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Engineering properties of neem (*Azadirachta indica*) fruit and seed for the development of depulper and decorticator

S. Ganga Kishore, P. Rajkumar, P. Sudha, J. Deepa, P. Subramanian, Z. John Kennedy

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Authors:
S. G. Kishore ✉, P. Rajkumar, P. Sudha, J. Deepa
Department of Food Process Engineering, Tamil Nadu Agricultural University, Coimbatore, India

P. Subramanian
Department of Renewable Energy Engineering, Tamil Nadu Agricultural University, Coimbatore, India

Z. J. Kennedy
Centre for Post Harvest Technology, Tamil Nadu Agricultural University, Coimbatore, India

✉ gangakishore024@gmail.com

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Abstract

Studies had been carried out to study the engineering properties of neem fruits and seeds collected from the southern region of India at different moisture content which would be useful in studying drying characteristics, designing equipment, and developing neem fruit depulper. Engineering properties varied when moisture content varied, so for different moisture content of neem seeds study had been carried out. The moisture content, one thousand mass, mean linear axial dimensions (length, breadth and thickness), arithmetic mean diameter, geometric mean diameter, equivalent mean diameter, sphericity, surface area, volume, aspect ratio, frontal surface area, cross sectional area, shape index, bulk density, true density, porosity, angle of repose, coefficient of friction, compressive strength, terminal velocity and color value of the samples (fresh neem fruit, dry neem fruit, fresh neem seed at 30% MC, dried neem seed at 20% MC and dried seed at 10% MC) ranged between 10 to 38 %, 276.7 to 1200 g, (12.1 to 18.10, 8.452 to 12.63 and 8.15 to 12.18) mm, 9.57 to 14.30 mm, 9.41 to 14.07 mm, 28.876 to 52.77mm, 65.83 to 78.08 %, 278.10 to 621.92 mm2, 2617.874 to 8750.48 mm3, 55.29 to 70.60 %, 80.28 to 179.54 mm2, 71.87 to 160.68 mm2, 83.94 to 187.53 mm2, 157.639 to 726.36 kgm-3 , 730.14 to 929.33 kgm-3 , 21.84 to 78.40%, 30.29 to 42.80 ◦ , 0.21 to 0.86, 39.24 to 412.02 N, 108.25 to 223.16 m/s and 3.0 to 84.1 respectively. The engineering properties of neem fruits and seeds increased with an increase in moisture content. While porosity, coefficient of friction, and compressive strength decreased.

Keywords correlation analysis, depulping, neem, physical properties, regression analysis

Introduction

Neem (*Azadirachta indica*) is one of the most valuable trees which belongs to the family Meliaceae and got its origin in India. It is predominantly found in countries like India, Myanmar, Bangladesh, Sri Lanka, Malaysia, and Pakistan. It can grow up to 15-20 m tall (max up to 35-40 m) and requires annual rainfall between 400 and 1200mm. The neem tree is highly drought resistant [1-3]. According to Neem Foundation, India has around 20 million neem trees [4]. The bark, leaves, root, flower, and fruit are rich in medicinal properties and also contain.

bioactive components like Azadirachtin, Nimbin, Nimbinin, Nimbidin, Palmitic acids, Quercetin, and other limonoids that have antioxidant, antimicrobial, antifungal properties [4]. The Neem fruit is used for urinary tract disorders, eye disorders, diabetes, wounds, and leprosy. The neem seeds are used in curing leprosy and intestinal worms [5]. The stem, root bark, and fruit are used as tonic and astringent. Besides the therapeutic values, it can be also used as a mosquito repellent, skin softener, and insecticide [6]. Neem tree yields an ovoid fruit (2cm × 1cm) which contains a pericarp that has a resinous substance with a garlicky odor. Each seed has a single kernel and it contains azadirachtin which has pesticide properties and other constituents [7]. The seed kernels weigh up to 50-60% of the seed weight and 25% of the fruit weight and contain the fat content of 30-50%. On average 45% neem oil and 55% neem cake are obtained from seed kernels. The seed cake is used as manure [8]. In India, the neem tree yields 3.5 million tonnes of kernels which can result in the production of 7 lakh tonnes of neem oil every year. Due to improper storage and processing condition, only 2.5 lakh tonnes of oil are produced which is only 30% of the total yield of the neem tree. About 50% of collected neem seeds are wasted without having a proper depulping facility [9].

