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Engineering Properties of Tamarind: A Comparison Between Shelled and Unshelled Tamarind

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ABSTRACT

The experiment was conducted during April–June, 2024 in the department of Agricultural Process Engineering, Dr. Panjabrao Deshmukh Krishi Vidhyapeeth Akola, Maharashtra, India to determine the physical, chemical and frictional properties of shelled and unshelled tamarind. Standard methods are used to calculate all the engineering properties. Moisture content was determined by hot air oven method and the color was determined by digital colorimeter. The obtained results of the study were: the mean length, width and thickness of unshelled and shelled tamarind were 81.36 mm, 22.31 mm, 15.28 mm and 75.01 mm, 17.41 mm, 10.24 mm respectively. The mean bulk density, true density and porosity of unshelled and shelled tamarind were 370.01 kgm^{-3}, 719.7 kg m^{-3}, 48.39% and 512.35 kg m^{-3}, 912.73 kg m^{-3}, 43.49% respectively. The mean arithmetic Mean Diameter, Geometric Mean Diameter, sphericity index, surface area of unshelled and shelled tamarind were39.65mm, 30.02mm, 0.38, 2866.80 mm^2 and 34.22 mm, 23.45 mm, 0.332, 1754.24 mm^2 respectively. The mean moisture content and color values of unshelled and shelled tamarind are 23.64%, L^*=47.606, a^*=8.944, b^*=21.604 and 23.14%, L^*=37.178, a^*=11.22, b^*=20.404 respectively. This study analyzed the critical differences between the engineering properties of unshelled and shelled tamarind fruit, providing valuable insights for optimizing the design and operation of machinery used in tamarind processing. Understanding these properties can improve handling, reduce processing losses, and enhance the efficiency of equipment used in cleaning, sorting, and packaging.

KEYWORDS: Physical properties, engineering properties, shelled tamarind, unshelled tamarind

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1. INTRODUCTION

Tamarind trees, scientifically known as *Tamarindus indica*,, which belongs to the Fabaceae family are very common and economically important in India (Kuru, 2014; Raja et al., 2022; Kidaha et al., 2017). It is native to Africa but it grows widely in forests, arid region and all over India, as well as in Bangladesh, Sri Lanka, Burma, and many other places worldwide. People also plant them along roadsides or in their gardens (Bhattacharya et al., 1993). India holds the title of being the world's largest producer of tamarind, with an annual production reaching 3,00,000 tons. Tamarind fruits in India are typically harvested between April and May, though in regions like Kerala and other parts of South India, collections may occur by the end of February. Particularly abundant in states like Andhra Pradesh, Karnataka, Tamil Nadu, Madhya Pradesh, Bihar, West Bengal, and Chhattisgarh (Kumar et al., 2017). It is a versatile tree that is thought to be medical, with practically every part of the tree having some kind of benefit, whether it be medicinal or nutritional (Okello et al., 2018; Soni et al., 2019; Kudus et al., 2020; Vuyyala et al., 2020). Tamarindus indica is separated into subtypes like sweet and acidic fruit. The fruit's remarkable ability to be both sweet and sour at the same time makes it popular in cookery (Farooq et al., 2022, Ferrara et al., 2019, Mani et al., 2020). The tamarind fruit has roughly 11% fiber and pod shell, 55% pulp, and 34% seeds (Israel and Murthy, 2019). Tamarind contains one to ten irregular shaped, flattened, or rhomboid seeds inside its pod. The seeds are reddish-brown, glossy, and extremely hard. They are attached to one other with strong fibers, entrenched in the pulp, and lined with a durable parchment that resembles a membrane. Fruit flavor and size can vary greatly from one another (Boudy et al., 2016, Mohite et al., 2019, Nagar et al., 2022). It is essential to determine its engineering properties to design and improve equipment and processes for processing, storing, transporting, and adding value to tamarind. Engineering properties of tamarind include physical, chemical, frictional, and mechanical properties of tamarind (Bidayalaxami et al., 2023; Shreedevi et al., 2022). When designing agricultural machinery and processing equipment, it is essential to have understanding of the physical characteristics of fruits (Pandian et al., 2017; Shiru and Gana, 2020; Lammari et al., 2022). Physical characteristics like size, shape, Surface area and density aid in designing equipment such as graders, sorters, handling and storage structures that can efficiently handle the fruit, ensuring optimal processing outcomes (Karthickumar et al., 2015). Chemical analysis of components such as moisture content, color variation informs the design of machinery suitable for preserving or extracting desired compounds. Frictional properties are essential for designing equipment that can effectively separate pulp from seeds while minimizing damage or loss (Sonawane et al., 2020; Viresh et al., 2016; Pathak et al., 2019). Assessment of these properties helps in machine design, maximization of efficiency, minimizes waste, and meets the diverse processing requirements of tamarind, ultimately enhancing productivity and sustainability. Comparing the engineering properties of shelled and unshelled tamarind was important for deciding on storage, transport, and processing methods. It helps in machine designing and optimizes parameters like processing speed, pressure, and temperature to suit the specific needs of each form.

