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Investigation on physical and engineering properties of the water chestnut (*Trapa natans* L.) for design of decorticator

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Abstract

Engineering properties of agricultural materials constitute important design parameters for the development and performance evaluation of efficient post-harvest processing equipment. However, limited information is available on the engineering properties of water chestnut (*Trapa natans* L.) relevant to mechanical decortication. Therefore, the present study was undertaken to determine the engineering properties of water chestnut at an average moisture content of 66.88% (w.b.) to provide basic design data for the development of a power-operated water chestnut decorticator. The principal dimensions, geometric characteristics, gravimetric properties, frictional properties and aerodynamic characteristics of water chestnut were determined using standard experimental procedures. The fruits exhibited average length, width and thickness of 31.50, 32.50 and 28.00 mm, respectively, with an average geometric mean diameter of 32.87 mm, arithmetic mean diameter of 38.85 mm, sphericity of 64.50%, surface area of 1989.88 mm² and aspect ratio of 71.50%. The average bulk density, true density and porosity were found to be 795.40 kg/m³, 960.40 kg/m³ and 17.17%, respectively. The average coefficients of static friction on mild steel and stainless steel were 0.72 and 0.70, respectively, while the average angle of repose was 43.62°. The average terminal velocity of the water chestnut was 7.482 m/s, whereas the average weight of 1000 chestnuts were 9513 g. These measured engineering properties provided essential design inputs for determining the dimensions of the feeding unit, decortication chamber, hopper, material-contact surfaces, clearance, power transmission and collection system of the developed water chestnut decorticator. The developed engineering database can therefore support the design optimization and future development of efficient, economical and suitable mechanical systems for water chestnut decortication and subsequent value addition.

Keywords: Water chestnut (*Trapa natans* L.), engineering properties, physical properties, geometric characteristics, gravimetric properties, frictional properties, terminal velocity, decorticator, machine design, post-harvest processing

Introduction

Water chestnut (*Trapa natans* L.) is a floating aquatic angiosperm cultivated widely in India, China, Southeast Asia and other tropical to subtropical regions. It is commonly consumed in fresh, boiled, roasted and flour forms and is increasingly recognized as an economically important underutilized food resource with potential for food diversification and value addition. The edible kernel of water chestnut is mainly rich in carbohydrates and starch, with additional contributions from protein, dietary fibre and minerals. It has also been reported as a source of polyphenols, flavonoids, vitamins and minerals such as potassium, phosphorus, iron, manganese and zinc, which contribute to its nutritional and functional importance (Chikara *et al.*, 2025; Rehman *et al.*, 2024; Alam *et al.*, 2001) [4, 23, 2]. The starch of water chestnut possesses distinctive physicochemical and functional characteristics compared with commonly used starches such as potato, maize, rice and wheat, creating opportunities for its utilization in various food and value-added products (Chikara *et al.*, 2025) [4].

Engineering properties of agricultural materials constitute an important database for the design, development and optimization of post-harvest processing equipment. Properties such as length, width, thickness, geometric mean diameter, sphericity, surface area, aspect ratio, moisture content, bulk density, true density, porosity, coefficient of friction, angle of repose, terminal velocity and

thousand-unit weight provide essential information for designing feeding, conveying, handling, decortication and collection systems. These properties are particularly important for water chestnut because its irregular shape, relatively high moisture content and hard outer husk influence its movement and interaction with mechanical surfaces during processing. Post-harvest research on water chestnut has identified drying, flour production, starch modification and machinery development as important areas for improving processing and commercial utilization (Sayyad *et al.*, 2021; Gupta *et al.*, 2025) [26, 7].

Water chestnut processing has traditionally depended largely on manual decortication. Freshly harvested fruits are cleaned and individually handled, after which the hard outer shell is cut or struck with a knife and the edible kernel is removed manually. This method requires continuous labour and considerable manual effort, has low processing capacity, is time-consuming and may result in uneven shell removal and kernel damage. The use of sharp cutting tools also increases the possibility of hand injuries during prolonged processing (Rehman *et al.*, 2024; Sayyad *et al.*, 2021) [23, 26].

Mechanical decortication provides an opportunity to overcome several of these limitations. Modern water chestnut decortication systems generally utilize controlled abrasion, impact or compression to break the hard outer shell while retaining the edible kernel. A typical mechanical decorticator consists of a feeding arrangement, decortication chamber or drum with an abrasive/corrugated surface, rotating mechanism, electric motor and outlet for collection of the decorticated material. Such mechanical action can improve processing efficiency, reduce labour requirement and provide more uniform processing compared with manual decortication (Gupta *et al.*, 2025) [7].

