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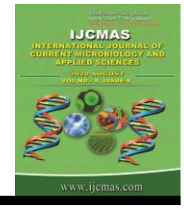

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Engineering Properties of Groundnut Pods and Kernels: A Key Role for Designing the Post-harvest Processing Equipment

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Some physical and mechanical properties of the groundnut pods and kernels were measured. The main motive of this study to provide a summary of the engineering properties of the TAG-24 variety of the groundnut pods and kernels. The average values of the geometric diameter, surface area, sphericity, angle of repose, and coefficient of friction were found to be 16.93 mm, 906.01 mm^2, 48.95%, 24.20^0, and 0.41, respectively at moisture content of 6.82% (db) for the groundnut pods. Furthermore, the average values of the geometric diameter, surface area, sphericity, angle of repose, and coefficient of friction were found as 8.65 mm, 237.03 mm^2, 71.94%, 20.43^0 and 0.43, respectively at moisture content of 5.02% (db) for the groundnut kernels. The energy required to crush the groundnut pods was determined as 1.88 kJ/kg for particular TAG-24 groundnut variety. The mean rupture force for the shelling of groundnut pods was measured by keeping the pods on the test bench longitudinally, laterally and vertically; the rupture force was found to be 62.37 N, 250.21 N and 32.74 N respectively.

Introduction

Groundnut (*Arachis hypogaea* L.) is an important oilseed crop in our country, and it is generally used for food and feed. Worldwide, it occupies the sixth rank in oilseed crops, and developing countries contribution 97% of cultivation area and produces 94% of the groundnut pods (Shubham, 2015). In India, the groundnut is grown around 4.91 million hectares, with the second position of production 9.18 million tones after China. India's five states, Gujarat, Rajasthan, Andhra Pradesh, Tamil Nadu, and Karnataka, cover around 82% of groundnut cultivation with the highest production 85%. Among these major producing states, Gujarat has the most top production of 42.88% from a total share of cultivation area 34.18% (Anon., 2018). Groundnut kernels have various utilizations viz., peanut butter, and edible oil. The edible oil used extensively not only for cooking but also in making soaps and cosmetics. The residual oilcake contains 7-8% of N, 1.5% of P_2O_5, and 1.2 % of K_2O used as a fertilizer and it can be used as a fodder for livestock

(Putnam *et al.,* 2013). In the world, almost 67% of groundnut pods crushed for edible oil and 33% used for food and its kernel contains 40-50% fat, 20-50% protein, 10-20% carbohydrate and 43-55% edible oil depending upon variety and agronomic conditions of the groundnut (Akcali *et al.,* 2006; Okello *et al.,* 2010).

In spite of the financial probable of groundnut pods, the post-harvest processing operations are mainly completed manually. A lot of time and laborious are needed in post-harvest processing operations, implicit unhygienic situations and output can be found with more broken of kernels of shelling of groundnut pods. Hence, a brief intellectuality of engineering properties of groundnut pods and kernels are played an important role in designing of agricultural harvesting and post-harvest processing units viz., shelling unit, sieve unit, conveying, cleaning, delivering, separation, packing, sorting, drying, mechanical oil expelling and handling (Davies, 2009; Mohsenin, 1986). Most of the agriculture machines engaged in harvesting and post-harvest processing of groundnut pods are available without considering the design parameters of the groundnut pods and kernels' engineering properties. Hence, a large amount of the output efficiency reduced and increases the losses from these machines (Manuwa and Afuye, 2004; Razari*et al.,* 2007). The physical properties of groundnut pods and kernels do not only build the general engineering data desired for machines and implement design, but also give the brief knowledge for choose the proper methods for receiving those data (Singh *et al.,* 1983).

Many of the researchers suggested only the physical properties of the groundnut kernels. Agarwal *et al.,* (1973) described the shapes of the one or two hulled peanuts as an ellipsoid, double ellipsoid, and cassinoid. Olajide and Igbeka, (2003) measured the size of peanuts. They were found mean major, intermediate, and minor diameters of the kernels as 8.54, 3.55, and 6.93 mm, respectively. It was also determined the angle of repose of kernels as 17°. Kaleemullah (1992) explained the variation in dimensions of groundnut kernels with moisture content. Still, the researchers have concentrated only on the groundnut kernels. Therefore, this study's motive was to describe the brief knowledge for the engineering properties of the groundnut pods and kernels for proper designing of agriculture equipment.