Depulping of neem fruit is done to remove the peel and pulp from the neem fruit to obtain neem seed [10]. Neem fruits usually mature during the rainy season and due to their highly perishable nature and high moisture content, it starts decomposing at a faster rate. So, it is necessary to process neem fruits within 4 to 5 days after harvesting to get good quality oil from seed kernels. A complete depulping of neem fruits is necessary to obtain good quality oil within a short period. Traditionally depulping is done manually in which the ripe fruit is rubbed between palms in the bucket of water easily but for unripe fruits, it is a tedious process. In addition to this manual depulping involves human drudgery and also produces poor-quality oil.

Earlier studies related to engineering properties of neem fruits and seeds for different Agroclimatic zones were mentioned by different researchers [11-17] and reported that neem Seed Area, Oil Content, and Azadirachtin content vary among individual tree and Agroclimatic Zones of India. Considering this, Fresh and dry neem fruits and seeds of the southern region of Tamil Nadu, India were studied for Engineering properties to design and develop depulper and decorticator for this zone.

Very few studies were conducted on mechanical depulping to overcome the difficulties [18, 19]. Solanki et al., [9] developed a hand-operated neem depulper of 22 kg fruits/h with a water flow rate of 20 l/h and with an efficiency of 98%. To design and develop neem depulper the determination of engineering properties seems to be of paramount importance. Suitable information on the physical properties such as sphericity, true density, bulk density, porosity, size, and shape of the fruit is beneficial in measuring the external quality and also in designing washing and grading equipment [20]. Proper knowledge of the frictional properties of agricultural commodities is very imperative in the design of processing and conveying equipment [21]. The mechanical properties of the products give us an idea of the forces required in designing processing equipment [9]. Any equipment designed without taking these properties into consideration results in decreasing work efficiency with increased product loss [22]. Only limited studies have been carried out to study the engineering properties of neem fruits. Hence, a study is undertaken to determine the engineering properties of neem seeds at different moisture content which will be useful in designing and developing a neem fruit depulper, neem seed decorticator, and in modernizing neem oil production [4, 11].

Methodology

Fresh and dry neem fruits were collected from Forestry College and Research Institute, Mettupalayam, India. The pulp of the fresh neem fruits (38% w.b) was manually removed by following the sampling procedure reported by Nde et al., [4]. To compare the results at different moisture content, fresh neem seeds of 30 (% w.b) were dried to 10 and 20 (% w.b.) moisture content using a tray drier at 60 °C for 8 and 4 hours, and the properties were compared at different moisture content. Engineering properties were studied for fresh neem fruits, dry neem fruits, fresh neem seeds, and neem seeds with different moisture content after drying and the images were shown in Figure 1.

Figure 1. (A) Fresh Fruit (B) Dry fruit (C) Fresh seed (D) Dried seed at 20%t moisture content (w.b) (E) Dried seed at 10%t moisture content (w.b)

Moisture content determination

A known weight of random samples measured using a weighing balance with 0.001 g sensitivity was taken from bulk samples and kept in a hot air oven at 105 °C for 24 hrs. By using the oven dry method, moisture content was determined using equation (1) as reported by Correa et al., [23].

$$Mc(w.b.) = \frac{M_{imc} - \mathrm{M}_{\mathrm{fmc}}}{\mathrm{M}_{\mathrm{imc}}} \quad \text{.........................} \ (1)$$

where, M_c represents moisture content (% w.b.), M_{imc}, M_{fmc} represents the initial and final moisture content (% w.b.)

Physical properties

Physical properties like shape, size, volume, surface area, density, porosity, and color are important for designing equipment for separation, sorting, processing, and transportation. It helps in designing specific machines and analyzing the behavior of the product while handling the material. Size and shape are important parameters for conveying the materials and also important for problems related to stress distribution in the material under load. Axial dimensions help in designing the sieve size for the separation of neem pulp and seed. Accurate estimates of areas are essential in the determination of terminal velocity, drag coefficient, and Reynolds number. For effective separation, sorting, and grading, surface color is a valuable physical parameter True density, porosity, and bulk density help in determining the capacity of the machine.