Although water chestnut has considerable food and value-addition potential, efficient removal of its hard outer covering remains an important post-harvest processing requirement. Mechanical processing can provide cleaner and more uniform kernels while reducing processing time, labour dependency and processing cost. Further, the decorticated kernels can be dried and processed into flour and other value-added products. Therefore, engineering information on water chestnut is required for the scientific design and optimization of a suitable decortication system. Hence, the present investigation was undertaken to determine the engineering properties of water chestnut and to develop and evaluate a power-operated water chestnut decorticator.

Therefore, the present investigation was undertaken to determine the engineering properties of water chestnut (*Trapa natans* L.) at the edible maturity stage. The generated engineering database is expected to provide scientifically validated design parameters for the development and optimization of mechanized processing equipment intended for handling, decortication, drying, storage and processing of decorticated water chestnut.

2. Materials and Methods

2.1 Sample collection

The water chestnuts were procured from local market Akola for conducting the experiments on chestnut decortication. The sophisticated equipment's and machineries viz: oven, moisture meter, tachometer, Variable frequency Drive etc. were used from AICRP on Post Harvest Engineering & Technology, Dr. PDKV, Akola. The average moisture content of the water chestnut varied between 66 and 82% (w.b.), representing the edible maturity stage commonly used for water chestnut preparation.

2.2 Determination of engineering properties of water chestnuts

Thirty randomly selected healthy and undamaged water chestnut were used for the determination of dimensional characteristics. The major axis, medium axis, and minor axis of individual grains were measured using a digital Vernier caliper with a least count of 0.01 mm. Grain size and sphericity were calculated from the measured principal dimensions using standard engineering relationships described by Mohsenin (1986) [18].

Thousand-grain weight was determined by weighing randomly selected grains using an electronic precision balance and expressed in grams. Bulk density was determined as the ratio of grain mass to the volume occupied in a graduated measuring cylinder without compaction, whereas true density was determined using the liquid displacement method. Porosity was calculated from the measured bulk and true densities using standard relationships.

The angle of repose of tender sorghum grains was determined using the fixed-funnel method by measuring the height and diameter of the grain heap formed after free discharge. The coefficient of static friction was measured on a mild steel surface using an adjustable inclined plane apparatus, and the coefficient was calculated from the tangent of the inclination angle at which grain movement was initiated. Terminal velocity was determined using a vertical air column by gradually increasing the airflow until individual grains attained a suspended state, and the corresponding air velocity was recorded.

All measurements were conducted in triplicate, and the results were expressed as mean values. The measured engineering properties were subsequently utilized to establish design parameters for mechanized processing equipment intended for water chestnut.

2.3 Calculation of engineering properties

The measured dimensions and physical characteristics of water chestnut were used to calculate various engineering properties required for the design and development of mechanized processing equipment.

2.3.1 Length (L), Width (W), Thickness (T)

These are the three principal dimensions of water chestnut measured along its major, intermediate, and minor axes. Water chestnuts have an irregular, often triangular or horned shape, so measuring these three dimensions helps in understanding their size variation. These dimensions are important for designing grading machines, hopper openings, and decortication units to ensure smooth feeding and minimal clogging. The length, width and thickness of fifty randomly selected freshly harvested groundnut pods was measured with the help of a digital vernier caliper having least count of ± 0.01 mm and the mean value was determined.



Plate 2.1: Measurement of water chestnut thickness using vernier calliper

2.3.2 Arithmetic mean diameter (Da)

Arithmetic mean diameter (Da) of water chestnut will be calculated using following equation (Krishnappa *et al.*, 2017) ^[14].

$$Da = \frac{L+W+T}{3} \quad \dots (3.1)$$

where,

L= Length, mm W= Width, mm T = Thickness, mm

2.3.3 Geometric mean diameter (Dg)

Geometric mean diameter (D_g) of groundnut pod was calculated by using following equation.