Materials and Methods

Physical Properties of Groundnut Pods and Kernels

A 10 kg local cultivar TAG 24 variety of groundnut pods were procured from the local farmers of Paschim Medinipur, West Bengal. The engineering properties of groundnut pods and kernels were measured at the Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur, West Bengal, India. The moisture content of groundnut pods was determined using the ASAE (1983) method by the hot oven dryer at 103°C for 72 hours (Koushkaki *et al.,* 2017), and it was found to be 9.82 % (db).

Determination of the size of the groundnut pods and kernels

One hundred groundnut kernels and pods were randomly selected, and their three principal dimensions (Fig. 1 and 2) were measured using digital Vernier caliper with 0.01 mm accuracy. The geometric mean diameter (D_g), sphericity (ϕ), surface area (S) and aspect ratio (R_a) were calculated by using Equations (1), (2), (3) and (4), respectively given by (Mohsenin, 1986; McCabe *et al.,* 1986).

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

$$\phi = \frac{(LWT)^{\frac{1}{3}}}{L} \times 100 \quad (2)$$

$$S = \pi D_g{}^2 \quad (3)$$

$$R_a = \frac{W}{L} \times 100 \quad (4)$$

Where, D_g = geometric mean diameter (mm); L = length (mm); W = width (mm) and T = thickness (mm); ϕ = sphericity (%); S = surface area (mm^2) and R_a= aspect ratio (%)

Determination of average weight of the groundnut pods and kernels

A sample of 1000 groundnut pods and kernels was selected randomly to determine the average weight at moisture content of 6.82% and 5.02% (db), respectively, using a digital balance with the accuracy of 0.01 g. The experiments were replicated five times to minimize the error.

Determination of bulk density of the groundnut pods and kernels

A sample of kernels and pods with known mass (56 g) was poured into a container of volume (500 ml) at a constant rate. The bulk density (kg/m^3) of groundnut pods and kernels were measured using the AOAC (1980) method from the mass of groundnut pods and kernels divided by the occupied volume of the groundnut pods and kernels in the container as using Equation (5).

$$\rho_b = \frac{M_m}{V_c} \quad (5)$$

Where, ρ_b= bulk density (kg/m^3); M_m = mass of material(kg); V_c = volume of container (m^3)

Determination of angle of repose of the groundnut pods and kernels

The angle of repose of groundnut pods and kernels was determined using the method described by (Waziri and Mittal, 1983). The groundnut pods and kernels were taken onto a circular disc with a hole that allowed the pods and kernels to fall onto a level surface via a funnel. The pods and kernels formed a free-standing cone after allowing them to settle on the level surface, as shown in Fig. 3. The cone height (H) and diameter (D) were measured, and the angle of repose of groundnut pods and kernels was determined by the following Equation (6).

$$\theta = \tan^{-1}\frac{2H}{D} \quad (6)$$

Determination of coefficient of friction of the groundnut pods and kernels

The coefficient of friction of groundnut pods and kernels was determined using the method described by (Dutta *et al.,* 1988). The groundnut pods and kernels were taken into a box of 160 mm length, 110 mm with and 50 mm height without base, and placed onto an adjustable inclined plate. The adjustable inclined plate was raised slightly until the sample box starts to slide onto the inclined plate and the inclined plate at which the sample box just begins to slide tight with the protractor through the adjustable screw, as shown in Fig. 4.

The vertical distance (P) and horizontal distance (Q) were measured by the scale, and the coefficient of friction of groundnut pods and kernels was determined by the following Equation (7).The angle of internal friction can be measured directly by the protractor at which the sample box just starts slide on the inclined plate.

$$\mu = \tan\alpha = \frac{P}{Q}$$

$$\alpha = \tan^{-1}\frac{P}{Q} \quad (7)$$

Where, P = vertical distance from the fixed plate to the adjustable plate while sample box just start slide; Q = horizontal distance between the connection point of plates to the point when sample box just start slide and α = angle between the inclined plate and horizontal plate at which the sample box just start slide (angle of internal friction).

