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RESEARCH PAPER

Engineering properties of tamarind fruits with shell and without shell

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Abstract: Tamarind (*Tamarindus indica*) is a globally valued tropical fruit known for its culinary, industrial, and medicinal applications. The average size of (20) tamarind fruits with shells were measured 105.29±2.50 mm (length), 23.10±0.22 mm (width) and 13.24±0.30 (thickness) while tamarind fruits without shell were 103.40±2.60 mm (length), 19.58±0.19 mm (width) and 9.69±0.12 mm (thickness), respectively. Average fruit weights for tamarind fruits with shell were 20.618±6.33 g and without shell were 15.504±5.23 g. Bulk density, true density, and porosity for tamarind fruits with shell were 507.66±10.78 kg m^{-3}, 1136.36±150.81 kg m^{-3} and 55.33±6.00% while for without shell were 392.66±2.51 kg m^{-3}, 613.01±12.03 kg m^{-3} and 35.94±1.32%. Coefficients of friction (external, internal) and angle of repose were also measured, tamarind fruits with shell exhibited higher friction coefficients and a steeper angle of repose. These findings provide critical insights for the design and optimization of tamarind processing equipment. The results underscore the importance of considering shell presence in machine development and material handling systems.

Key words: Angle of repose, Bulk density, Frictional properties, Fruits, Tamarind, Textural Properties

Introduction

Tamarind (*Tamarindus indica* L.) is an arboreal fruit belongs to the family Leguminoseae and sub family Caesalpinioideae. The tamarind fruits is native to Eastern Africa and found throughout the tropics and subtropics of the world. Tamarind has become established at many places especially in India, South East Asia, Tropical America and Robben Islands. The major production regions are the Asian countries including India, Thailand, Indonesia, Malaysia, Myanmar, Philippines and Sri Lanka. India is the world largest producer of tamarind, cultivated in an area of 44.05 thousand hectare with an annual production of 1.62 lakh tonnes at an average productivity of 3.68 tonnes per hectare (Anon., 2021). In India, the major tamarind producing states are Tamil Nadu, Karnataka, Kerala, Andhra Pradesh, Telangana, Maharashtra, Chhattisgarh and Madhya Pradesh.

Tamarind pulp is highly valued for its rich composition and versatility in food processing. Its components, such as tartaric acid, reducing sugars and pectin, make it suitable for various value-added products. The wide range of tartaric acid (8-18%) and reducing sugars (25-45%) suggests that tamarind can be tailored to products requiring varying sweetness or acidity levels. Pectin content (2-3.5%) highlights its usefulness as a natural gelling agent, contributing to the production of jams and syrups. Additionally, tamarind is high antioxidant capacity, largely due to its phenolic content, enhances its nutritional and preservative potential (Shankaracharya, 1998). This diversity in tamarind's composition and applications makes it a significant resource for developing new value-added products in both food and non-food industries (Ariwoola *et al*., 2022). The study aim the importance of understanding tamarind's engineering properties, which directly impact the design of processing equipment and storage facilities. The findings serve as a valuable resource for developing tamarind shelling, sorting, and packaging systems, improving efficiency, and minimizing losses during post-harvest handling and storage. These insights will aid farmers and processors by enhancing productivity and reducing operational costs associated with tamarind processing.

Material and methods

Freshly harvested tamarind fruits Manvi (MPK -1) variety were procured from Main Agricultural Research Station, UAS Raichur campus.

The tamarind fruits were spread uniformly on the tarpaulin and sun dried to bring moisture content from 28±1.2 % -25±0.95%. to 21% moisture content which is consider to be easy to operation during processing

Physical properties such as size, shape, surface area, projected area, colour, true density, bulk density, and porosity were determined through specific measurement techniques. Frictional properties, including the coefficient of internal friction, coefficient of external friction, and angle of repose of tamarind fruits were evaluated using established standard methodologies. Additionally, textural properties such as hardness, adhesiveness, and cohesiveness were assessed through designated testing procedures. The methods used to determine these engineering characteristics of tamarind fruits are discussed below.