Formula:

$$Dg = (L \times W \times T)^{1/3} \quad \dots (3.2)$$

Where:

D_g = geometric mean diameter (mm), L = length (mm), W = width (mm), T = thickness (mm)

2.3.4 Sphericity (φ)

Sphericity indicates how closely the shape of the water chestnut resembles a sphere. Water chestnuts generally have low sphericity due to their pointed edges or horns. This affects their rolling behavior on surfaces, which is important in conveying, cleaning, and grading operations. Low sphericity means they are more likely to slide rather than roll.

$$\text{Formula: } \Phi = \frac{(L \times W \times T)^{1/3}}{L} \times 100 \quad \dots (3.3)$$

Where:

φ = sphericity, L= Length, mm. W= Width, mm. T=Thickness, mm

2.3.5 Surface area (S)

The surface area of the water chestnut was calculated by using the equation (Krishnappa *et al.*, 2017) ^[14].

Formula:

$$S = \pi \times D_g^2 \quad \dots (3.4)$$

Where:

S = surface area (mm²), D_g = geometric mean diameter (mm), π = 3.1416

2.3.6 Aspect ratio (Ra)

The aspect ratio (R_a) of Water chestnut was calculated by following formula.

$$Ra = W/L \times 100 \quad \dots (3.5)$$

where,

R_a=Aspect ratio (%), L=Length, mm. W= Width, mm

2.3.7 Bulk density (pb)

A box having inner dimension 11 x 11 x11 cm was used to measure the bulk density of the Water chestnut. The box was filled with Water chestnut without compaction and weighed using an electronic weighing balance This procedure was repeated three times using different sets of Water chestnut and the bulk density

was calculated by using following formula (Maduako and Hamman, 2004) ^[17].

$$\text{Bulk density (kg/m}^3\text{)} = \frac{\text{Weight of sample in container}}{\text{Volume of sample}}$$

Formula:

$$\rho_b = \frac{w}{v} \quad \dots (3.6)$$

Where:

ρ_b = bulk density (kg/m³), M = mass (kg), V_b = bulk volume (m³)

$$\text{True density (kg/m}^3\text{)} = \frac{\text{Weight of sample}}{\text{True volume of sample}}$$

2.3.8 True density (pt)

It was determined by toluene displacement method (Mohsenin, 1980) ^[31]. Water chestnut sample were submerged in toluene in a measuring cylinder having an accuracy of 0.1 ml. The increase in liquid volume due to sample was noted as true volume of the sample, which was then used to determine the true density of the sample. Average of three replications was considered as true density value of sample.

Formula:

$$\rho_t = \frac{M}{v} \quad \dots (3.7)$$

Where:

ρ_t = true density (kg/m³), M = mass (kg), V_t = true volume (m³)

2.3.9 Porosity (ε)

It was the percent of volume of the voids in the test sample at given moisture content. It was determined as the ratio of difference in true and bulk density to the bulk density value and expressed in percentage. (Mohsenin, 1986) ^[18]. Bulk and true density values obtained from previous experiments were used to calculate porosity of Water chestnut Formula:

$$\varepsilon = \frac{(pt - pb)}{pt} \times 100 \quad \dots (3.8)$$

where:

ε = porosity (%), ρ_t = true density (kg/m³), ρ_b = bulk density (kg/m³)

2.3.10 Angle of repose (θ)

The angle of repose is the angle between the base and the slope of the cone formed on a free vertical fall of the material to a horizontal plane. The dynamic angle of repose of Water chestnut will be measured by the emptying method. A cone was placed over a plain surface and samples were filled in. The cone was raised slowly allowing the sample to flow down and form a natural slope. The dynamic angle of repose was calculated from the height and diameter of the pile (Mohsenin, 1980) ^[31].

Formula:

$$\theta = \tan^{-1} 2h/D \quad \dots (3.9)$$

Where:

θ = angle of repose (degrees), h = height of heap (m), r = radius (m), D -Diameter of the base of pile, cm



Plate 2.2: Measurement of angle of repose of groundnut pod

2.3.11 Thousand kernel weight

Thousand nut weight was determined by counting 100 Water chestnut then weighing them in electronic balance to an accuracy of 0.001g and then multiplied by 10 to give weight of 1000 Water chestnut (Mohsenin, 1980) ^[31]. It will be helpful in design of collection unit.

2.3.12 Moisture content (MC)

Amount of water present in water chestnuts. Water chestnuts have high moisture content, which affects their hardness, peeling efficiency, and storage life. Proper moisture control is essential to reduce spoilage and improve decortication performance. The moisture content of Water chestnut was determined by using standard method of moisture determination. First weight of sample was measured and placed in hot air oven at 105°C ± 2 for 24 h (AOAC, 2012) ^[3].

