Mirzabe et al. 2017). The cone height and diameter weremeasured to calculate an angle of repose (θ_f) utilizing a formula (10).

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

Where D and H are the cone diameter and height, respectively.

A fibreglass box of dimension 200×200 ×200 mm was utilized for finding a dynamic or emptying angle of repose. The complete box was filled by Charoli nut and front panel of the box was immediately slid upwards. Because of this sudden slid the sample nuts were flowing outside and form a heap. Samples height between two points (b1, b2) in the sloping Charoli nut heap and horizontal dimensions at a different point (a1, a2) were noted. A dynamic or emptying angle of repose (θ_e) was determined with a relationship (11). (Galedar et al. 2010)

$$\theta_e = \tan^{-1}\left[\frac{(b2-b1)}{(a2-a1)}\right] \quad (11)$$

Dynamic and static angle of repose plays a key role in designing hoppers for Charoli nuts where the bulk of the materials is in motion. (Khodabakhshian et al. 2010).

2.6.Measurement of aerodynamic properties

Terminal velocity of Charoli nut was measured by air column at 9.06, 10.92, 12.51, 15.29, and 17.86 % db moisture content. The schematic of the arrangement for measurement of terminal velocity is as shown in Fig. 4. During the test, Charoli nut sample was dropped inside stream of air from upper side of the air column. (Gezer et al. 2002). Then the flow of air was increased gradually until nut sample got suspended into stream of air. The digital anemometer (least count 0.1 m/s) was utilized for measurement of air velocity near nut suspension point (Ünal et al. 2006).

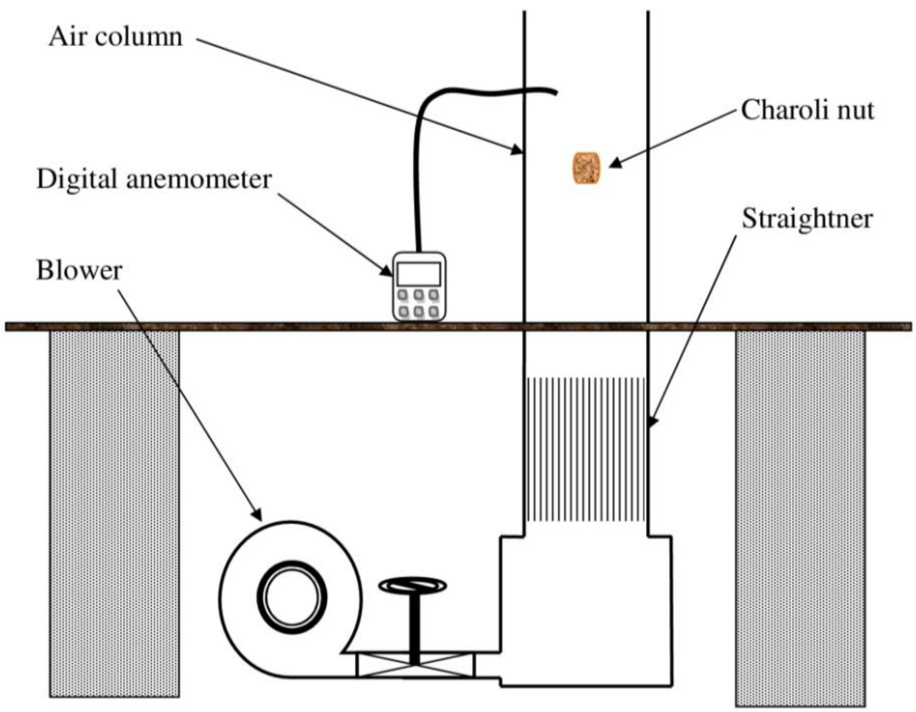


Figure 4. Schematic of the arrangement for measurement of terminal velocity of Charoli nut.

3. Results and discussions

3.1.Dimensional properties

Table 2 shows the various mean ± SD values of various dimensional properties of Charoli nut.Dimensional properties of nut help in the design process of sorting, deshelling, and separating equipments. Fig. 5 (a) show the bar chart for the variation in mean dimensions like length (L), width (W), thickness (T) and geometric mean diameter (D_g) of Charoli nut for individual moisture level. It can be seen from Fig. 5 (a), dimensions of L, W, T and D_g increases by an increment in moisture from 9.06 to 17.86%. The dimensions of nut thickness significantly lower than the other two dimensions (length and width). Fig. 5 (b) shows a linear dimension for variation in mean dimensions at an individual moisture content of Charoli nut. The dimensions of nut length were mostly recorded more than the width, while in few cases, the nut widths were found more than the length.