The dimensions of the (20) random tamarind fruits were measured using a vernier caliper. To ascertain the size of tamarind fruits, the geometric mean of its three spatial dimensions length (L), width (W) and thickness (T) was calculated. The geometric mean diameter (Dg) of the sample was derived using a specific formula, (Mohsenin, 1986),

$$D_g = (L \times W \times T)^{1/3} \quad \text{——————(1)}$$

Where,

L= Length of tamarind fruits, mm

W= Width of tamarind fruits, mm

T= Thickness of tamarind fruits, mm

The surface area of tamarind fruits was measured for 20 randomly selected fruits using a digital planimeter (Placom; KP90N roller-type digital planimeter). Tamarind fruits were wrap with aluminium foil and placed on a graph sheet and their outlines were traced using a sharp lead pencil. Starting from an initial point marked on the outline, the planimeter was moved along the outline in a clockwise direction until it returned to the initial point. This experiment was repeated for 20 different-sized tamarind fruits to minimize error and the average value was recorded as the surface area of the tamarind (Mohsenin, 1986).

The projected area is an important physical property of biological materials. To determine the projected area, tamarind fruits was placed on drawing paper and sketched with a pencil. The initial point was marked on the outline of the drawing paper and the digital planimeter was traced clockwise along the outline until it reached the original point. The planimeter displayed the anticipated area of the fruits, which was then recorded. To reduce error, a similar experiment was repeated with 20 different tamarind fruits. The average value was taken as the surface area of the tamarind fruits (Mohsenin, 1986).

Aspect ratio is used to express the shape of a material. The aspect ratio is the ratio between the sizes in different directions *i.e*., length to width (Mohsenin, 1986).

$$R_a = \frac{L}{W} \quad ....2$$

Where,

Ra = Aspect ratio

L = Length (in mm)

T = Thickness (in mm)

Sphericity is determined by calculating the ratio of the geometric mean diameter of the tamarind fruits to its major diameter. The sphericity was then computed using the following formula (Mohsenin, 1986).

$$\text{Sphericity} = \frac{\sqrt[3]{L.W.T}}{L} \quad ....(3)$$

Where,

L = Major diameter, mm W = minor diameter, mm

T = intermediate diameter, mm

To determine bulk density, a cylindrical container of known volume was fully filled with tamarind fruits to up a specific height. Subsequently, the weight of the tamarind fruits was measured using an electronic weighing balance with an accuracy of 0.001 g. Bulk density was then calculated as the ratio of the weight of the tamarind to its volume (Kachru *et al.,* 1994).

$$\text{Bulk density} = \frac{\text{Actual weight of tamarind fruits}}{\text{Volume occupied by tamarind fruits}} \quad ....4$$

The true density of the tamarind fruits determined using the toluene displacement method. This method involves measuring the volume of a toluene displaced by the sample and using following information to calculate the true density using formula given by (Kachru *et al.,* 1994).

$$\text{True density} = \frac{\text{Weight of tamarind fruits}}{\text{Displaced volume of the liquid}} \quad ....5$$

The porosity of tamarind fruits was determined from the values of bulk density and true density using the following equation (Sahay and Singh, 1994),

$$\text{Porosity} = \frac{\text{True density - Bulk density}}{\text{True density}} \times 100 \quad ....6$$

Hunter's lab colourimeter (Colour Flex EZ; Hunter Associates Laboratory; Inc., United States) (Plate 2) was used to measure the colour of tamarind pulp. The colour was measured by using CIELAB scale at 10° observer with D_{65} illuminate. The instrument was calibrated initially using both a black and a standard white plate. Once calibration was completed, the instrument was ready to measure colour. Measurements were taken in triplicate for each sample and the average values was calculated (Obulesu and Bhattacharya, 2011).

The coefficient of friction, representing the friction between sample materials against each other and sample and surface of stainless steel (SS) and mild steel (MS), was measured using a table equipped with changeable surfaces. A box of dimensions 7.5 × 7.5 × 9.5 cm was attached to a cord passing over a pulley. The changeable surface was filled with tamarind fruits. Initially, weights (W_1) were added to a pan until the empty box began to slide on the surface. Subsequently, the box filled with a known weight of the sample (W) was added and weights were again placed in the pan to induce sliding. The weights (W_2) required to slide the filled box on the surface were then recorded (Mohsenin, 1986).

$$\text{Co efficient of internal friction } (\mu_i) = \frac{W_2 - W_1}{W} \quad ....7$$

Where;