Determination of shape of the groundnut pods and kernels

The shape of groundnut pods and kernels was determined using the formula explained by (Abd Alla *et al.*, 1995). It was suggested that the value of index-K > 1.5, then the grain is observed oblong, and the value of index-K ≤ 1.5 the grain is observed spherical.

The average values of the length, width, and thickness of the groundnut pods and kernels were placed in the Equation (8), and the values of index-K for groundnut pods and kernels were found to be 2.96 and 1.65, respectively.

$$\text{Index} - K = \frac{L}{\sqrt{W \times T}} \quad (8)$$

Where, L = length of grain (mm); W = width of grain (mm); T = thickness of grain (mm)

Mechanical Properties of Groundnut Pods

The unconscionable forces applied on the groundnut pods for breaking them to remove the whole kernels cause of two outcomes: (i) more damaged kernels and (ii) unbroken pods. Therefore, the rupture force's measurement is required to found out the actual force needed to break the pods without any damage to the kernels. The Universal Testing Machine (UTM) (model: UTB9052 and capacity 5kN) was used to measure the rupture force at loading rate of 100 mm/min. The groundnut pods were placed on the test bench longitudinally, laterally, and vertically as shown in Fig. 5.

The applied forces on the groundnut pods were noted when the pods were placed with different orientations on the test bench. Cracking forms on the groundnut pods were analyzed when the pods placed on the test bench longitudinally, laterally, and vertically. When the groundnut pods were placed on test bench longitudinally and vertically, the longitudinally cracking occurs. Furthermore, the groundnut pods were placed on the test bench laterally, the transversely cracking occurs. The cracking forms on groundnut pods are shown in Fig. 6 for various load orientations.

Determination of energy requirement to crush the groundnut pods

The energy requirement for the crushing of groundnut pods was determined using the formula explained by (Bond, 1952).

$$E = 0.3162 \times W_i \left(\frac{1}{\sqrt{L_2}} - \frac{1}{\sqrt{L_1}}\right) \quad (9)$$

Where, E = energy required to crush (kJ/kg), W_i = work index of groundnut pods for crushing (9 to14 kWh/ton) (Gelgelo, 2016), L_1 = average length of uncrushed groundnut pod (mm) and L_2 = average length of crushed groundnut kernel (mm). The average length of groundnut pods and kernels were measured L_1=35.00 mm and L_2=12.12 mm, respectively (Table 1), and the energy required to crush the groundnut pods was calculated as E = 1.88 kJ/kg.

Results and Discussion

Physical Properties of Groundnut Pods and Kernels

The recorded physical properties of groundnut pods and kernels are given in Table 1. The average length, width, and thickness of groundnut pods and kernels were measured as 35.00, 12.27, 11.40mm and 12.12, 7.63, 7.04respectively for TAG 24 variety of groundnuts. These measured dimensions will be beneficial in designing of hopper, the opening of the concave, crushing drum, and clearance between drum and concave unit as described by (Maduako and Hamman, 2005). The mean geometric diameter, surface area, percent sphericities, and percent aspect ratio of groundnut pods and kernels were found to be 16.93, 8.65mm, and 906.01, 237.03 mm^2 and 48.95, 71.94% and 35.71, 63.74%, respectively. The percentage sphericity of groundnut kernels was observed higher than the groundnut pods, which means the sliding ability of kernels is higher than that of the pods. The bulk density and average weight of one thousand groundnut pods and kernels were measured as 289.54, 622.43 kg/m^3, and 1290.5 g, 629.57 g, respectively. The measured bulk density and the average weight of groundnut pods and kernels will be used to decide the size and capacity of hopper and crushing chamber that provide the stability of the machine during operation. The angle of repose and coefficient of friction of the groundnut pods and kernels were found to be 24.20°, 20.43°, and 0.41, 0.43, respectively. It was observed that the angle of repose for groundnut pods was more than the kernels, and this may be due to the irregular and roughness surface of the groundnut pods. The conical structure of groundnut pods was raised by stick the pods one another, and it made a larger angle than kernels. The static coefficient of groundnut pods and kernels is needful in designing storage bins, pneumatic conveyor systems, screw conveyors, and threshing (Sahay and Singh, 2003). These measured physical properties of groundnut pods and kernels may be slightly deviate from the other physical properties of groundnut pods and kernels explained by Muhammad *et al.*, (2015), Odesanya *et al.*, (2015).