Formula:

$$MC = \frac{w_1 - w_2}{w_1} \times 100 \quad \dots (3.10)$$

Where:

MC = moisture content (%), w_i = initial weight (g), w_d = dry weight (g)

2.3.13 Coefficient of static friction of pod

The co-efficient of static friction (μ_s) of Water chestnut is determined against surface of mild steel sheet. The samples will be placed on the test surface at the top edge. The inclined surface was tilted until the samples begin to move leaving an inclined surface. The angle of inclination with the horizontal was measured by a scale provided and taken as an angle of internal friction and tangent of the angle was taken as co-efficient of static friction between surface and sample (Mohsenin, 1980) ^[31].

$$\mu_s = \tan \theta \quad \dots (3.11)$$

where, μ_s - Co-efficient of static friction, θ - Angle of inclination of material surface



Plate 2.3: Experimental setup for measurement of coefficient of friction

2.3.14 Terminal velocity

Terminal velocity was measured by using an air column system. For each experiment, a sample was dropped into the air stream from the top of the air column. The air was blown up to suspend the material in the air stream. The air velocity near the location of the pod suspension was measured by a hot wire anemometer having a least count of 0.01 m/s.



Plate 2.4: Experimental setup of air column for determination of terminal velocity

3. Results and Discussion

3.1 Dimensional and shape characteristics of water chestnut

The average length, width and thickness of water chestnut were observed as 31.50 ± 8.03 mm, 32.50 ± 7.44 mm and 28.00 ± 9.52 mm, respectively. The length varied from 18 to 45 mm, width from 20 to 45 mm, and thickness from 12 to 44 mm. The variation in fruit dimensions may be attributed to differences in maturity, variety, growing conditions and natural biological variability among individual fruits. The measured dimensions provided essential information for determining the feeding opening, decortication chamber dimensions and clearance required for effective movement and decortication of water chestnut.

Table 1: Engineering properties of water chestnut at 66.88% moisture content (w.b.)

Sr. No.	Eng. property	Max	Min	Average	SD
1	Length (mm)	45	18	31.5	8.03
2	Width (mm)	45	20	32.5	7.44
3	Thickness (mm)	44	12	28	9.52
4	Geometric mean diameter (mm)	37.21	28.53	32.87	2.58
5	Arithmetic mean diameter (mm)	44.5	33.2	38.85	3.36
6	Sphericity (%)	75.15	53.86	64.5	6.33
7	Surface area (mm ²)	2919	1060.76	1989.88	552.82
8	Aspect ratio (%)	86	57	71.5	8.6
9	Moisture content with husk (w. b%)	70.2	62.7	66.88	3.06
10	Bulk density (kg/m ³)	821	760	795.4	23
11	True density (kg/m ³)	970	952	960.4	7.7
12	Porosity (%)	21.33	13.94	17.17	2.77
13	(a) Coefficient of static friction on MS	0.83	0.62	0.72	0.07
	(b) Coefficient of static friction on Stainless steel	0.75	0.63	0.7	0.04
14	Angle of repose	45	42.51	43.62	0.96
15	Terminal velocity (m/s)	8.31	5.62	7.482	1.081
16	1000 chestnut weight	10400	8960	9513	775.71

The engineering properties of water chestnut (*Trapa natans* L.) were determined at an average moisture content of 66.88% (w.b.) to establish the design parameters required for the development of the water chestnut decorticator. The measured properties included length, width, thickness, geometric mean diameter, arithmetic mean diameter, sphericity, surface area, aspect ratio, bulk density, true density, porosity, coefficient of static friction, angle of repose, terminal velocity and 1000-chestnut weight. The statistical parameters of these properties are presented in the corresponding table.

The average geometric mean diameter and arithmetic mean diameter were found to be 32.87 ± 2.58 mm and 38.85 ± 3.36 mm, respectively, while the average sphericity and aspect ratio were $64.50 \pm 6.33\%$ and $71.50 \pm 8.60\%$, respectively. The average surface area was observed as 1989.88 ± 552.82 mm². The variation in these geometric characteristics indicated that water chestnut fruits possessed considerable variation in size and shape. These properties were important for selecting suitable chamber clearance and decortication-surface configuration so that fruits of different sizes could be effectively subjected to rubbing and impact without excessive kernel damage.

3.2 Gravimetric properties of water chestnut

The average bulk density and true density of water chestnut were observed as 795.40 ± 23.00 kg/m³ and 960.40 ± 7.70 kg/m³, respectively, whereas the average porosity was $17.17 \pm 2.77\%$. The bulk density varied from 760 to 821 kg/m³, while true density ranged from 952 to 970 kg/m³. The difference between bulk and true density resulted from the void spaces present between individual fruits, which was also reflected in the measured porosity. These properties provided useful information for estimating the feeding and hopper capacity, material loading and volume requirements of the developed water chestnut decorticator.