Table 2. Moisture content dependent mean ± SD values of various dimensional properties of Charoli nut.

Moisture Content	Length (mm)	Width (mm)	Thickness (mm)	Geo. mean dia. (mm)	Surface area (mm^2)	Sphericity (%)
9.06	7.5844 ± 0.6601	7.7543 ± 0.6740	4.7608 ± 0.3462	6.5318 ± 0.3974	134.53 ± 16.07	86.427 ± 4.936
10.92	8.8725 ± 0.6615	8.7765 ± 0.6477	6.0136 ± 0.3247	7.7575 ± 0.3959	189.54 ± 19.08	87.662 ± 4.227
12.51	9.7811 ± 0.6202	9.5680 ± 0.6291	6.8819 ± 0.3482	8.6291 ± 0.3929	234.41 ± 21.11	88.379 ± 3.602
15.29	11.141 ± 0.629	10.678 ± 0.643	7.7786 ± 0.3562	9.7389 ± 0.4101	298.49 ± 24.98	88.428 ± 3.012
17.86	11.962 ± 0.579	11.583 ± 0.595	8.5923 ± 0.3853	10.593 ± 0.378	352.98 ± 25.12	88.643 ± 2.780

The L, W, T and D_g of the Charoli nuts varied linearly from 7.58 to 11.96 mm, 7.75 to 11.58 mm, 4.76 to 8.59 mm, and 6.53 to 10.59 mm, respectively by varying moisture level between 9.06 to 17.86% on dry basis. The extension in length and width were seen as very closer than the thickness, which could be because of a cellular arrangement of Charoli nuts. The percentage increment in L, W, T and Dg dimensions are 57.72, 49.37, 80.47, and 62.17 %, respectively. Comparative patterns in the measurements were also found for Jamun (Syzgiumcuminii) seed with respect to dimensions of L, B, T, and Dg within the moisture level within 11.54 – 26% d.b. (Bajpai et al. 2019). The moisture content (M_C) dependent relationship of the L, B, T, and Dg dimensions are shown in Equations (12), (13), (14) and (15)

$$L = 0.4953\ M_C + 3.367\ (R^2 = 0.9809) \quad (12)$$
$$B = 0.4309\ M_C + 4.015\ (R^2 = 0.9914) \quad (13)$$
$$T = 0.4211\ M_C + 1.278\ (R^2 = 0.9678) \quad (14)$$
$$Dg = 0.4532\ M_C + 2.700\ (R^2 = 0.9798) \quad (15)$$