Axial dimensions

Hundred neem fruits and seeds (at different moisture content) were selected randomly. Using a vernier caliper having a least count of 0.01 mm, the length (major dimension), width (intermediate dimension), and thickness (minor dimension) were measured for each neem fruit and seed as specified by [4, 11].

Arithmetic mean diameter

The ratio of the sum of all the three linear dimensions (Length, Width, and Thickness) and the total number of linear dimensions gives the Arithmetic mean diameter. The arithmetic means diameter of the neem fruits and seeds was calculated using the measured length (X), width (Y), and thickness (Z) from equation (2) as stated by . Sharifi et al., [24].

$$A_{MD} = \frac{X + Y + Z}{3} \quad \text{.........................} (2)$$

where, A_{MD} denotes arithmetic mean diameter in mm, X denotes the length in mm, Y denotes the width in mm, Z denotes the thickness in mm.

Geometric mean diameter

The geometric mean diameter for neem fruits and seeds was calculated from the determined length (X), width (Y) and thickness (Z) using equation (3) as suggested by Nde et al., [4].

$$G_{MD} = (XYZ)^{1/3} \quad \text{.........................} (3)$$

where, G_{MD} signifies geometric mean diameter (mm), X, Y, and Z signifies the length, width, and thickness in mm.

Equivalent mean diameter

The equivalent means diameter for neem fruits and seeds was determined using the length (X), width (Y), and thickness (Z) from equation (4) as given by Gholami et al., [25].

$$E_D = \left[[\frac{X(Y + Z)}{4}]^{1/2} \right] \quad \text{.........................} (4)$$

where, E_D indicates equivalent diameter (mm), X indicates length, Y indicates width and Z indicates thickness in mm.

Sphericity

Sphericity measures the shape of the food material. The ratio of the geometric mean diameter and the length gives the sphericity. It was obtained using equation (5) as revealed by Adedeji and Owolarafe [12].

$$S_p = \frac{(XYZ)^{1/3}}{Z} \quad \text{.........................} (5)$$

where, S_P, X, Y, Z symbolizes sphericity in %, length, width, and thickness in mm.

Aspect ratio

The ratio of the width to the length of the sample gives the Aspect ratio. It was obtained by using equation (6) as given by Owolarafe and Shotonde [26].

$$A_R = \frac{Y}{X} \quad \text{.........................} (6)$$

where, A_R means aspect ratio (%), X means length (mm), Y means width (mm).

Surface area and volume

The surface area and volume were calculated by using geometric mean diameter from equations (7) and (8) as declared by Nde et al., [4].

$$S_A = \pi (G_{MD})^2 \text{ .... } (7)$$

$$V = \pi (G_{MD})^3 \text{ .... } (8)$$

where, S_A implies surface area in mm², V implies volume in mm³, GMD implies geometric mean diameter in mm

Frontal surface area

Frontal surface area is the representation of a solid object if cut by an intersecting plane. The frontal surface area (FSA) of samples was determined by using equation (9) as proposed by Mohsenin [27].

$$F_{SA} = \pi \frac{\pi}{4} XY \text{ .... } (9)$$

where, F_{SA} is the frontal surface area in mm², X and Y are the length and width of the samples in mm.

Cross sectional area

Cross sectional area is the area of the section made by a plane cutting an object transversely at right angles to the longest axis. The cross-sectional area of the samples was determined using equation (10) as cited by Mohsenin [27].

$$C_{SA} = \frac{\pi}{4\,x\,9} (\mathrm{X} + \mathrm{Y} + \mathrm{Z})^2 \text{ .... } (10)$$

where, C_{SA} embodies cross sectional area (mm2), X, Y and Z denotes length, width, and thickness in mm.

Shape index

The ratio of the width and root of the product of length and thickness gives the shape index. The shape index was determined by using equation (11) as given by Mohsenin [27].

$$S_I = Y \sqrt{X\ Z} \text{ .... } (11)$$

where, S_I signifies shape index in mm², X is length (mm), width (mm) and thickness (mm).

