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Investigating the Role of Moisture in the Physical Properties of Harra (*Terminalia chebula*) Fruit

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Abstract

Harra (Terminalia chebula) is known as the "king of medicines" in Ayurveda. Its fruits include astringent, purgative, antibacterial, antifungal, and laxative effects. The behavior of harra fruit is mainly dependent on the moisture present. It affects the harvest, post-harvest machinery, separation, packaging, and transportation of harra fruit. This study focused on T's physical qualities of chebula fresh fruit at 20%–25% (wb) moisture content, such as 50 fruit mass, length, width, thickness, arithmetic-geometric mean diameter, sphericity, surface area, volume, bulk density, true density, porosity, and inclination angle, as engineering properties were 271–290.2 g, 31.91–31.95 mm, 18.43–18.44 mm, 17.34–17.35 mm, 22.70–22.72 mm, 21.69–21.71 mm, 1472.15–1476.44 mm^2, 10272.83–10286.01 m^3, 581.33–597.84 kg/m^3, 1020.73–1098.68 kg/m^3, 42.39–46.38%, and 28.78–29.16, respectively. Mechanical properties, such as coefficient of friction were observed on galvanized steel sheet, stainless steel sheet, glass sheet, and mild sheet, as friction coefficients were determined as 0.29–0.31, 0.23-0.24, 0.24-0.25, and 0.28–0.29, respectively. The dried harra fruit must be manually decorated or dehulled in tribal areas by striking it with a stone; this is an extremely labor-intensive and time-consuming process. The study's physical and mechanical characteristics of T. chebula fruit revealed that, depending on the moisture content, the harra seed can be easily removed from the fruit at a moisture content of 20–25%. Harra fruit which has 20–25% moisture content can be used with machines for embellishment.

Keywords: Harra, physical properties, coefficients of friction, Bulk density, Porosity

INTRODUCTION

Harra, also known as *Terminalia chebula*, belongs to the family *Combretaceae* and is a medicinal plant commonly used in traditional Ayurvedic medicine. Renowned for its multiple health advantages, it is sometimes lauded in Ayurveda as the "crown jewel of remedies" due to its broad therapeutic capabilities. *Terminalia chebula* is a tree that can grow up to 30 meters tall, with a rounded crown and a trunk covered with dark brown bark. The leaves are ovate or elliptic, and the tree produces small, yellowish-green oval drupe fruit. In tropical and subtropical climates, with temperatures ranging between 15°C and 30°C (59°F to 86°F), *Terminalia chebula* thrives. It prefers well-drained, loamy soils, but it can also thrive in sandy or clay-based environments. *T. chebula*, also known as Harra in Chhattisgarh, Haritaki in Sanskrit, Harad in Hindi, and Chebulic Myrobalan in English, has a wide range of therapeutic qualities. *Terminalia chebula*, often known as Harra, is a strong and adaptable herb with a long history in traditional medicine. Harra, known for its wide range of

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therapeutic qualities, includes antibacterial, antifungal, antiviral, antidiabetic, antimutagenic, antioxidant, antiulcer, and wound-healing activities. In addition, it promotes heart health and is commonly used to treat kidney problems. Haritaki is a fundamental element of Triphala, a well-known herbal formula consisting of three fruits: Amalaki (*Emblica officinalis*), Bibhitaki (*Terminalia bellirica*), and Haritaki. Triphala is widely recognized for its potential to improve digestive health and overall well-being.

Harra can be found in deciduous forests throughout India, including Himachal Pradesh, Tamil Nadu, Kerala, Karnataka, Uttar Pradesh, Chhattisgarh, Andhra Pradesh, and West Bengal [1, 2]. In Chhattisgarh, the estimated annual potential output of harra exceeds 50, 000 quintals, although actual production varies each year. Major harra-producing districts in Chhattisgarh include Kanker, Keshkal, South Kondagaon, East Bhanupratappur, Jagdalpur, Rajnandgaon, Dharamjaigarh, Raigarh, and Jashpur.