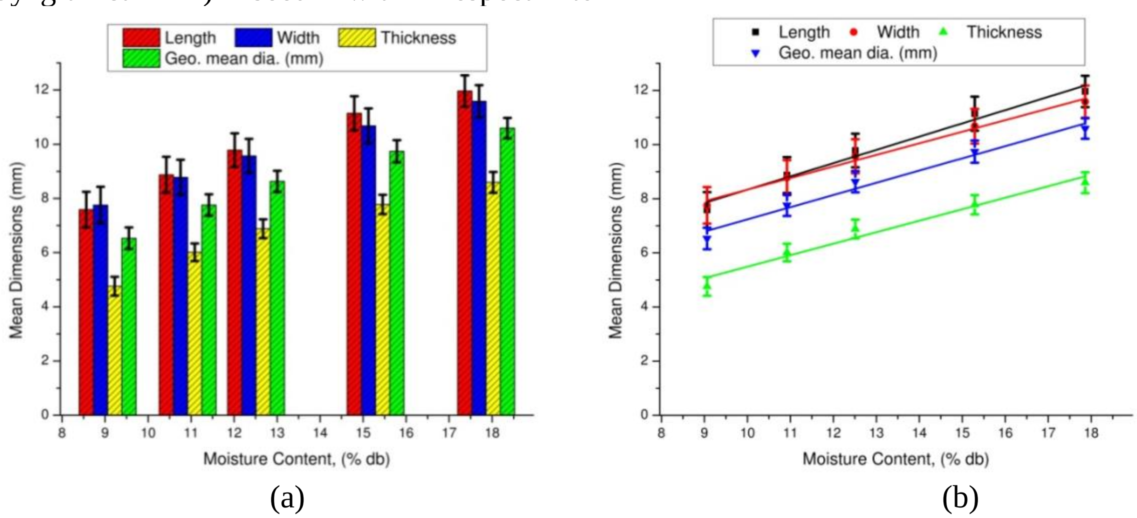
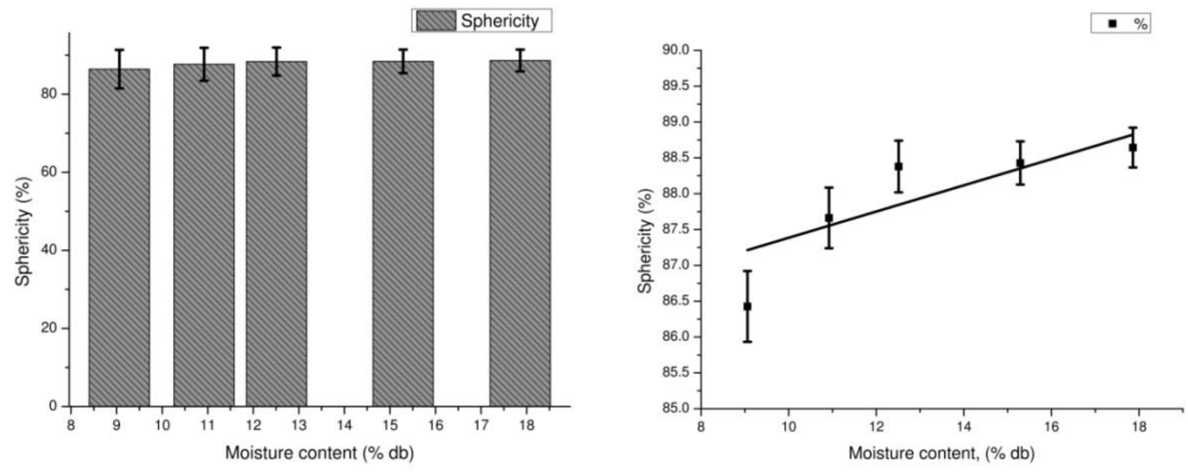


Figure 5. (a) Bar chart and (b) linear dimension for variation in mean dimensions at individual moisture content of Charoli nut.

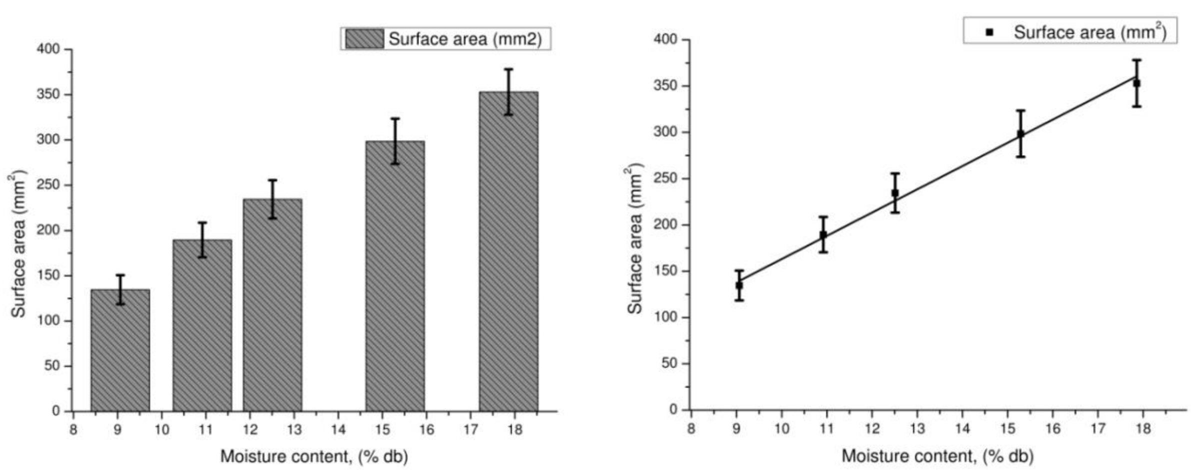


(a) (b)

Figure 6. (a) Bar chart and (b) linear dimension for variation in sphericity at individual moisture content of Charoli nut.