One thousand mass

One hundred neem fruits and neem seeds were weighed using the digital weighing balance with the least count of 0.001 g and it is repeated ten times using random samples for getting the average value of weight. To obtain the thousand-unit mass of the neem fruits and seeds, the average weight obtained was multiplied by ten following the procedure mentioned by Nde et al., [4].

Bulk density

The samples were filled in a cylindrical and rectangular container without any compaction. The weight of the samples was measured using a digital weighing balance with the least count of 0.001g and the volume of the container was also determined. The 20 trials were repeated and the average value was taken for calculating the bulk density from equation (12) as stated by Solanki et al., [9].

$$B_D = \frac{x}{y} \quad \text{.......................... (12)}$$

where, B_D represents bulk density in kg m^{-3}, x represents the weight of the sample in kg, y represents the volume of the container in m^3.

True density

By using the toluene displacement method, the true density of the samples was determined Sacilik et al., [28] . The 20 trials were repeated and the average value was taken for determining the true density of the samples using equation (13) as stated by Solanki et al., [9].

$$T_D = \frac{x}{y} \quad \text{.......................... (13)}$$

where, T_D indicates true density (kg.m^{-3}), x is the mass of neem seed in kg and y is the volume of toluene displaced by the sample (m^3).

Porosity

By using bulk density and true density values, the porosity of the samples was calculated from equation (14) as specified by Nde et al., [4].

$$P_O = (1 - \frac{B_D}{T_D}) \text{ x } 100 \quad \text{.......................... (14)}$$

where, P_0 implies porosity in %, BD represents bulk density in kg m^{-3} and TD indicates true density (kg/m^{-3}).

Color

The Color of the fresh and dry samples was determined by using Lovibond Tintometer (Lovibond, LC 100, The Tintometer Ltd, UK). The values of Lightness (L*), redness to greenness (±a*), yellowness to blueness (b*), Chroma (c*), hue angle (h*), and ΔE were measured for the samples.

Frictional properties

Frictional properties like the coefficient of friction and angle of repose are important for designing the equipment for flow and storage structures. It is an essential engineering property for designing storage bins, hoppers, screw conveyors, etc. Knowledge of frictional properties is important because frictional losses may result in additional power requirements for the machine.

Coefficient of static friction

The coefficient of static friction for neem fruits and seeds was determined for different surfaces like a rubber sheet, cardboard, stainless steel, and galvanized iron steel. The setup consists of a hollow cylindrical container (90 mm x 80 mm x 80 mm) connected to a frictionless pulley fitted on a frame with a thread mechanism having a loading pan. The known weight of samples was filled in the bottomless cylindrical container without any compaction placed on a different surface. Weight was added at the loading pan and the final weight at which the cylindrical container slides on the surface is noted. The coefficient of static friction was measured as per the procedure and equation (15) stated by Sasikumar et al., [29].

$$\mu = \frac{F_A}{W_G} \text{ .... } (15)$$

where, μ represents the coefficient of friction, F_A represents the force applied (kg), WG represents the weight of the grain (kg).

Angle of repose

The angle of repose of neem fruits and seeds was measured using an apparatus consisting of a cylindrical container with a discharge port at the bottom and a circular steel plate having a diameter of 20 cm. The fruits and seeds were filled in the cylindrical container and then allowed to fall vertically on the circular plate to form an inverted cone. The experiment was repeated 5 times to get the average height and radius of the cone. The angle of repose was measured as per the procedure and equation (16) given by Solanki et al., [9].

$$\theta = \tan^{-1}(\frac{h}{r}) \text{ .... } (16)$$

where, θ, h, and r stand for the angle of repose, height, and radius of the cone (mm).

Mechanical properties

Mechanical properties are necessary engineering data for studying the product resistance to cracking during handling conditions and can be used to determine the best method for the breakup (shear, impact, or static crushing). It gives knowledge on understanding the energy requirements and process of the machine.

Compressive strength

The ASTM standard was used to test the Compressive strength of the samples. The compressive strength was measured using a Universal testing machine (Model: UNITEX 9410, Fuel Instruments & Engineers Pvt. Ltd, Maharashtra, India) with a crosshead speed of 5 milliseconds. The force-displacement curve was drawn and the peak compressive force was obtained by Jahanbakhshi et al., [30].