The objective of this study was to determine the engineering properties of the shelled and unshelled tamarind. The investigation covered different physical properties such as dimensions, arithmetic mean diameter, geometric mean diameter, surface area, sphericity, bulk density, true density, and porosity. Additionally, chemical properties and frictional properties were analyzed. Factors such as moisture content, color, angle of repose, and coefficient of friction were assessed on different surfaces.

2. MATERIALS AND METHODS

The experiment was conducted during April–June, 2024 in the department of Agricultural Process Engineering, Dr. Panjabrao Deshmukh Krishi Vidhyapeeth Akola, Maharashtra, India.

2.1. Raw material

Freshly harvested tamarind fruits were sourced from local farmers at Akola Market and from the horticulture department of the University for the Experiment. To ensure quality, the fruits were cleaned by removing foreign matters like dust, dirt, stones, and defective or immature fruits. The tamarind was then divided into two sets: one with shelled tamarind and the other with unshelled tamarind. Through manual cracking and sorting, the fruits were prepared for analysis.

2.2. Physical property

Samples were collected to measure the physical properties of tamarind. The mature tamarind fruits were selected to calculate the physical properties. To determine these dimensions, tamarind fruits were randomly chosen from a batch to create a representative sample. Observations were made on both shelled and unshelled tamarind fruits. The physical properties examined included size, shape, geometrical mean, sphericity index, bulk density, true density, porosity, and surface area (Uba et al., 2020).

2.2.1. Dimension

A digital vernier caliper with a precision of 0.01 cm was used to measure the length, width, and thickness of both tamarind fruits and their seeds. Fifty random samples were taken to determine the average measurements for each dimension of the shelled and unshelled tamarind fruits. (Pandian et al., 2013)

2.2.2. Arithmetic mean diameter

The arithmetic mean diameter of both shelled and unshelled tamarind was calculated using the formula proposed by Mohsenin (1970) (Sanusi et al., 2022).

D_a=(L+W+T)/3..(1)

Where,

D_a=Arithmetic mean diameter (mm)

a=major diameter (mm)

b=intermediate (mm)

c=minor diameter (mm)

2.2.3. Geometrical mean diameter

The Geometrical Mean Diameter (D_g) was determined by taking the cube root of the product of the length (L), width (W), and thickness (T) of the tamarind. It is represented by the formula:

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

Where:

D_g=Geometrical mean diameter in millimeters (mm)

L=Length in millimeters (mm)

W=Width in millimeters (mm)

T=Thickness in millimeters (mm)

2.2.4. Sphericity index

The sphericity index was calculated as the ratio of the geometrical mean diameter (D_g) to the length (L) of the fruit. Alternatively, it could be defined as the ratio of the geometric mean diameter to the major diameter of the fruit. Mathematically, it was expressed as:

Φ=Dg/L...(3)

Where:

- Φ=Sphericity
- D_9=Geometrical mean diameter in millimeters (mm)
- L=Length (longest intercept) in millimeters (mm)

2.2.5. Surface area

The surface area was determined by multiplying the geometrical mean diameter (D_g) by ϖ. Mathematically, it is represented as

$S=\pi D^2_g$ ....(4)

Where:

- S=Surface area in square millimeters (mm²)
- D_g=Geometrical mean diameter in millimeters (mm)

2.2.6. Bulk density

Bulk density refers to the mass of a substance per unit volume, indicating its compactness typically expressed in units like gcm^{-3} or kgm^{-3}. To determine the bulk density of tamarind, a square box was prepared (Benestante et al., 2023) A sample of tamarind was placed in the box and weighed using an electronic balance with a least count of 0.001g. The bulk density (bd) is then calculated using the relationship

Bulk density=(Mass, kg /Volume, m^3)........................(5)

2.2.7. True density

The true density was assessed by employing the toluene displacement method. The procedure entailed utilizing fruits to displace toluene within a measuring cylinder subsequent to the measurement of their masses. The true density was then determined as the average ratio of the masses of the fruits to the volume of toluene displaced by each fruit. (Shreedevi et al., 2020).