Mean values for the sphericity (φ) of Charoli nuts were 86.42, 87.66, 88.37, 88.42, and 88.64 %, respectively, with varying moisture content between 9.06 to 17.86% on a dry basis. Fig. 6 (a) shows the bar chart, and Fig. 6 (b) shows the linear dimension for the variation in sphericity of Charoli nut for individual moisture level.This indicates that average values of sphericity increased with increment in moisture content, which depicts nut's becoming more spherical. This result gives confirmation with results of Arjun et al. (2017) for makhana and Vilche et al. (2003) for hemp seeds. The higher value shows the tendency of rolling than sliding upon the surface. Therefore while designing the transfer, transport and sorting systems, make nut roll rather than slide. The moisture content effect on the sphericity of Charoli nuts is represented by regression equation (16).

$$\varphi = 0.2226\ M_C + 84.99 (R^2 = 0.7367) \quad (16)$$



(a) (b)

Figure 7. (a) Bar chart and (b) variation in surface area at individual moisture content of Charoli nut.

The surface area (SA) of the Charoli nuts varied between 134.52 and 352.97 mm^2. Values show a notable increment in surface area by means of increment of moisture content. The moisture content effect on the surface area of Charoli nuts is shown in Fig. 7 (a) and (b).

A similar linear increasing trend found in Taghi Gharibzahedi et al. (2011) for castor seeds; and Malik and Saini (2016) for sunflower seeds. The surface area plays a significant function in sizing systems design. Apart from this, surface areas are utilized to model material and heat transfer while freezing or drying nuts (Vivek et al. 2018; Pathak et al. 2019). Equation (17) shows the moisture content effect on the surface area of Charoli nuts

$$SA = 24.66\ M_C - 81.7\ (R^2 = 0.9948) \quad (17)$$

3.2.Gravimetric properties

3.2.1.Thousand nut mass (M_{1000})

Table 3 shows the mean ± SD values of various gravimetric properties of Charoli nut. In contrast, variation in a thousand Nut Mass of Charoli nut by the moisture content is illustrated in Fig. 8 (a) and (b). A result indicates the linear increment in mean value from 0.134 kg to 0.421 kg with moisture content.

Table 3. Moisture content dependent mean ± SD values of various gravimetric properties of Charoli nut.

Moisture Content	Thousand gram Weight	Bulk Density	True Density	Porocity
9.06	0.1342 ± 0.01579	657.23 ± 15.30	917.94 ± 43.9	28.25249± 3.84
10.92	0.196667 ± 0.0364	638.99 ± 10.01	898.43 ± 41.3	28.77164± 2.671
12.51	0.2765 ± 0.01893	616.58 ± 13.35	883.25 ± 45.7	30.04625± 3.46
15.29	0.3524 ± 0.02210	599.32 ± 19.87	874.65 ± 46.5	31.3178± 4.07
17.86	0.4215 ± 0.02371	578.32 ± 14.93	851.21 ± 46.9	31.9583± 2.050

The increase in thousand nuts mass illustrates the considerable moisture absorption by the Charoli nut for increase in moisture range. The nut mass is the important parameter while considering the flow rate of the equipment, therefore, deciding Charoli nut mass for acknowledgement of the impact of moisture content on increment of each nut weight.

Similar incremental tendency for thousand Nut mass were observed by Izli et al. (2009) and Sacilik et al. (2003) for rapeseeds and hemp seed respectively. The variation of the thousand nut mass (kg) is mathematically expressed as in equation (18)

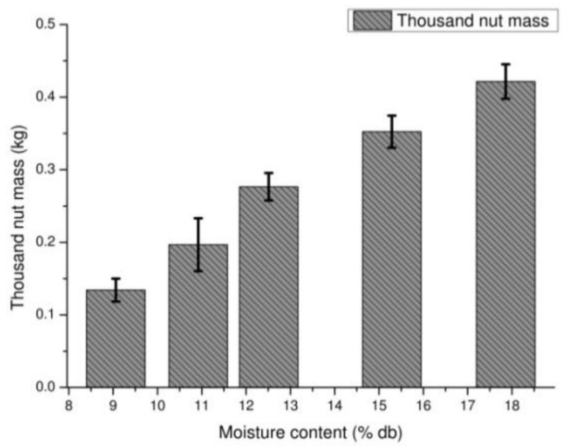
$$M_{1000} = 0.03285\ M_C - 0.1550\ (R^2 = 0.9874) \quad (18)$$

3.2.2.Bulk and true density

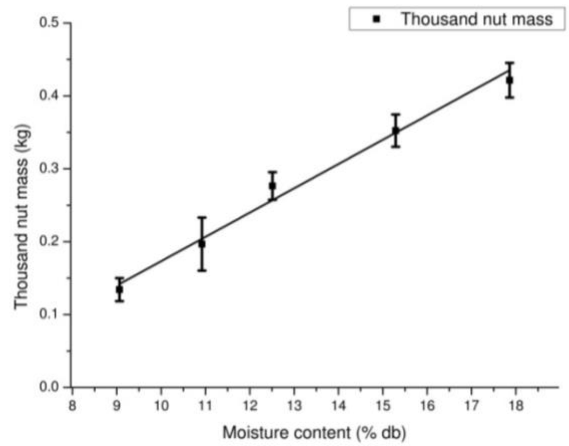
Because of moisture content increment in nuts, bulk and true density values are significantly reduced from 657.23 to 578.32 kg m^{-3} and 917.94 to 851.21 kg m^{-3}. The bulk and true density relationship of Charoli nut is illustrated in **Fig.** 9 (a) and (b).