The metabolic activity of *Terminalia chebula* fruits has been extensively studied due to their rich phytochemical composition and therapeutic potential [3]. These fruits contain a variety of bioactive compounds, including phenolics, flavonoids, and organic acids, which contribute to their antioxidant, anti-inflammatory, antiviral, anticancer, antibacterial, hepatoprotective, nephroprotective, neuroprotective, and anti-diabetic properties [4]. The metabolic activities of these compounds have shown promising results in both in vitro and in vivo studies, highlighting the significant therapeutic potential of *Terminalia chebula* fruits.

Designing and developing equipment for agricultural processing, transportation, sorting, separation, and storage requires a detailed understanding of material engineering features. Important engineering parameters include shape, size, weight, bulk density, true density, porosity, static and dynamic friction coefficients on various surfaces, and the product’s rupture behavior. This data is critical for determining the performance and efficiency of crop machinery. Furthermore, moisture content is an important consideration when developing appropriate equipment since moisture-related qualities influence process design, product quality, processing, and packaging [5]. The physical qualities of agricultural goods are critical in developing processing systems, such as washing, separation, storage, transportation, and drying. Sphericity aids in understanding heat and mass transport, whereas the stagnation angle indicates how easily a food product flows. Another significant feature used to describe and process food products is porosity [6].

Analyzing the physical and mechanical qualities of agricultural goods is critical for building gear for harvesting, post-harvest processing, sorting, packaging, and transportation [7–9].

MATERIALS AND METHODS

Sample

Harra fruits used in this study were procured from forests of Charama, Kanker district (North Baster) of Chhattisgarh (India). Foreign materials were cleaned and dried properly, and foreign materials were removed, fruits were stored in jute bags for further processing (Figure 1).

Figure 1. *Terminalia chebula* fruit.

Variation of Moisture Contents

The fruits were washed by hand to eliminate dirt, dust, unripe or broken fruits, and any other foreign matter. The moisture content of the fruit was measured by using the hot air oven at 105℃ for 24 hr [10]. The moisture content of harra was determined using the method reported by [3]. The samples were transferred to separate polythene bags and reconditioned to desired moisture content levels, 50 harra fruits were randomly selected for each of the moisture content levels for the measurement of length (L), Width (W), and Thickness (T) with the use of a vernier caliper with least count of 0.01 mm. The arithmetic and geometric average diameters of harra fruit were calculated using the relationships.

Physical Characteristics

Randomly selected 50 samples of *T. chebula* fruit were used. The dried fruit measurements were measured using a digital caliper with a 0.01 mm precision Figure 2.

Figure 2. Size measurement of *T. chebula* fruit.

The seeds' arithmetic mean diameter (Da) and geometric mean diameter (Dg) were calculated using the following relationships.

$$Da = \frac{L + W + T}{3}$$

$$Dg = (LWT)^{\frac{1}{3}}$$

The sphericity, of harra fruits was calculated by using the following relationship (Mohsenin, 1980):

$$\mu = \frac{(LWT)^{\frac{1}{3}}}{L}$$

where, L is the length, W is the width and T is the thickness (all in mm).

R_a = W/L

where,
R_a is the aspect ratio, W is the width (mm), and L is the length (mm).

The mass of 1000 seeds were determined using a digital electronic balance with a precision of 0.001 g.

The surface area of the seed sample was estimated as a sphere with an equivalent geometric mean diameter, using the approach described by [8–10].

S = $\pi . Dg2$

where,
S is the surface area (mm^2).