Table.1 Physical properties of groundnut pods and kernels

Properties	No. of Samples	Mean Value		Standard Deviation	
		Pods	Kernels	Pods	Kernels
Length (mm)	100	35.00	12.12	± 4.87	± 1.56
Width (mm)	100	12.27	7.63	± 1.03	± 0.73
Thickness (mm)	100	11.40	7.04	± 0.84	± 0.81
Geometric mean diameter (mm)	100	16.93	8.65	± 1.26	± 0.79
Surface area (mm^2)	100	906.01	237.03	± 133.71	± 43.31
Sphericity (%)	100	48.95	71.94	± 4.81	± 6.41
Aspect ratio (%)	100	35.71	63.74	± 5.62	± 7.99
Bulk density (kg/m^3)	5	289.54	622.43	± 22.65	± 16.54
Groundnut sample weight (g)	1000	1290.50	629.57	± 32.29	± 20.63
Moisture content (%, db)	5	6.82	5.02	± 0.45	± 0.53
Angle of repose pods (°)	5	24.20	20.43	± 1.87	± 1.56
Coefficient of friction	5	0.41	0.43	± 0.001	± 0.002
Shape	Oblong				

Table.2 Rupture force of groundnut pods with different loading orientation

Loading orientation	Rupture force (N)			Compressive extension (mm)		
	Max.	Min.	Mean	Max.	Min.	Mean
Longitudinally	80.86	37.27	62.37	3.58	1.99	2.26
Laterally	250.21	250.02	250.21	6.70	4.73	5.33
Vertically	43.41	28.19	32.74	2.09	0.54	1.22