Bulk and true density consideration is very important while designing different devices for cleaning, separation, and conveyance systems of nut. The mass of the nut increased because of moisture gaining of Charoli nuts ultimately decreased the bulk density. A similar trend of contrary connection between moisture content and bulk density has been concluded by Ghosh et al. (2017) for Jamun seed and Pradhan et al. (2008) for Karanja kernel. Bulk density and moisture content relationship of Charoli nut has expressed as in equation (19)

$$\rho_b = -8.864\ M_C + 734.46 (R^2 = 0.9834) (19)$$

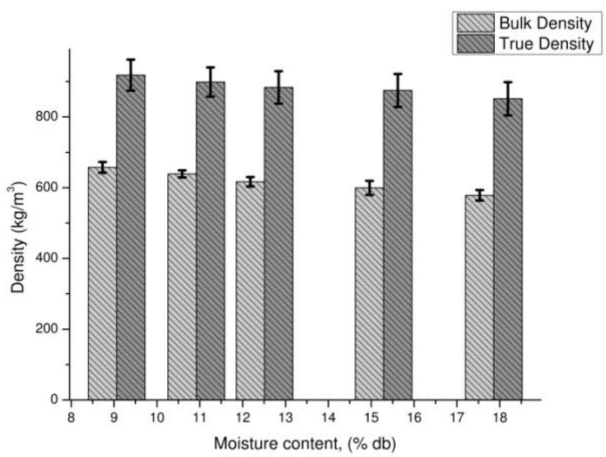


(a)

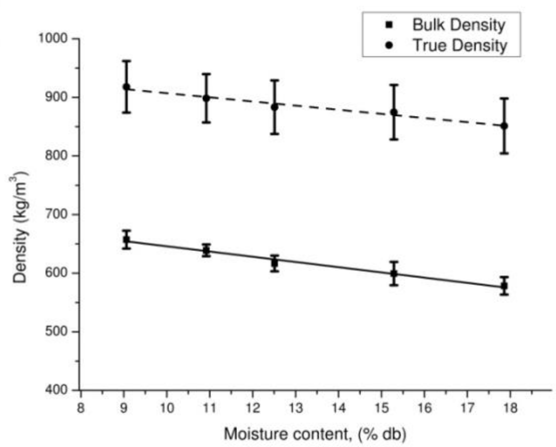


(b)

Figure 8. (a) Bar chart and (b) variation in thousand nuts mass at individual moisture content of Charoli nut.



(a)



(b)

Figure 9. (a) Bar chart and (b) variation in bulk and true density at individual moisture content of Charoli nut.

The true density is a real mass of Charoli nuts with excluding a pores / empty spaces. Decrease in true density might be because of a higher true volume. The true density signifies the nuts are heavy in weight and will not float on water. Similar trend of contrary connection between moisture content and true density has been reported for pistachio nuts (Kashaninejad et al. 2005); sorghum (Mwithiga and Sifuna 2006); and spinach seeds (Kilickan et al. 2010). The variation in true density has expressed as in equation (20)