The bulk density was determined by filling a 1000 ml cylindrical container with fruit at a continuous rate up to the 500 ml mark, then weighing the contents using a digital electronic balance (Shimadzu Corporation, Japan, AY120) with a precision of 0.001 g [11]. There was no further hand compression of the fruit. "The mass of the fruit and the volume of the container were used to determine the bulk density. The real density was estimated using the toluene (C7H8) displacement method to prevent water absorption throughout the experiment. Toluene was chosen over water because of its low absorption by fruits, low surface tension, ability to fill even shallow depressions, and low dissolution number" [12]. The true density was estimated by immersing a weighed number of harra fruits in toluene and measuring the volume of toluene displaced. This value was then used to calculate the average ratio of the mass of the fruit to the displaced volume.

Porosity is a grain property determined by both bulk density and true density. The porosity, ε, in %, is the parameter indicating the number of pores in the bulk materials. It was calculated from bulk and a true density using the relationship given as follows [13, 14].

$$porosity\ (\varepsilon) = (1 - \frac{\rho_b}{\rho_t}) \times 100$$

where,
$\varepsilon\ is$ the porosity (%);
ρ_b is the bulk density (kg/m^3);
and ρ_t is the true density (kg/m^3).

The angle of repose is the steepest angle at which a sloping surface formed of loose material is stable. It was calculated by the following expression reported by

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

where,
H is the height of the heap and D is the diameter of the heap.

The static coefficient of friction was determined with respect to four test surfaces namely: stainless steel sheet, mild steel sheet, galvanized steel sheet, and glass. The static coefficient of friction was calculated based on this equation.

$$\mu o = \left(\frac{Fo}{W}\right)$$

where,
μ_0 = Coefficient of friction,
F_0 = Weight at which sliding started,
W = Weight of the sample.

RESULTS AND DISCUSSION

The dimensional characteristics of the *T. chebula* fruit were measured at the different moisture content of levels 20% and 25%. The average principal dimensions of the fruit viz. length (L), width (W), and thickness (T) were found to be 31.91 ± 3.32 to31.95 ± 3.47 mm, 18.43 ± 1.84 to 18.44 ± 1.62 mm and 17.34 ± 1.81 to 17.35 ± 1.59 mm respectively (Figures 3 and 4).

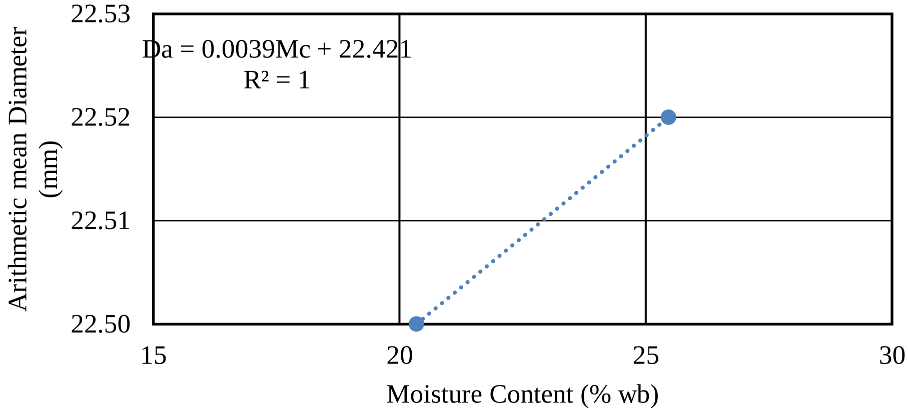

Figure 3. Effect of moisture content on the geometric mean diameter of *T. chebula* fruit.