Fig.1 Measurement of principal dimensions (mm) of groundnut pods

(a) Length (b) Width (c)Thickness

Fig.2 Measurement of principal dimensions (mm) of groundnut kernels

(a) Length (b) Width (c) Thickness

Fig.3 Measurement of angle of repose of groundnut pods and kernels

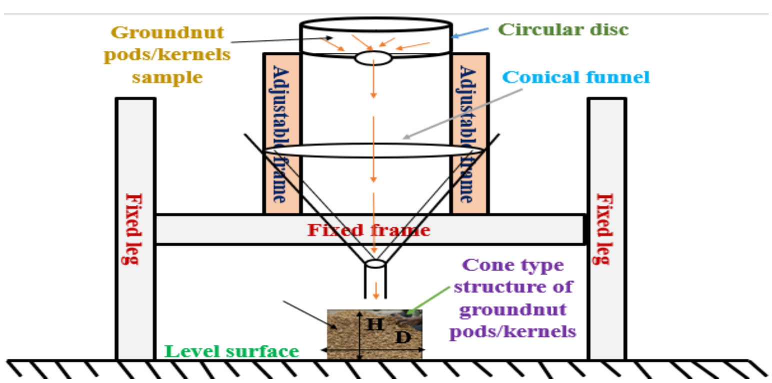


Fig.4 Inclined plate apparatus for measurement of coefficient of friction

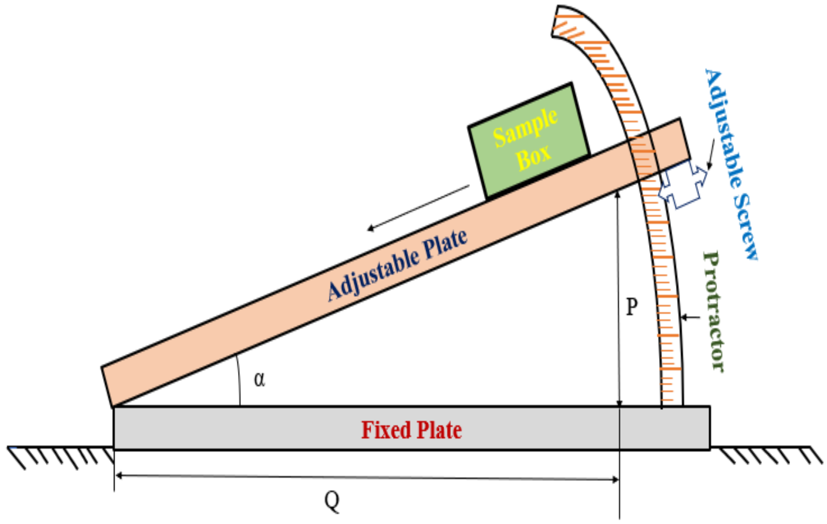
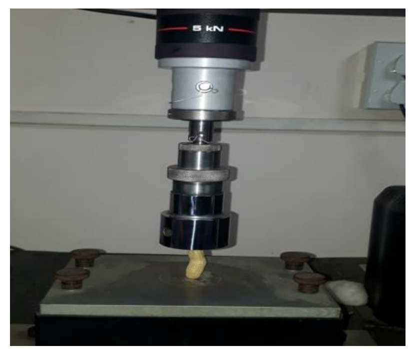


Fig.5 Rupture force measurement of groundnut pods on UTM

(a) Longitudinally

(b) Laterally



(c) Vertically

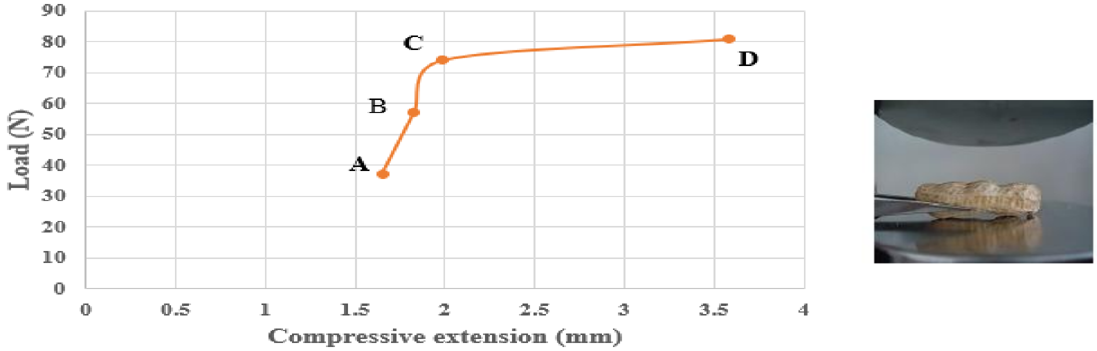
Fig.6 Cracking forms on groundnut pods with various loading orientation