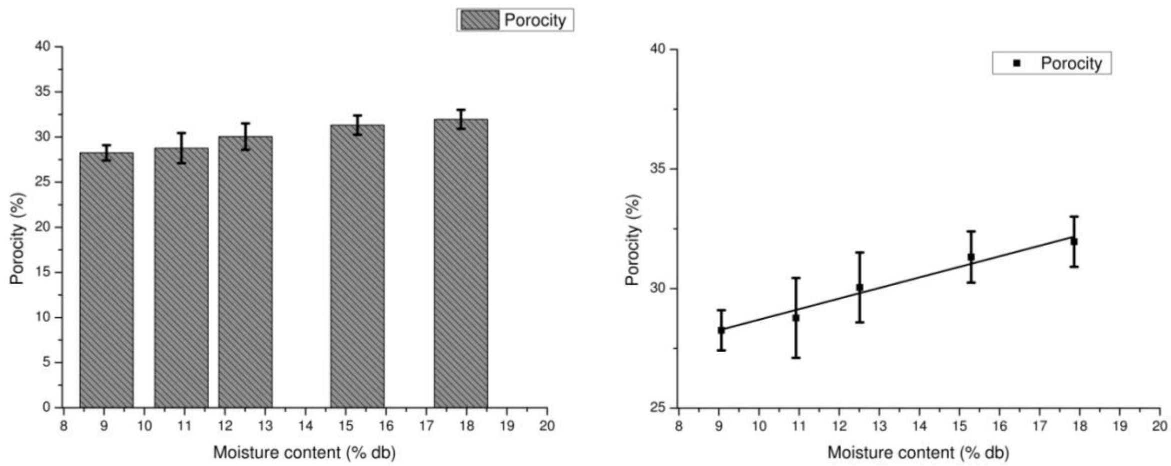
$$\rho_t = -7.056\ M_C + 977.7 (R^2 = 0.9666) \quad (20)$$

3.2.3. Porosity

Porosity (ε) % value communicates the inter–granular to a total occupied space of the nut. Porosity dependency on a bulk and true density is diverse for individual nut with moisture content increment. A slight increment in porosity value of Charoli nut was observed with increment in moisture content. Porosity of Charoli nuts increased from 28.40% to 32.05% with moisture content increment from 9.06% to 17.86% (d.b.). A moisture content effect on porosity is shown in Fig. 10 (a) and (b).

The porosity of nuts provides the significance of the resistance to the air flow at aeration or drying. A similar linear increment in porosity has been found for gram (Chowdhury et al. 2001); chickpea seed (Konak et al. 2002); and Brachystegia Eurycoma seed (Aviara et al. 2014). While linear decrement into porosity has been observed in the research by Sacilik et al. (2003) and Suthar and Das (1996) for hemp and karingda seed, respectively. Morphological characteristics play an important role in increase or decrease of porosity of nuts observed by the result. The linear correlation was observed in porosity and moisture content of nuts, and it can be shown by a regression equation (21):

$$\varepsilon = 0.4461\, M_C + 24.345 \quad (R^2 = 0.9654) \quad (21)$$



(a) (b)

Figure 10. (a) Bar chart and (b) variation in porosity at individual moisture content of Charoli nut.

3.3.Frictional properties

3.3.1 Coefficients of static friction

The result of the coefficient of static friction (μ) of Charoli nut having different moisture contents (9.06, 10.92, 12.51, 15.29, and 17.86 % db) on three frictional surfaces as aluminium, plywood, and rubber is presented into Fig. 11 (a) and (b). A value of μ increased significantly with moisture content. The μ increases linearly from 0.367 to 0.495, 0.381 to 0.512, and 0.432 to 0.585 for aluminium, plywood, and rubber respectively within the moisture range between 9.06–17.86% (d.b.).

The value of (μ) varies linearly with increment in moisture content. A highest value of (μ) found at high moisture content in all of three surfaces. An increment in value of (μ) may be because of an increment in cohesive force between Charoli nut and contact surfaces. Nut becomes rough with increase in moisture content which ultimately reduces its sliding characteristics. Coefficient of friction results were similarly stated by Mirzabe et al. (2017) for cucumber seeds and Tabatabaeefar (2003) for wheat.

The correlation in coefficient of static friction with moisture content of aluminium, plywood, and rubber are presented in equations. (22), (23), and (24), respectively:

$$\mu_{al} = 0.01509\, M_C + 0.2331 \quad (R^2 = 0.9766) \quad (22)$$

$$\mu_{ply} = 0.01552\, M_C + 0.2428 \quad (R^2 = 0.9790) \quad (23)$$

$$\mu_{ru} = 0.017847\, M_C + 0.2699 \quad (R^2 = 0.9944) \quad (24)$$

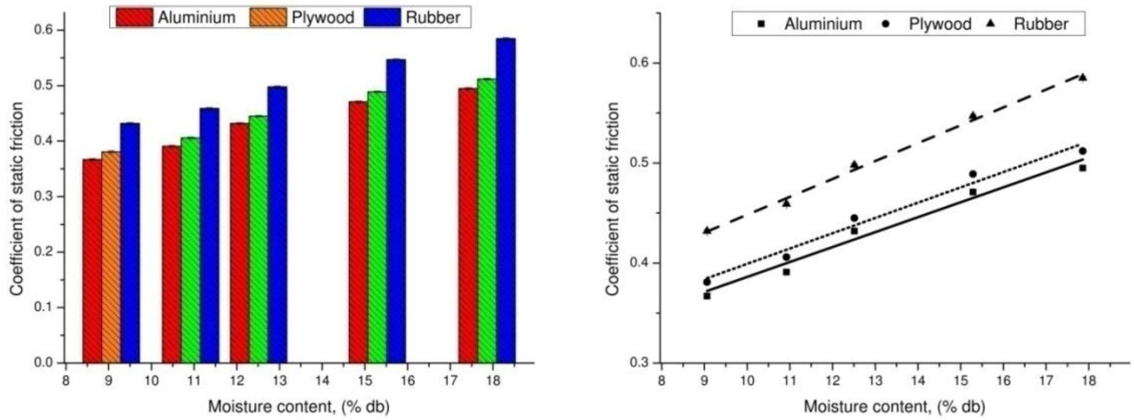


Figure 11. (a) Bar chart and (b) variation in coefficients of static friction at individual moisture content of Charoli nut.

3.3.2.Static (θ_s) and dynamic angle of repose (θ_d)

Variations of the static and dynamic angle of repose of Charoli nut within moisture range of 9.06–17.86% (db) are presented in Fig. 12 (a) and (b). A value of static and dynamic angle of repose increased significantly by 16.52° to 22.31° and 27.91° to 33.23° respectively with respect to moisture content ranging from 9.06–17.86% (db).

The angle of repose indicates the nuts flow–ability. It is also characteristic indicating the cohesion between nut and the surface layer of moisture of nut. With increase in moisture content, surface of nut becomes rough. Therefore, for easier flow–ability of nut, hopper angle must be more than 35°.

Similar linear increasing trends with increasing moisture content were reported by Oje and Ugbor, (1991); and Chowdhury et al. (2001) for oilbean and gram respectively.

The relationship between static and dynamic angle of repose of Charoli nut with respect to moisture content is represented in equation 25 and 26.

$\theta_s = 0.6503\ M_C + 10.777$ (R^2= 0. 9965 (25)

$\theta_d = 0.6274\ M_C + 22.156$($R^2$= 0. 9928 (26)

3.3.3 Aerodynamic properties

An experimental result for variations of the terminal velocity (V_t) of Charoli nut with respect to moisture content ranging from 9.06–17.86% (db) are shown in Fig. 13 (a) and (b). With increment in moisture content (9.06–17.86% (db)), increment into terminal velocity noted from 13.21 to 14.94 m/s.

Similar results were stated by Suthar and Das (1996); Nimkar and Chattopadyay (2001) and Sacilik et al. (2003) for karingda seed, green gram, and hemp seed respectively. An increment into terminal velocity with respect to moisture content is due to an increment in frontal area mass of a nut offered to a stream of air. Terminal velocity data may be useful for various post-harvest operations like separation from impurities, cleaning and transportation. The relationship between the terminal velocity of Charoli nut with respect to moisture content is represented in equation 27.

$V_t = 0.1784\ M_C + 11.634$($R^2$= 0. 9465)(27)

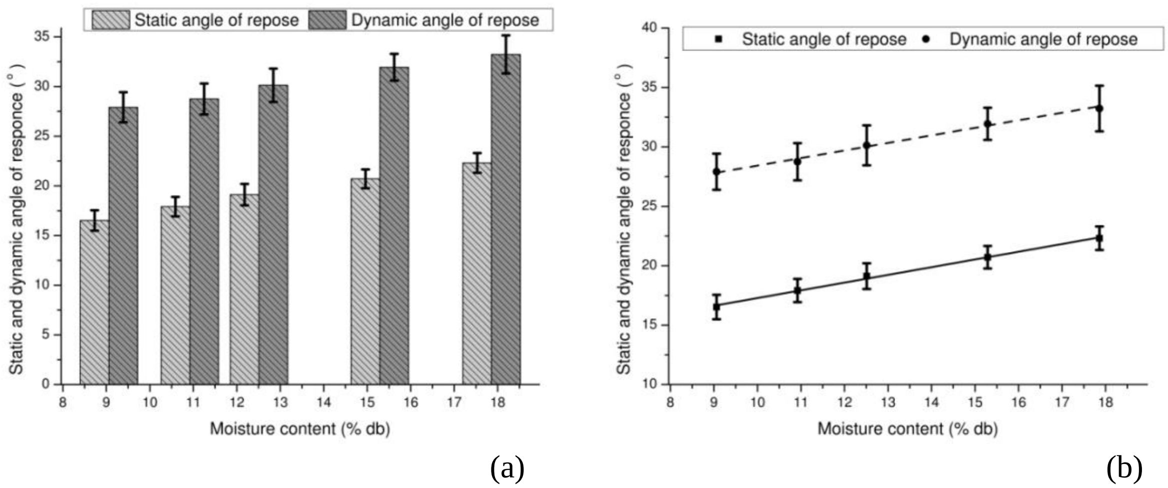


Figure 12. (a) Bar chart and (b) variation in coefficients of angle of repose at individual moisture content of Charoli nut.