Aerodynamic properties

Aerodynamic properties are important characteristics in hydraulic sorting, transport, and handling of products. It is needed for the separation of foreign materials and the processing of agricultural products.

Terminal velocity

The equivalent diameter and shape factor were determined to calculate the terminal velocity. Terminal velocity was theoretically calculated using equations (17) and (18) as proposed by Gursoy and Guzel, and Ndeet al., [31-32].

$$T_V = \frac{4\,g\,ED\,TD_S\,(6S/\pi)}{3\,TD_A \text{ x } 0.44} \text{ .... } (17)$$

$$S = \frac{\pi}{6}(\frac{ED}{G_{MD}})^3\,S_p \text{ .... } (18)$$

where, T_V signifies terminal velocity (m s^{-1}), S, S_p represents shape factor and sphericity (%), TD_S, TD_A denotes the true density of the sample and air in kg m^{-3}, GMD signifies geometric mean diameter (mm), ED is the equivalent diameter (mm), g is the acceleration due to gravity (m s^{-1}).

Statistical analysis

All the experiments were conducted thrice and the average values were reported as mean ± standard deviation. The best relationships between moisture content and engineering properties of neem seeds were calculated using regression and correlation analysis were found using Microsoft Excel Software (2019). The data were statistically analyzed at $p < 0.01$ using SPSS 2020 software (IBM Corporation, New York, USA). ANOVA, Correlation, and Regression Analysis of Neem Seeds at Different Moisture Content are shown in Table 1.

Results and Discussion

Engineering properties of fresh and dry neem fruits and seeds are given in Tables 1 and 2 (Tables 2 and 3).

Moisture content

The initial moisture content of the fresh neem fruits, dry neem fruits, and fresh neem seeds was found to be 38, 15, and 30% w.b respectively. Drying resulted in a decrease in the moisture content of the samples. Similar studies with a different moisture content of neem seeds were reported by Solanki et al., [11].

Physical Properties

One thousand mass

The average one thousand mass of the dry and fresh neem fruits were 720 ±20.086 and 1200 ± 16.97 g with an increase of 66.66%. Similarly, for dry and fresh neem seeds, the values were 276.7± 9.034 and 460± 10.642 g with an increase of 66.24% and showed a regression coefficient of 0.8477. The difference in mass was due to the high moisture content in fresh fruits and seeds followed by low in dried ones. The average values of fresh neem fruits were lower and the values of fresh neem seeds were higher than the values (1569 ± 84.18 and 309.10 ± 3.65g for fresh neem fruit and seed) reported by Nde et al., [4]. The values of fresh neem fruits were higher than the values (597.80 ± 15.88 g) mentioned by Adedeji and Owolarafe [12]. Similar trends in the variation of one thousand mass were stated by Visvanathan et al., [13].

Axial dimensions

The level of significance, correlation, and regression coefficients ranged between 0 to 0.1%, -0.269 to 0.617, and 0.8477 to 0.9209 for mean linear axial dimensions (length, width, and thickness) of neem seeds at different moisture content. Linear axial dimensions of dry and fresh neem fruits were (12.1 (11.95 to 12.8), 8.45 (8.00 to 9.01) and 8.15 (8.09 to 8.28)) mm, and (12.4 (11.54 to 12.56), 8.74 (8.24 to 9.24) and 8.35 (8.28 to 8.42)) mm. It showed an increase of 2.48% in length, 3.43% in width, and 2.45% in thickness. Correspondingly for dry and fresh neem fruits, the values were (17.55 (16.91 to 18.41), 9.71 (8.99 to 10.57) and 9.07 (8.29 to 9.87)) mm, and (18.10 (13.59 to 20.5), 12.63 (8.05 to 14.68) and 12.18 (7.95 to 14.23)) mm respectively with an increase of 3.13% in length, 30.07% in width and 34.29% in thickness. It is observed that moisture content is directly proportional to the axial dimensions. The mean length values were higher and mean width and thickness values were lower for fresh neem fruits when compared with the values (17.66 and 13.18 mm) given by Solanki et al., and Kureel et al., [11, 14]. All three axial dimensions of fresh neem fruits were higher than the