True density=Mass of tamarind, kg / True volume of displace fluid m^3..(6)

2.2.8. Porosity

It is defined as the proportion of empty space within bulk fruits, which was determined in this study. It was calculated based on the true density and bulk density values using the following relationship.

ε=1-bulk density/true density×100..........................(7)

2.3. Chemical properties

2.3.1. Moisture content

The moisture content of ten samples of each unshelled and shelled tamarind was measured by the hot air oven method. Clean and dry petridishes were weighed and their weights, denoted as W_1, were recorded. Each sample was then placed into the empty petridish and their weights were recorded as W_2. The petridishes, along with the samples, were subjected to drying in an oven at 105°C for three days. After drying, the petridishes were transferred to a desiccator and allowed to cool for one hour before being reweighed, denoted as W_3. The percentage moisture content was determined using the drying method, which relies on weight loss during the drying process. (Remi et al., 2022).

Moisture content (%)=$[(w_2-w_3)/(w_2-w_1)]\times 100$ ....(8)

2.3.2. Color

The color of shelled and unshelled tamarind fruits was measured using a digital colorimeter. Representative samples of both shelled and unshelled tamarind were selected to reflect the overall color of the batch. A digital colorimeter objectively measured the color by analyzing reflected light, providing information in terms of three parameters: L^*, a^*, and b^*. L^* represents brightness on a scale from 0 (black) to 100 (white), while a^* indicates redness for positive values and greenness for negative values, and b^* signifies yellowness for positive values and blueness for negative values. (Mitcham et al., 1996)

2.4. Frictional properties

2.4.1. Angle of repose

The angle of repose referred to the steepest angle at which a shelled and unshelled tamarind can be piled on a horizontal surface without slumping or sliding. The angle between the base and the slope of the cone formed during the free vertical fall of the sample onto a horizontal plane was measured (Ambrose, 2020).

$\tan\theta = 2h/d$..(9)

2.4.2. Coefficient of friction

The coefficient of friction of shelled and unshelled tamarind was measured by the inclined plane apparatus method. In this technique coefficient of friction was measured between two surfaces. It involved placing a flat surface (the inclined plane) at an angle to the horizontal and gradually increasing this angle until an object placed on the surface began to slide. By measuring the angle at which sliding occurred and applying trigonometric principles, the coefficient of friction could be calculated. The static coefficient of friction was evaluated concerning four test surfaces which were plywood, stainless steel, mild steel and glass. The calculation of the static coefficient of friction was based on the following equation. (Davies, 2012; Soni et al., 2020).

$\mu = \tan\Phi$......................................(10)

3. RESULTS AND DISCUSSION

This study discussed the comparison of results pertaining to various engineering properties for both shelled and unshelled tamarind.

3.1. Physical properties of unshelled and shelled tamarind

The Physical properties of unshelled tamarind were mentioned in Table 1. For unshelled tamarinds, the minimum and maximum length ranged from 44.32 mm to 133.07 mm, while the minimum to maximum width ranged from 11.76 mm to 28.33 mm. The minimum and maximum thickness varied from 11.76 mm to 17.66 mm. The Geometric Mean Diameter ranged from 24.31 mm to 37.72 mm, and the arithmetic Mean Diameter varied from 27.01 mm to 57.53 mm. The sphericity of unshelled tamarind ranged from 0.274 to 0.548, indicating an almost cylindrical or ellipsoidal shape. Bulk density varied between 350.59 kg m^{-3} to 403.90 kg m^{-3}, while true density ranged from 656.7 kg $m^{-3}$to 786.6 kg m^{-3}, depend on the size, shape and orientation of the tamarind. The Physical properties of

Table 1: Physical properties of unshelled tamarind

Sl. No.	Unshelled tamarind				
	Physical properties	Min. value	Max. value	Mean	SD
1.	Length	44.32 mm	133.07 mm	81.36 mm	±22.14
2.	Width	17.92 mm	28.33 mm	22.31 mm	±2.14
3.	Thickness	11.76 mm	17.66 mm	15.28 mm	±1.044
4.	Arithmetic mean	27.01 mm	57.53 mm	39.65 mm	±7.709
5.	Geometric mean	24.31 mm	37.72 mm	30.02 mm	±3.384
6.	Sphericity index	0.27	0.54	0.38	±0.068
7.	Surface area	1856.08 mm^2	4469.57 mm^2	2866.80 mm^2	±653.77
8.	Bulk density	350.59 kg m^{-3}	403.90 kg m^{-3}	370.01 kg m^{-3}	±18.56
9.	True density	656.7 kg m^{-3}	786.6 kg m^{-3}	719.7 kg m^{-3}	±43.04
10.	Porosity	42.11%	54.22%	48.39%	±4.460