The average 1000-chestnut weight was found to be 9513 ± 775.71 g, with values ranging from 8960 to 10400 g. The variation in 1000-chestnut weight may be attributed to differences in fruit size, maturity, moisture content and individual fruit development. The average value indicated that approximately 9.51 kg of water chestnut represented 1000 fruits under the conditions of the present study. This property provided useful information for estimating the relationship between number of fruits and batch weight, and was therefore useful for determining feeding requirements and material loading during performance evaluation of the developed decorticator.

3.3 Frictional properties of tender sorghum

The coefficient of static friction of water chestnut on mild steel and stainless steel was found to be 0.72 ± 0.07 and 0.70 ± 0.04 , respectively. The values indicated appreciable friction between the water chestnut surface and the material-contact surfaces. The coefficient of friction is an important design parameter because it influences the movement of fruits through the feeding and decortication chamber and determines the tendency of the material to slide or remain in contact with the decortivating surface. These values were therefore useful in selecting suitable materials and designing the feeding and decortication surfaces of the developed machine.

The angle of repose of water chestnut was found to be $43.62 \pm 0.96^\circ$, with values ranging from 42.51 to 45.00° , indicating relatively stable heap formation and moderate flowability of the fruits. The angle of repose is an important parameter for determining the inclination of the hopper and feeding surfaces. A suitable hopper inclination greater than the measured angle of

repose would help facilitate movement of the fruits towards the decortication chamber and reduce the possibility of bridging or accumulation during feeding.

3.4 Aerodynamic properties of tender sorghum grains

The terminal velocity of water chestnut was observed as 7.482 ± 1.081 m/s, with values ranging from 5.62 to 8.31 m/s. The variation in terminal velocity may be associated with differences in fruit size, shape, mass and surface characteristics. Terminal velocity is an important aerodynamic property for determining the air velocity required for pneumatic separation or cleaning. Although the developed decorticator primarily operated through mechanical rubbing and impact, the measured terminal velocity provided useful information for any subsequent cleaning or separation operation associated with the decortication process. Overall, the obtained engineering properties indicated that the size, shape, density, frictional and flow characteristics of water chestnut were important considerations in the design and operation of the developed decorticator. The measured dimensions and geometric properties were useful for determining the feeding and decortication chamber dimensions, while density and porosity were useful for material handling and capacity calculations. The frictional properties and angle of repose provided information for designing the feeding and material-contact surfaces, whereas terminal velocity provided a basis for possible cleaning and separation operations. Thus, the engineering-property data generated in the present study provided fundamental design information for the development, performance evaluation and optimization of the water chestnut decorticator.

3.5 Engineering significance of measured properties in the design of water chestnut decorticator

The engineering properties determined for water chestnut (*Trapa natans* L.) provided essential design inputs for the development and optimization of the mechanized water chestnut decorticator. Unlike many conventional dry agricultural materials, water chestnut used in the present study contained relatively high moisture content, with an average value of 66.88% (w.b.), and possessed an irregular shape with a hard outer husk and comparatively soft edible kernel. Consequently, accurate characterization of its dimensional, geometric, gravimetric, frictional and flow properties was important for designing machine components that could provide effective husk removal while minimizing kernel damage and decortication losses.

The measured dimensional properties, including average length of 31.50 mm, width of 32.50 mm and thickness of 28.00 mm, provided the basic design information for determining the dimensions of the feeding opening, decortication chamber and clearance between the rotating disc and stationary corrugated surface. The average geometric mean diameter (32.87 mm) and arithmetic mean diameter (38.85 mm) further represented the overall size of the fruit and assisted in selecting suitable chamber dimensions. The average sphericity (64.50%) and aspect ratio (71.50%) indicated that the water chestnut fruits were not perfectly spherical and had considerable variation in shape. Therefore, sufficient clearance and an appropriate chamber configuration were required to allow fruits of different sizes and orientations to enter and move through the decortication chamber without excessive compression or obstruction.