μ_i = Coefficient of friction

W_1 = Weight to cause sliding of empty box , g

W_2 = Weight to cause sliding of filled box, g

W= Weight of the material inside the box, g

W_o = Weight of sliding box with filled material, g

The angle of repose is defined as the angle between the base and the slope of the cone formed by a free-falling tamarind fruits onto a horizontal plane. Its determination follows the procedure described by Sahay and Singh (1994). By measuring the height and diameter of tamarind heaped in natural piles, the angle of repose is determined using the following formula

$$\text{Coefficient of external friction } (\mu_e) = \frac{W_0 - W_1}{W} \quad \text{.................8}$$

Where,

H= Height of piled material, mm

D= Horizontal distance measured from middle of piled material, mm

$$\text{Angle of repose } (\theta) = \tan^{-1}\frac{2H}{D}$$

The hardness, adhesiveness, and cohesiveness of tamarind fruits at different positions was observed using the Texture Analyzer (Stable Micro System; Texture Export Version 1.22, UK). This device is a microprocessor-controlled system connected to a personal computer. The instrument measures force, distance and time, enabling three-dimensional product analysis. The following settings of the apparatus were utilized for measuring hardness. Comparative analyses between tamarind fruits with and without shells were performed using a two-sample t-test to evaluate significant differences at a 5% significance level ($p < 0.05$). Regression analysis was employed to establish relationships between different parameters, such as density, porosity, and fruit dimensions, while correlation analysis was conducted to identify interdependencies among the measured properties. All statistical analyses were performed using IBM SPSS Statistics (Version XX) and Microsoft Excel.

Test for finding out the cutting force Parameters of machine

Pre-test speed	-	1.0 $mm.s^{-1}$
Test speed	-	5.0 $mm.s^{-1}$
Post-test speed	-	5.0 $mm.s^{-1}$
Distance	-	10 mm
Trigger force	-	25 g
Load cell	-	5 kg
Type of probe used	-	Flat probe
Test module	-	Compression
Test option	-	Return to start

Results and discussion

The important engineering properties of tamarind fruits *viz.*, size, shape, aspect ratio, sphericity, surface area, projected area, bulk density, true density, porosity, colour, coefficient of friction, angle of repose, hardness, adhesiveness, and cohesiveness were determined and given in Table 1 and 2. The random samples of tamarind fruits were meticulously selected based upon the evaluation of engineering properties at 21 % wet basic moisture contents.

The mean length, width, thickness, and geometric mean diameter of tamarind fruits with shells were 105.29±2.50 mm, 23.10±0.22 mm, 13.24±0.30 mm, and 36.65±1.29 mm, respectively. In comparison, tamarind fruits without shells exhibited slightly lower values for length (103.40±2.60 mm) and width (19.58±0.19 mm), while the geometric mean diameter was slightly higher (39.08±1.41 mm). This indicates that removing the shell reduces the width and thickness but may lead to a marginally increased diameter due to the softer internal structure, which likely deforms differently under measurement.

$$\text{Co efficient of internal friction } (\mu_i) = \frac{W_2 - W_1}{W}$$

The aspect ratio and sphericity of tamarind fruits with shells were 9.98±0.63 and 0.30±0.03, while for tamarind without shells, they were 10.77±0.30 and 0.25±0.03, respectively. A lower sphericity in fruits without shells suggests that the removal of the shell alters the fruit's shape, making it less spherical. This change in shape could impact rolling behavior during handling or transportation, highlighting the importance of these measurements for designing processing systems.

Surface area and projected area for tamarind fruits with shells (5105±2070 mm^2 and 3377±2414 mm^2) were higher compared to fruits without shells (3034±1027 mm^2 and 2486±1518 mm^2). This significant difference indicates that the shell contributes considerably to the overall size and contact area of the fruit, which may influence drying, storage, and heat transfer during processing.

The average fruit weight decreased from 20.618±6.33 g (with shells) to 15.504±5.23 g (without shells), which reflects the weight contribution of the shell. Similarly, bulk density and true density values were higher for tamarind fruits without shells (507.66±10.78 $kg{\cdot}m^{-3}$ and 1136.36±150.81 $kg{\cdot}m^{-3}$) compared to those with shells (392.66±2.51 $kg{\cdot}m^{-3}$ and 613.01±12.03 $kg{\cdot}m^{-3}$). This increase in density without shells could be attributed to the compactness of the pulp and seeds in comparison to the porous structure of the shell. Porosity, however, was higher in tamarind fruits with shells (55.33±6.00%) than without shells (35.94±1.32%), reflecting the presence of void spaces within the shell. These properties are critical for designing storage bins and pneumatic conveying systems.