shelled tamarind were mentioned in Table 2. For shelled tamarinds, the minimum and maximum length ranged from 34.91 mm to 127.91 mm, while the minimum to maximum width ranged from 11.12 mm to 24.91 mm. The minimum and maximum thickness varied from 8.58 mm to 11.45 mm. The geometric mean diameter ranged from 17.519 mm to 30.53 mm, and the arithmetic mean diameter varied from 20.033 mm to 52.69 mm. The sphericity of shelled tamarind ranged from 0.22 to 0.50, indicating an almost cylindrical or ellipsoidal shape. Bulk density varied between 490.38 kg m^{-3} to 403.90 kg m^{-3}, while true density ranged from 798.4 kg m^{-3} to 1012.1 kg m^{-3}. The result shown in Table 1 and Table 2 Indicated that the length, width, thickness, arithmetic mean and geometric mean of unshelled tamarind higher than the shelled tamarind. The bulk density and true density of unshelled tamarind was less than shelled tamarind whereas, the porosity and surface area of unshelled tamarind was higher than shelled tamarind which depicted that the same weight of unshelled tamarind required more space for storage than shelled tamarind similar observation were obtained by Asoiro et al., 2017; Sinha et al., 2015; Arudra, 2015; Oaya, 2012. These properties had significant role in design of machine part such as hopper, seed and pulp separating equipment and dehulling equipment for shell removal.

Table 2: Physical Properties of shelled Tamarind

Sl. No.	Shelled tamarind				
	Physical properties	Min. value	Max. value	Mean	SD
1.	Length	34.91 mm	127.91 mm	75.01 mm	±23.21
2.	Width	11.12 mm	25.91 mm	17.41 mm	±2.36
3.	Thickness	8.58 mm	11.45 mm	10.24 mm	±0.65
4.	Arithmetic mean	20.033 mm	52.69 mm	34.22 mm	±7.93
5.	Geometric mean	17.519 mm	30.533 mm	23.45 mm	±2.92
6.	Sphericity index	0.223	0.501	0.332	±0.071
7.	Surface area	963.76 mm^2	2927.42 mm^2	1754.24 mm^2	±442.9
8.	Bulk density	490.38 kg m^{-3}	545.85 kg m^{-3}	512.35 kg m^{-3}	±15.92
9.	True density	798.4 kg m^{-3}	1012.1 kg m^{-3}	912.73 kgm-3	±73.59
10.	Porosity	34.03%	50.45 %	43.49%	±5.37

3.2. *Chemical property of unshelled and shelled tamarind*

The moisture content and color were determined by the chemical properties of shelled and unshelled tamarind which was presented in Table 3. For unshelled tamarind, the minimum and maximum moisture content varied from 19.9% to 27.1% on a dry basis. The average moisture content of unshelled and shelled tamarind obtained 23.64% and 23.14% respectively which was almost the same. The minimum and maximum color values for unshelled tamarind were reported as L^*=46.14 to 49.94, a^*=8.36 to 9.57, b^*=20.11 to 22.37 and for shelled tamarind the minimum and maximum moisture content varied from 20.9% to 25.6%. Similar kind of results was obtained by Kumar et al. (2017) and Soni et al. (2023). The variation in color value for unshelled tamarind was reported as L^*= 35.79 to 39.09, a^*=10.55 to 11.8, b^*=18.98 to 23.47. L^* represented lightness, with a value of L^*=0 indicated black and L^*=100 indicated white. a^* describes the intensity in the green-red spectrum, where $a^*<0$ signified green and $a^*>0$ signified red. Similarly, b^* denotes intensity in the blue-yellow spectrum, where $b^*<0$ indicated blue and $b^*>0$ indicated yellow (Chudy et al., 2020; Belasco et al., 2020; Durmus, 2020). Shelled tamarind tends to have slightly lower lightness values compared to unshelled tamarind. This suggested that shelled tamarind may appear slightly darker or less bright than unshelled tamarind.