The surface area (1989.88 mm²) was also important in understanding the extent of contact between the fruit and the decortivating surfaces. Since the developed machine operated mainly through rubbing and impact between the rotating emery-

glued surface and the corrugated steel chamber, the contact characteristics of the fruit influenced husk removal. The average surface area provided a useful basis for understanding the contact behavior during decortication, while the dimensional variation indicated the need for a decortication chamber capable of accommodating different fruit sizes. Appropriate contact and clearance were necessary to provide sufficient mechanical action for breaking the hard husk while avoiding excessive pressure on the edible kernel.

The gravimetric properties also played an important role in the design of the decorticator. The average bulk density of 795.40 kg/m³ was useful for estimating the volume required for the feeding hopper and determining the material quantity corresponding to a particular batch capacity. The average true density of 960.40 kg/m³ and porosity of 17.17% provided information about the actual material density and the void spaces present between individual fruits. These properties were useful for estimating the packing behavior and effective volume occupied by water chestnut in the hopper and decortication chamber. The average 1000-chestnut weight of 9513 g also helped in relating the number of fruits to batch weight and was useful for determining material loading during machine performance evaluation.

The frictional and flow properties were particularly important for designing the feeding and decortication surfaces. The average coefficient of static friction was 0.72 on mild steel and 0.70 on stainless steel, indicating considerable resistance to the initiation of sliding. These values were useful for selecting suitable materials for the hopper, feeding surfaces and internal machine components. The relatively high friction between water chestnut and the contact surfaces could assist in maintaining adequate contact during the rubbing and impact action of decortication, although excessive friction could increase resistance and power requirement. The average angle of repose of 43.62° provided an important criterion for determining the inclination of the hopper and feeding surfaces. A suitable hopper inclination above the measured angle of repose would facilitate movement of the fruits towards the decortication chamber and reduce the possibility of bridging or accumulation.

The measured terminal velocity of 7.482 m/s provided useful aerodynamic information for possible cleaning or separation operations associated with the decorticated material. Although the principal mechanism of the developed machine was mechanical decortication rather than pneumatic separation, terminal velocity could be used as a reference for selecting air velocity if a cleaning or aspiration system were incorporated after decortication. The variation in terminal velocity from 5.62 to 8.31 m/s could be related to differences in fruit size, shape and mass. Thus, this property could assist in designing a subsequent cleaning system capable of separating lighter husk particles from the heavier decorticated material.

Collectively, the measured engineering properties constituted an important design database for the developed water chestnut decorticator. The dimensional and geometric properties were used to establish appropriate feeding and chamber dimensions, while density and 1000-chestnut weight were useful for determining material loading and batch capacity. The frictional properties and angle of repose provided information for designing feeding and contact surfaces, and terminal velocity provided a basis for possible cleaning and separation operations. The engineering-property data provided the fundamental technical basis for developing a compact, efficient and suitable mechanized system for water chestnut decortication.

3.6 Comparison with published literature

The engineering properties determined for water chestnut (*Trapa natans* L.) at an average moisture content of 66.88% (w.b.) exhibited characteristics associated with its high moisture content, irregular fruit geometry and hard outer husk. The average length, width and thickness were 31.50, 32.50 and 28.00 mm, respectively, with a mean geometric mean diameter of 32.87 mm, arithmetic mean diameter of 38.85 mm, and sphericity of 64.50%. The relatively wide variation in fruit dimensions, with length ranging from 18 to 45 mm, width from 20 to 45 mm, and thickness from 12 to 44 mm, indicated considerable variation in size and shape among individual fruits. These characteristics were important for determining the feeding opening, chamber dimensions and clearance of the decortication unit.

The measured surface area of 1989.88 mm² and aspect ratio of 71.50% further indicated the irregular and non-spherical geometry of water chestnut. Such variation in shape was particularly relevant to the developed decorticator because the fruits had to remain in effective contact with the rotating emery-glued surface and corrugated steel chamber during rubbing and impact. The average bulk density of 795.40 kg/m³ and true density of 960.40 kg/m³ reflected the packing and internal density characteristics of the fruits, while the average porosity of 17.17% represented the void spaces between individual water chestnuts in a bulk mass. These properties were useful for determining hopper volume, material loading and batch capacity of the decorticator.

The frictional and flow properties of water chestnut also showed important characteristics for mechanical handling. The average coefficient of static friction was 0.72 on mild steel and 0.70 on stainless steel, indicating sufficient frictional interaction between the fruit and machine surfaces. Such frictional behaviour was relevant to the movement of water chestnut through the feeding and decortication chamber and to the rubbing action required for husk removal. The average angle of repose of 43.62° indicated that the fruits required an appropriately inclined feeding surface for smooth movement towards the decortication chamber. Similarly, the average terminal velocity of 7.482 m/s provided useful aerodynamic information for subsequent cleaning or separation of decorticated material, although pneumatic separation was not the primary mechanism of the developed decorticator.