(b) Longitudinally

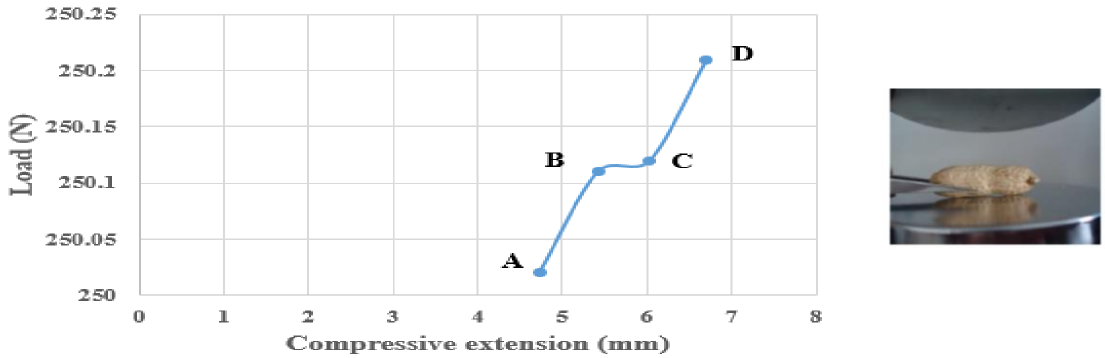
(b) Laterally

(c) Vertically

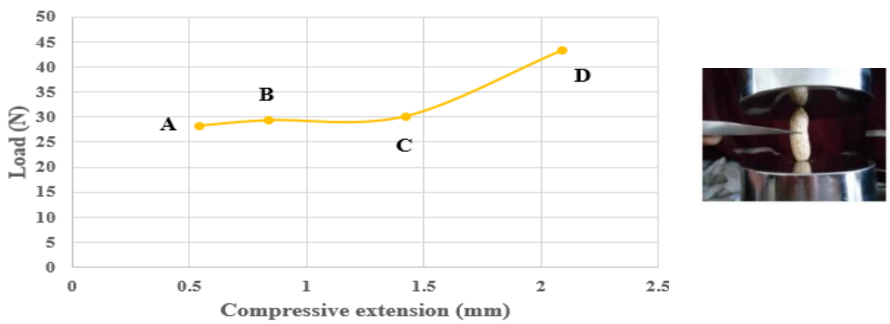
Fig.7 Rupture force measurement by UTM



(a) Longitudinally orientation



(b) Laterally orientation



(c) Vertically orientation

Mechanical properties of groundnut pods

The mechanical properties of groundnut pods also discussed, and the rupture force measured by the UTM machine is given in Table 2. The load-compressive extension graphs of longitudinally, laterally, and vertically are shown in Fig. 7 (a), (b) and (c). When the groundnut pods placed on the test bench longitudinally, laterally and vertically, the rupture force graph initially obtained a straight line, as shown in graphs A-B line. This A-B line follows the Hook's law. Beyond point B, the load increased by the UTM machine; elasticity of the groundnut pod surface is proceeded; thus, the surface of groundnut pod is supposed to be viscous. Due to the increasing load, the linearity of the curve changed, as shown in the graphs B-C curve. At point C, the surface of groundnut pod leaks and the void space was removed; hence, resulting in a sudden variation in the curve. After that point, C, a continuous loading on the groundnut pod outcomes in rupture of the groundnut pod at point D. Therefore, the point D in graphs represents the cracking force required to remove the kernels from groundnut pods. The mean rupture forces were measured to be 62.37, 250.21, and 32.74 N at 6.28 % (db) moisture content with different loading orientations, such as longitudinally, laterally, and vertically, respectively. The maximum and minimum rupture forces were noted as 80.86 and 37.27 N, 250.21 and 250.02 N, 43.41, and 28.19 N in longitudinally, laterally, and vertically orientation, respectively, as shown in Fig. 7. It could be analyzed that the highest rupture force required, when the load applied along with the laterally orientation and minimum in the vertically orientation. These rupture forces were useful to decide the power consumption to break the groundnut pods. These measured rupture forces may be slightly deviate from the other rupture forces explained by (Aydin, 2007; Muhammad *et al.*, 2015). It may be due to the groundnut variety and agronomic conditions of the crop. The energy required to crush the groundnut pods was determined as1.88 kJ/kg for particular TAG-24 groundnut variety**.**

In conclusion the physical and mechanical properties of groundnut pods and kernels are fundamental parameters that provide a brief knowledge and useful to design the agriculture machine in harvesting, threshing, shelling, and post-harvest processing operation. The measured physical properties and rupture force to remove the kernels from the groundnut pods depend on the groundnut variety and agronomic conditions of the crop. These mechanical properties of groundnut pods at different loading orientations are superior important in designing of milling, handling, storage, and transportation unit. Lack of knowledge of mechanical properties might lead to more breakage of kernels in processing operations, causing minimum germination rate and increasing the chances of inset and pest infection of the quality of the final product.

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Conflict of interest

The authors declare that there are no conflicts of interest.

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