Table 3: Chemical property of unshelled and shelled tamarind

Sl. No.	Chemical Properties	Minimum value	Maximum value	Mean	SD
Unshelled Tamarind					
1.	Moisture content	19.9%	27.1%	23.64%	±2.53
2.	Color				
	L^*	46.14	49.94	47.606	±1.50
	a^*	8.36	9.57	8.944	±0.43
	b^*	20.11	22.37	21.604	±0.92
Shelled Tamarind					
1.	Moisture content	20.9%	25.6%	23.14%	±1.53
2.	Color				
	L^*	35.79	39.09	37.178	±1.2
	a^*	10.55	11.8	11.22	±0.58
	b^*	18.98	23.47	20.404	±1.85

Shelled tamarind showed higher values of a^* compared to unshelled tamarind, indicated a shift towards reddish hues. Slightly higher b^* values in shelled tamarind, suggested a shift towards yellow tones compared to unshelled tamarind. This shift could be due characteristics of the tamarind when it is shelled, which results in changes in the chemical composition and moisture content of shelled and unshelled tamarind. It depicted the change in the moisture content and chemical composition had significant effect on the color of the tamarind. Similar observation were found by Obulesu and Bhattacharya, 2011; Sinha et al., 2015; Hernandez-Unzon and Lakshminarayana, 1982.

3.3. *Frictional properties of unshelled and shelled tamarind*

The angle of repose and coefficient of friction was the frictional properties which were determined. The frictional properties of unshelled and shelled tamarind were presented in Table 4. The angle of repose of unshelled tamarind varied from 24.7°–5.93° whereas, the angle of repose of shelled tamarind varied from 25.6°–37.87°. The variation in the angle of repose between unshelled and shelled tamarind suggested the differences in their physical properties, particularly regarding their ability to resist slumping or sliding when piled up (Asoiro et al., 2017). The wider range of angles observed for shelled tamarind compared to unshelled tamarind, indicated that shelled tamarind tends to have a higher angle of repose. which implied that shelled tamarind have a greater tendency to maintain stability and resist movement when piled up compared to unshelled tamarind which could be due to differences in surface characteristics, internal structure, and moisture content, cohesive or adhesive force between the two tamarind or

Table 4: Frictional properties of unshelled and shelled tamarind

Sl. No.	Frictional property	Unshelled		Shelled	
		Minimum -Maximum	Mean	Minimum -Maximum	Mean
1. Angle of repose		24.7°-35.93°	32.03°	25.6°-37.87°	34.04°
2. Coefficient of friction					
	Wood	0.518		0.906	
	Stainless steel	0.395		0.705	
	Mild steel	0.449		0.85	
	Glass	0.445		0.731	
	Fiber	0.513		0.88	

tamarind and surface (Shemsanga et al., 1983; Visvanathan et al., 1990). The coefficient of friction is the property that can help to choose the material for the design of machinery (Tambe and Bhushan, 2005). At a moisture content of 25 to 27% on a dry basis, the static coefficient of friction was evaluated for unshelled and shelled tamarind on various surfaces including wooden surface, stainless steel, mild steel, glass, and fiber sheet. The results, as depicted in Table 4, revealed average coefficient of friction for unshelled tamarind of 0.518, 0.395, 0.449, 0.445, and 0.513 for wood, stainless steel, mild steel, glass, and fiber sheet, respectively. Notably, the maximum coefficient of friction of 0.518 was observed for wooden surface, followed closely by fiber sheet. Similarly, for shelled tamarind, wood exhibited the highest coefficient of friction followed by fiber sheet, mild steel, glass and stainless steel. These findings suggested that wood and fiber sheet surfaces provide greater frictional resistance to tamarind compared to other surfaces (Reddy et al., 2015). Conversely, stainless steel surfaces consistently displayed the lowest coefficients of friction, indicating minimal resistance to the movement of both unshelled and shelled tamarind. Among shelled and unshelled tamarind, Unshelled tamarind exhibits a lower coefficient of friction (0.395) compared to shelled tamarind (0.705), suggested that unshelled tamarind experiences less resistance in flow on stainless steel surfaces than shelled tamarind. This difference is likely due to the smoother and less textured surface of the tamarind shell compared to the tamarind pulp, which had higher moisture content and adhesive properties.

4. CONCLUSION

Shelled tamarind had smaller dimensions, higher bulk density and true density, lower porosity, smaller diameters, higher angle of repose and coefficient of friction as compared to unshelled tamarind. Shelled tamarind color was with more redness (higher a^* value) and slightly yellowness (lower b^* value), this suggested that shelled tamarind appear slightly darker or less bright than unshelled tamarind. Among all the experimented surfaces Stainless steel displayed the lowest coefficients of friction for both unshelled and shelled tamarind followed by glass.

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