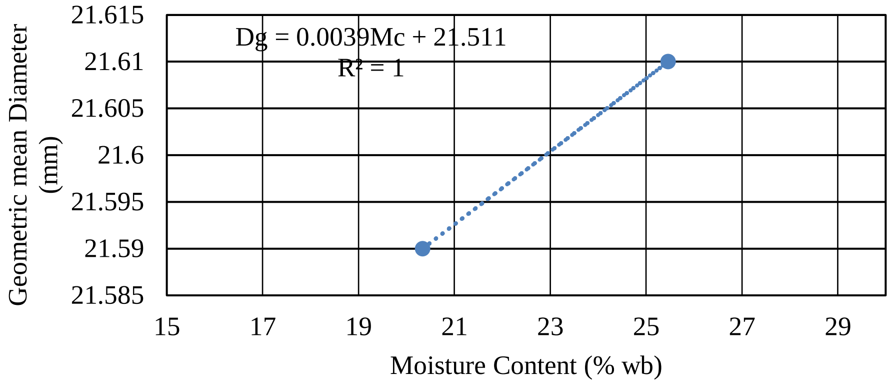

Figure 4. Effect of moisture content on the arithmetic mean diameter of *T. chebula* fruit.

The average *T. chebula* AMD and GMD were found to be 22.70 ± 1.80 to 22.72 ± 1.77 mm, and 21.69 ± 1.77 to 21.71 ± 1.68 mm, respectively. The assessment of the projected area of a fruit particle moving in the near turbulent or turbulent zone of an air stream, as well as the evaluation of the machine's aperture size in fruit segregation, will benefit from these average diameters. The determination of the sizing system, water loss, modeling of mass and heat transfer during fruit drying and cooling, forecasting optimum harvest time, and assessing gas permeability, ripeness index, and respiration rate all rely on the fruit's surface area. The mean value for the surface area of the *T. chebula* was recorded as1472.15 ± 239.40 to1476.44 ± 226.22 mm^2 respectively. The results for the investigated physical properties are tabulated in Table 1.

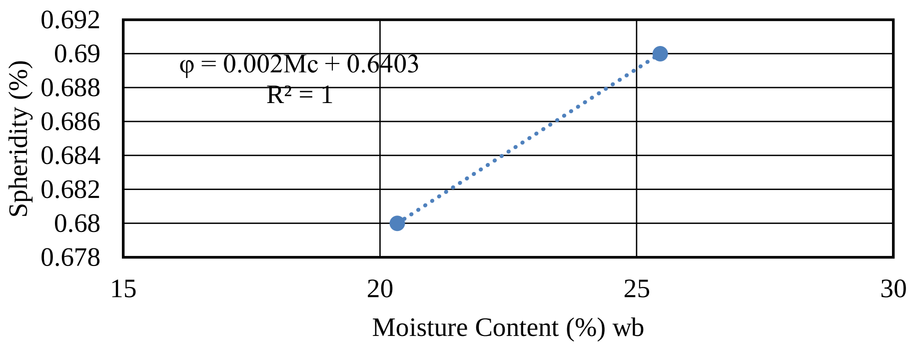

Figure 5. Effect of moisture content on the sphericity of *T. chebula* fruit.

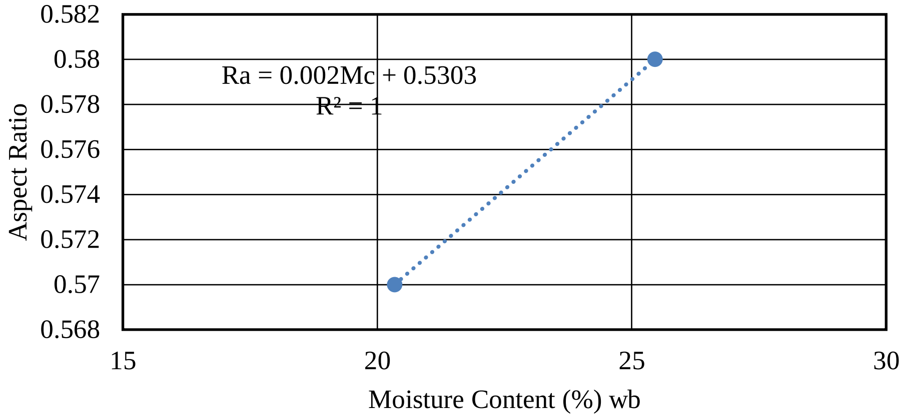

Figure 6. Effect of moisture content on the aspect ratio of *T. chebula* fruit.