The coefficient of friction and angle of repose were also influenced by the presence of the shell. For tamarind fruits with shells, the coefficient of external friction against mild steel and stainless steel surfaces was 0.65±0.44 and 0.62±1.27, respectively, while for tamarind without shells, it increased to 1.08±0.002 and 0.89±0.09, respectively. The increased friction values without shells could be due to the stickier pulp surface compared to the smoother shell. The angle of repose also increased from 29.81±0.89° (with shells) to 37.11±1.22° (without

Table 1. Physical properties of tamarind fruits

	Property	Mean
	Length (mm)	105.29±2.50
Tamarind fruits with shell	Width (mm)	23.10±0.22
	Thickness (mm)	13.24±0.30
	Length (mm)	103.40±2.60
Tamarind fruits without shell	Width (mm)	19.58±0.19
	Thickness (mm)	9.69±0.12
Tamarind fruits fiber	Length (mm)	103.00±2.42
	Thickness (mm)	2.25±0.17

Table 2. Engineering properties of tamarind fruits with shell and without shell

Property		Mean (fruits with shell)	Mean(fruits without shell)
Aspect ratio		7.98±0.63	10.77±0.30
Sphericity		0.30 ±0.03	0.25 ±0.03
Average tamarind weight (g)		13.74±3.60	10.36±3.60
Surface area (cm^2)		51.05±20.71	30.34±10.27
Projected area (cm^2)		33.77±24.14	24.86±15.81
Bulk density ($kg.m^{-3}$)		392.66±2.51	507.66±10.78
True density ($kg.m^{-3}$)		613.01±12.03	1136.36±150.81
Porosity (%)		35.94 ± 1.32	55.33±6.00
Colour	L^* value	46.49±0.07	29.77±7.03
	a^* value	8.73±0.03	31.00±0.02
	b^* value	24.60±0.08	14.64±0.07
Co-efficient of internal friction (SS)		0.82±04	0.92±0.39
Co-efficient of internal friction (MS)		1.12±0.13	1.34±0.31
Co-efficient of external friction [SS]		0.62±1.27	1.08±0.00
Co-efficient of external friction [MS]		0.65±0.44	0.92±0.39
Angle of repose (°)		29.81±0.89	37.11±1.22
Hardness (kg)		2.54±0.02	2.25±0.03
Adhesiveness (g.s)		-91.7±0.11	-27.94±0.62
Cohesiveness		0.61±0.02	0.53±0.02

shells), indicating that fruits without shells have a higher tendency to resist flow, which is important for hopper design.

The hardness, adhesiveness, and cohesiveness of tamarind fruits were found to be 2.25±0.03 kg, 27.94±0.62, and 0.53±0.02, respectively. The higher adhesiveness suggests the pulp's tendency to stick, which may impact machinery and handling equipment by increasing cleaning requirements.

Overall, these findings provide insights into the engineering properties of tamarind fruits that are crucial for designing equipment for shelling, sorting, packaging, and storage. The differences observed between tamarind fruits with and without shells highlight the need for tailoring post-harvest systems based on the condition of the fruits to optimize efficiency and reduce losses.

Conclusion

The findings revealed that the presence of the shell significantly influenced key parameters, such as surface area, bulk density, true density, porosity, and the coefficient of friction. Tamarind fruits with shells exhibited larger surface areas (5105 mm^2) and lower bulk and true densities (392.66 $kg\cdot m^{-3}$ and 613.01 $kg\cdot m^{-3}$, respectively), while unshelled fruits were more compact (507.66 $kg\cdot m^{-3}$ bulk density and 1136.36 $kg\cdot m^{-3}$ true density) and had higher porosity (55.33%). These variations are directly relevant to the design of storage bins, dryers, and sorting systems, as they affect material flow, aeration, and heat transfer. The coefficient of friction and angle of repose were higher for unshelled fruits, highlighting the need for specialized equipment surfaces and hopper designs to accommodate their greater stickiness and reduced flowability. Furthermore, the textural analysis revealed insights into the hardness and adhesiveness of the fruits, which are critical for shelling and packaging operations.

The study successfully met its objective of providing detailed property data for tamarind fruits. These results serve as a foundation for designing and optimizing post-harvest and processing equipment, contributing to enhanced efficiency, reduced operational costs, and improved handling practices in tamarind processing. Overall, this work fills a critical gap in the engineering data required for developing tamarind-specific processing technologies, ultimately benefiting both industrial processors and farmers.

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