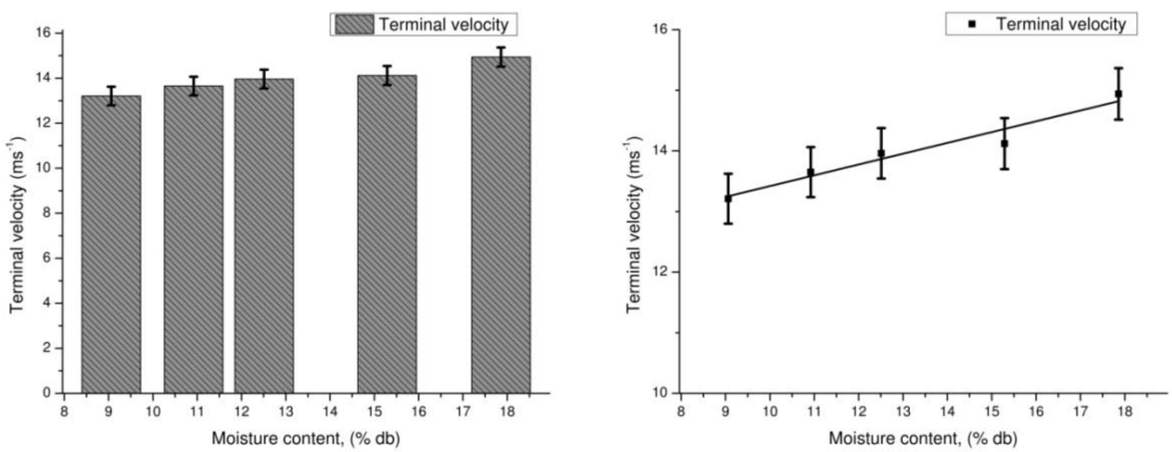


Figure 13. (a) Bar chart and (b) variation in terminal velocity at individual moisture content of Charoli nut.

4. Conclusions

Charoli has extremely high nutritional and medicinal values. Because of ignorance of its value and its processing difficulty, this ultimate product has been underestimated and unexplored. For making extra efficient and simple processing, a present experiment has been conducted to find various characteristics like physical, frictional and aerodynamic characteristics of nut. The results of this study indicated moisture content significantly influences and modifies the physical, frictional and aerodynamic properties. Following major conclusions are obtained by the study.

In all properties, only the true and bulk densities decreased with increment in moisture content whereas remaining properties were increased. Increments in the properties are attributed mostly to the cellular arrangements and water absorption by the nut.

The mean values for the sphericity of nuts were increased from 86.42 to 88.64 % with moisture content which shows the tendency of rolling than sliding upon the surface. This is helpful while designing handling and sorting systems for the nuts.

The surface area increased from 134.52 and 352.97 mm^2 which shows more attention needs to take while designing of sizing system. The nuts having higher moisture content needs more space for heat transfer while freezing or drying.

The gravimetric properties such as thousand nut mass and porosity increased linearly from 0.134 kg to 0.421 kg and 28.40% to 32.05%, respectively, whereas bulk and true density decreased. Decrease in a bulk density was noted because of increase of mass due to gaining of moisture. Whereas the true density signifies the nuts are heavy in weight and will not float on water.

The coefficient of static friction increased with moisture content and found highest in case of rubber as compared to aluminium and plywood. An increment in the value of (μ) is because of cohesive force increment.

The static and dynamic angle of repose increased significantly from 16.52° to 22.31°, and 27.91° to 33.23°. Therefore, for easier flow–ability of nut, hopper angle must be more than 35°.

Terminal velocity of nut increased in linear manner from 13.21 to 14.94 m/s. This terminal velocity data may be useful in different post–harvest operations like separation from impurities, cleaning and transportation.

These results provide valuable information to various scientists, technologists, and engineers having keen interest for development of sustainable mechanization for postharvest processing of Charoli nut.

5.References

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