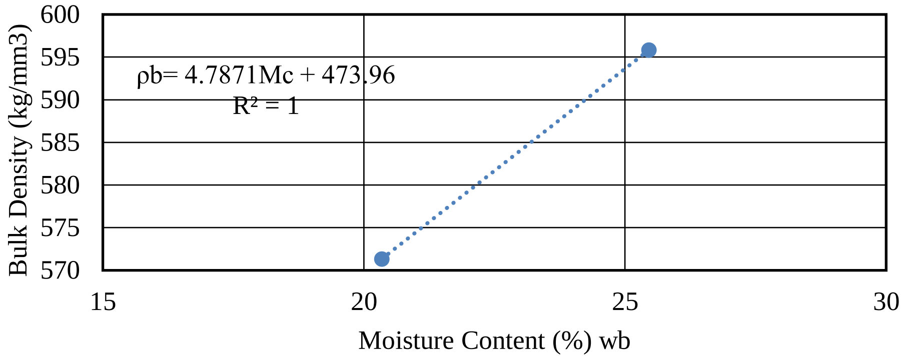

Figure 7. Effect of moisture content on the bulk density of *T. chebula* fruit.

The aspect ratio and sphericity were used to measure the shape of the fruit. The aspect ratio of *T. chebula* was found to be 0.56 ± 0.06 to 0.58 ± 0.06 respectively. Sphericity values are essential for designing sizing and separation equipment. These two parameters aspect ratio and sphericity significantly influence the flow behavior of the fruit [15]. When the sphericity value exceeds 0.80, the fruit is considered spherical in shape (Bal & Mishra, 1988). *T. chebula's* low sphericity value of 0.68 indicates that the fruit will slide on a specified surface rather than roll down. Figures 5 and 6 illustrates the relationship between moisture content (wb%), sphericity and aspect ratio of Terminalia chebula (Harra) fruit. The graph shows an increasing trend, indicating that sphericity and aspect ratio rises as moisture content increases. With an R^2 value of 1, the data exhibits a perfect linear correlation, signifying that sphericity and aspect ratio is directly proportional to moisture content within this range. This sliding tendency is a crucial factor in hopper design [16]. From the obtained values of aspect ratio (0.56 ± 0.06 to 0.58 ± 0.06) and sphericity (0.67 ± 0.04 to 0.68 ± 0.05), respectively, the *T. chebula* fruit was confirmed as an ellipsoid in shape.

The volumes for *T. chebula* fruit ranged from 10272.83 ± 2487.58 to 10286.01 ± 2335.10 respectively, which are crucial for calculating fruit densities during storage and post-harvesting. The recorded true density and bulk density were 1020.73±0.98 to 1098.68±20.33 g/m³ and 581.33 ± 13.73 to 597.84 ± 15.17 g/m³, respectively. A similar trend in bulk density and true density was observed for jujube fruits [17]. These fruit densities are essential for designing storage bins, silos, and for segregating desirable materials from impurities. Figures 7 and 8 illustrates the relationship between moisture content (wb%), bulk density and true density (kg/m³) of Terminalia chebula (Harra) fruit. The graph shows an increasing trend, indicating that bulk density and true density rises as moisture content increases. With an R^2 value of 1, the data exhibits a perfect linear correlation, signifying that bulk density and true density is directly proportional to moisture content within this range. They also play a role in cleaning, grading through aerodynamic separation processes, and evaluating product quality [18]. The porosity value for the entire fruit was measured to be 42.39 ± 1.40 to 46.38 ± 2.19%. Figure 9 illustrates the relationship between moisture content (wb%) and porosity of Terminalia chebula (Harra) fruit. The graph shows an increasing trend, indicating that porosity rises as moisture content increases. With an R^2 value of 1, the data exhibits a perfect linear correlation, signifying that porosity is directly proportional to moisture content within this range. This value is essential for airflow and heat flow studies and provides insight into the intergranular space occupied by the fruit.