Unlike conventional post-harvest studies that mainly focus on processing, drying, flour production and utilization of water chestnut, the present investigation specifically characterized the engineering properties of water chestnut at its high-moisture condition for application in mechanical decortication. The measured properties therefore provided the necessary design information for developing the feeding system, decortication chamber, rotating disc, material-contact surfaces and collection system. Thus, the engineering properties generated in the present study provided a useful technical basis for the design, performance evaluation and optimization of a power-operated water chestnut decorticator, with the objective of achieving efficient husk removal while minimizing decortication loss and kernel damage.

4. Conclusions

The engineering properties of water chestnut (*Trapa natans* L.) were determined at an average moisture content of 66.88% (w.b.) to generate essential design data for the development of a mechanized water chestnut decorticator. The average length, width and thickness were 31.50 mm, 32.50 mm and 28.00 mm, respectively, with a mean geometric mean diameter of 32.87 mm, arithmetic mean diameter of 38.85 mm, sphericity of 64.50%,

surface area of 1989.88 mm², and aspect ratio of 71.50%. These properties indicated considerable variation in chestnut size and shape and provided important information for determining the feeding opening, decortication chamber dimensions and clearance.

The average 1000-chestnut weight, bulk density, true density, porosity, angle of repose, terminal velocity, and coefficient of static friction on mild steel and stainless steel were 9513 g, 795.40 kg/m³, 960.40 kg/m³, 17.17%, 43.62°, 7.482 m/s, 0.72 and 0.70, respectively. These engineering properties provided essential design inputs for determining hopper capacity, feeding arrangement, chamber clearance, material-contact surfaces and material flow characteristics. Overall, the measured properties provided a suitable technical basis for the design, optimization and future development of an efficient mechanized water chestnut decorticator.

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Author contributions

Naveen Kumar: Conceptualization, Prototype development, Experimental trials, Data analysis, Writing - original draft; P.H. Bakane: Methodology, Design Optimization, Testing, Writing - review & editing, Fabrication Assistance, Trial support, Data recording, Literature review; R. D. Bisen: Literature survey, Data collection, Writing - review & editing.

Conflict of interest

The authors declare that there is no conflict of interest in any from that could have influenced the research work reported in this paper

Data availability statement

All data generated or analyzed during this study are included in this article, and will be made available by the corresponding author on receiving a reasonable request.

References

- Ahmed J, Al-Attar H, Arfat Y. Effect of particle size on compositional, functional, pasting and rheological properties of commercial water chestnut flour. *Food Hydrocolloids*. 2015. DOI:10.1016/j.foodhyd.2015.08.028.
- Alam MS, Singh DS, Sehgal VK. Optimization of screen in a water chestnut decorticator. *J Agric Eng (India)*. 2001;38(3):29-34.
- AOAC International. Official method 925.10: Moisture in nuts and nut products. In: *Official methods of analysis of AOAC International*. 19th ed. Gaithersburg (MD): AOAC International; 2012.
- Chikara A, Chaudhary S, Sahal A, Hussain A, Kumar V, Dobhal A, *et al.* Water chestnut unveiled: a comprehensive review of its nutritional profile, bioactive potential, and food applications of peel and kernel. *Waste Biomass Valor*. 2025. DOI:10.1007/s12649-025-03278-0.
- Deshpande SD, Bal S, Ojha TP. Physical properties of soybean. *J Agric Eng Res*. 1993;56(2):89-98.
- Dodd LL, Rybicki N, Thum R, Kadono Y, Ingram K. Genetic and morphological differences between water chestnut (*Myrtales: Lythraceae: Trapa*) populations in the northeastern United States, Japan, and South Africa. 2019.
- Gupta AK, Singh M, Patel S, Gour M, Nandanwar S, Saini R. Post-harvest processing and value addition of water chestnut - A review. *J Pharmacogn Phytochem*. 2025;14(2):39-43. DOI:10.22271/phyto.2025.v14.i2a.15273.
- Hate S, Thakre M, Kunjalwar S. Assessment of phytochemical and nutritional composition of *Trapa natans* L. and physicochemical characteristics of associated water bodies in Deni Village, Maharashtra. *J Divers Stud*. 2026;5(1):151. DOI:10.51470/jod.2026.5.1.151.
- Irfan M, Butt MS, Haider MB, Ahmad MT, Khaliq B, Ramzan MM, *et al.* A water chestnuts (*Trapa natans*): physicochemical properties of starch and industrial applications across food, textile and pharmaceutical sectors. *UCP J Sci Technol*. 2025. doi:10.24312/ucp-jst.02.02.427.
- Jain RK, Bal S. Properties of pearl millet. *J Agric Eng Res*. 1997;66(2):85-91.
- Kaleemullah S, Gunasekar JJ. Moisture-dependent physical properties of arecanut kernels. *Biosyst Eng*. 2002;82(3):331-338.
- Kaur K, Kaur G, Singh A. Water chestnut starch: extraction, chemical composition, properties, modifications, and application concerns. *Sustain Food Technol*. 2023. doi:10.1039/D2FB00041E.
- Khurmi RS, Gupta JK. A textbook of machine design. 14th ed. New Delhi: Eurasia Publishing House; 2005.
- Krishnappa MA, Maddi A, Matamari V, Kulkarni P, Desai B, Vasudevan SN. Engineering properties of selected groundnut (*Arachis hypogaea* L.) varieties. *Int J Agric Sci Res*. 2017;7(4):203-216.
- Liu X, Meng X. Progress research on resource development and utilization of water chestnut. *Food Res Dev*. 2021;42(3):212-217.
- Lu Y, Zhao SM, Jia C, Xu Y, Zhang B, Niu M. Textural properties of Chinese water chestnut (*Eleocharis dulcis*) during steam heating treatment. *Foods*. 2022;11(9):1175. DOI:10.3390/foods11091175.
- Maduako JN, Hamman J. Determination of some physical properties of three groundnut varieties. *Niger J Technol*. 2004;24(2):12-18.
- Mohsenin NN. Physical properties of plant and animal materials: structure, physical characteristics and mechanical properties. 3rd ed. New York: Gordon and Breach Science Publishers; 1986.
- Mrema GC, McNulty PB. Physical and mechanical properties of agricultural materials and their importance in machine design. *J Agric Eng Res*. 1985;32:123-134.
- Myers R, Montgomery DC. Response surface methodology. New York: John Wiley & Sons; 1995.
- Myers RH, Montgomery DC. Response surface methodology: process and product optimization using designed experiments. 2nd ed. New York: Wiley; 2002.
- Rajput JD, Singh A. Water chestnut: Functional characteristics, nutritional properties and applications in food industry. *J Phytopharmacol*. 2023;12(2):119-126. DOI:10.31254/phyto.2023.12209.
- Rehman AU, Khan AU, Sohaib M, Rehman H. Comparative analysis of nutritional properties, phytochemical profile, and antioxidant activities between red and green water chestnut (*Trapa natans*) fruits. *Foods*. 2024;13(12):1883. doi:10.3390/foods13121883.
- Bolpagni R, Pierobon E, Longhi D, Nizzoli D, Bartoli M, Tomaselli M, *et al.* Diurnal exchanges of CO₂ and CH₄ across the water-atmosphere interface in a water chestnut meadow.

- Aquat Bot. 2007;87(4):304-310.
DOI:10.1016/j.aquabot.2007.02.002.
25. Sahay KM, Singh KK. Unit operations of agricultural processing. New Delhi: Vikas Publishing House; 1994.
 26. Sayyad F, Akbari S, Vyas D, Kumar N, Sutar R. Mathematical modelling of hot air drying of water chestnut kernels. J Pharmacogn Phytochem. 2021;10(3):236-240. DOI:10.22271/phyto.2021.v10.i3d.14084.
 27. Singh DS. Development of a manual water chestnut decorticator. J Food Sci Technol. 2003;40:340-343.
 28. Rouhullah S, Dar MUD, Ali M, Bhat SA, Ahuja M. Design and development of manual water chestnut (*Trapa natans*) decorticator for Kashmir Valley, India. J Pharmacogn Phytochem. 2017;6(5):1430-1433.
 29. Tabatabaefar A. Moisture-dependent physical properties of wheat. Int Agrophys. 2003;17:207-211.
 30. Zhang G, Chen L, Guo Z, Liu H, Dong Z, Liang F. Design and experiment of a combined peeling machine for water chestnut. Sci Rep. 2023;13. DOI:10.1038/s41598-023-28472-9.
 31. Mohsenin NN. Physical properties of plant and animal materials: structure, physical characteristics and mechanical properties. New York: Gordon and Breach; 1980.