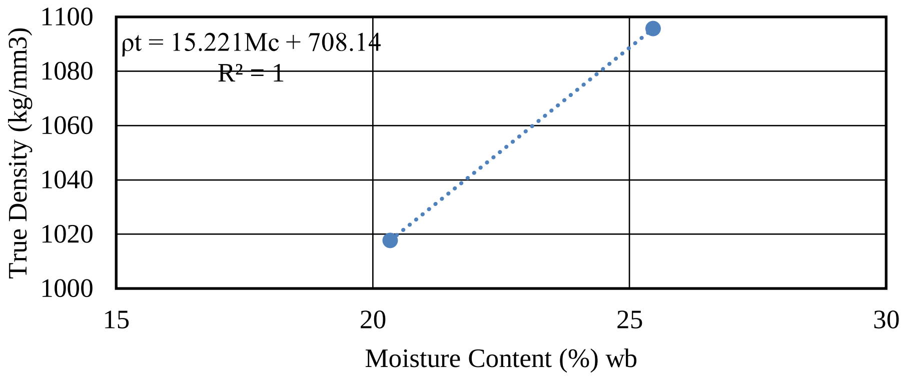

Figure 8. Effect of moisture content on the true density of *T. chebula* fruit.

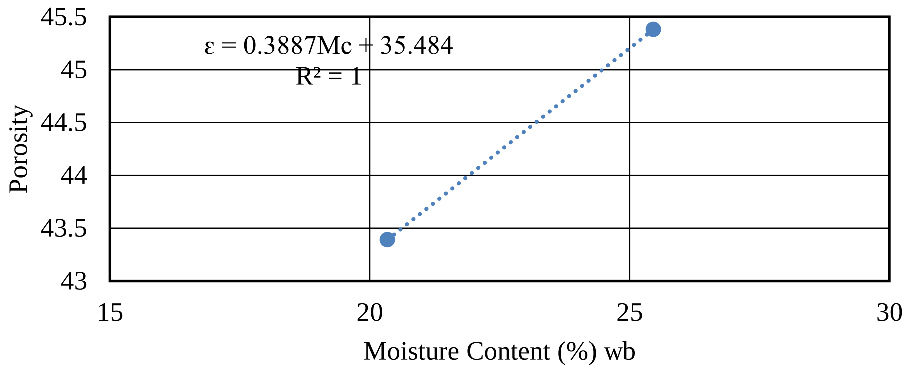

Figure 9. Effect of moisture content on the porosity of *T. chebula* fruit.

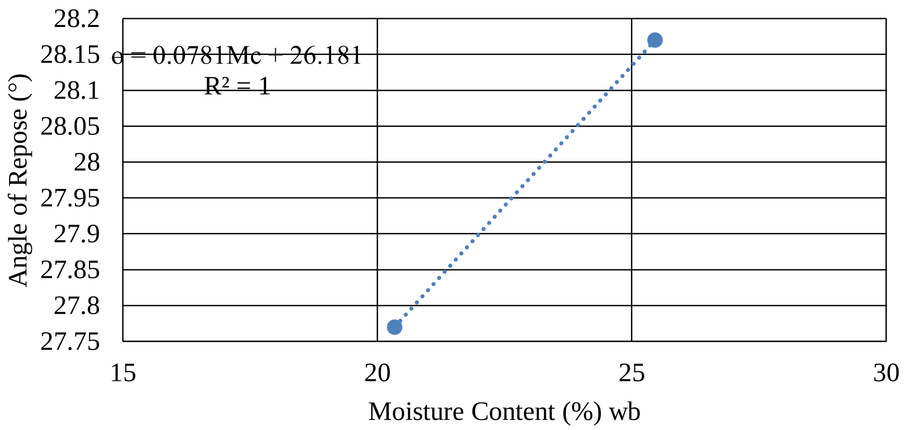

Figure 10. Effect of moisture content on the angle of repose of *T. chebula* fruit.

The cohesion among individual fruits can be expressed in terms of the angle of repose.

A higher angle of repose indicates greater cohesion and lower flowability of the material, or vice versa. "The angle of repose is the angle formed with the horizontal at which a material creates a stable pile For *T. chebula* fruit, the recorded angle of repose was 28.78º ± 3.62 to 29.16º ± 1.98, respectively, suggesting that it will form a flatter pile compared to fruits with a higher angle of repose." Figure 10 illustrates the relationship between moisture content (wb%) and angle of repose of Terminalia chebula (Harra) fruit. The graph shows an increasing trend, indicating that angle of repose rises as moisture content increases. With an R^2 value of 1, the data exhibits a perfect linear correlation, signifying that angle of repose is directly proportional to moisture content within this range. The low angle of repose indicates that *T. chebula* has good flowability. This angle is determined by particle density, surface area, shape, and coefficient of friction. Table 2 shows the friction coefficients of *T. chebula* fruits on various surfaces and moisture levels. These coefficients often decreased slightly as the moisture content of all materials rose.

Table 1. Physical properties of *Terminalia chebula* fruit.

Physical Properties	**Moisture Content (%) wb**							
	25 %				***20 %***			
	Mean	*Minimum*	*Maximum*	*SD*	*Mean*	*Minimum*	*Maximum*	*SD*
Length (mm)	31.95	24.84	39.16	3.47	31.91	25.47	38.74	3.32
Width (mm)	18.44	14.38	22.55	1.62	18.43	13.33	24	1.84
Thickness (mm)	17.35	12.85	22.54	1.59	17.34	12.8	23.63	1.81
Arithmetic mean diameter (mm)	22.72	18.23	26.4	1.77	22.70	18.03	26.96	1.80
Geometric mean diameter (mm)	21.71	17.37	25.88	1.68	21.69	16.83	26.61	1.77
Surface area (mm^2)	1476.44	947.56	2103.38	226.22	1472.15	890.05	18862.41	239.40
Volume	10286.01	5242.29	17337.32	2335.10	10272.83	4772.35	0.80	2487.58
Sphericity (%)	0.68	0.59	0.81	0.05	0.67	0.57	0.80	0.05
Aspect ratio (R_a)	0.58	0.46	0.74	0.06	0.56	0.44	0.72	0.06
Bulk Density (kg/m^3)	597.84	585.33	619.33	15.17	581.33	557	588.66	13.73
True Density (kg/m^3)	1098.68	1078.51	1124.22	20.33	1020.73	1016.6	1019	0.98
Porosity (%)	46.38	42.57	47.93	2.19	42.39	42.09	45.33	1.40
Angle of repose	29.16	26.56	30.96	1.98	28.78	22.83	31.43	3.62

Table 2. Coefficient of friction.

	25%	**20%**
Ass	0.25 ± 0.01	0.24 ± 0.00
Mild steel	0.29 ± 0.00	0.28 ± 0.00
Galvanized steel	0.31 ± 0.00	0.29 ± 0.00
Stainless steel	0.24 ± 0.00	0.23 ± 0.00

CONCLUSIONS

The physical qualities of harra fruit were evaluated in relation to their moisture content. In the moisture range between 25% and 20% w.b., the following changes in physical properties were observed: the axial dimensions and average diameters decreased as the moisture content decreased. Additionally, the angle of repose, static coefficient of friction, sphericity, bulk density, true density, and porosity all decreased with the reduction in moisture content.

The results and regression equations from the study on the physical and mechanical properties of *T. chebula* fruit in relation to moisture content offer essential technical and functional information. This information is crucial for developing harvest and post-harvest equipment, as well as for tasks, such as sorting, separating, packaging, and transporting items.

An essential highlight to note is that the harra seed can be effortlessly extracted from its fruit when the moisture content ranges between 20–25% wb.

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