Table 1. ANOVA, Correlation and regression analysis of Neem seeds at different moisture content

Properties	Correlation			pr(>f)	Regression Analysis
	Correlation B/W				
	AB	BC	CA		
L, mm	0.08724	-0.26926	0.17654	0.0154 *	y = -0.143x + 12.564, R^2 = 0.8477
W, mm	-0.0327	-0.11218	0.43000	0.119	y = -0.144x + 8.8767, R^2 = 0.9923
T, mm	0.61746	-0.06383	0.07030	2.37e-09***	y = -0.0995x + 8.4327, R^2 = 0.9209
A_{MD}, mm	-0.2548	-0.03665	0.50338	0.0014 **	y = -0.1288x + 9.9578, R^2 = 0.9976
G_{MD}, mm	-0.2054	-0.03339	0.5608	0.00164 **	y = -0.1286x + 9.7957, R^2 = 1
E_D, mm	-0.2163	-0.03042	0.51510	0.00186 **	y = -0.5971x + 30.668, R^2 = 1
S_P, %	0.53420	-0.20722	-0.1536	0.359	y = -0.1536x + 78.009, R^2 = 0.1356
S_A, mm^2	-0.2099	-0.04026	0.51641	0.00166 **	y = -8.4x + 302.96, R^2 = 0.9926
V, mm^3	-0.2180	-0.03471	0.51802	0.00168 **	y = -110.3x + 2948.3, R^2 = 1
A_R, %	0.4298	-0.18304	0.12919	<2e-16 ***	y = -0.3721x + 70.709, R^2 = 0.402
F_{SA}, mm^2	-0.2597	-0.10624	0.69785	0.0198 *	y = -2.3513x + 87.501, R^2 = 0.9854
C_{SA}, mm^2	-0.2053	-0.04924	0.67372	0.00142 **	y = -1.9635x + 77.812, R^2 = 0.9979
S_I, mm^2	-0.1704	-0.0676	0.48318	0.011 *	y = -2.4692x + 91.308, R^2 = 0.9991
One thousand mass, g	**Level of significance**				y = -0.143x + 12.564, R^2 = 0.8477
Bulk Density, kgm^{-3}	() - 0.1 (*) - 0.01				y = -14.561x + 197.09, R^2 = 0.7982
True Density, kgm^{-3}	(**) - 0.001 (***) – 0				y = -11x + 756.14, R^2 = 0.4515
Porosity, %	A – Fresh seeds 30% m.c (w.b)				y = 1.62x + 73.893, R^2 = 0.8751
Bulk Density, kgm^{-3}	B – Dried seeds at 20% m.c (w.b)				y = -18.748x + 370.58, R^2 = 0.9424
True Density, kgm^{-3}	C – Dried seeds at 10% m.c (w.b)				y = -11x + 756.14, R^2 = 0.4515
Porosity, %					y = 1.87x + 50.888, R^2 = 0.6387
Angle of repose					y = -1.125x + 33.333, R^2 = 0.7932
Rubber sheet					y = -0.005x + 0.2233, R^2 = 0.75
Cardboard					y = -0.005x + 0.3633, R^2 = 0.75
Stainless steel					y = 0.0025x + 0.3033, R^2 = 0.75
Galvanized iron steel					y = 0.0065x + 0.309, R^2 = 0.8622
Compressive strength, N					y = 34.335x + 4.905, R^2 = 1
Terminal velocity, m/s					y = -3.325x + 117.42, R^2 = 0.8515

values (14.89 ± 1.24, 9.22 ± 1.05, and 8.95 ± 0.98 mm) mentioned by Adedeji and Owolarafe [12]. The mean axial dimensions of neem seeds were lower when related to the values (length and major diameter of 12.84 to 14.01 and 7.57 to 9.01 mm) as specified by Solanki et al., [11]. Similar interpretations of a decrease in axial dimensions with the decrease in moisture content were given by Visvanathan et al., and Nde et al., [13, 32]. The axial dimensions ranged from 17.66 to 12.84 mm for neem fruits and seeds as reported by Solanki et al., [11]. Graphical representations of axial dimensions are mentioned in figure 2.

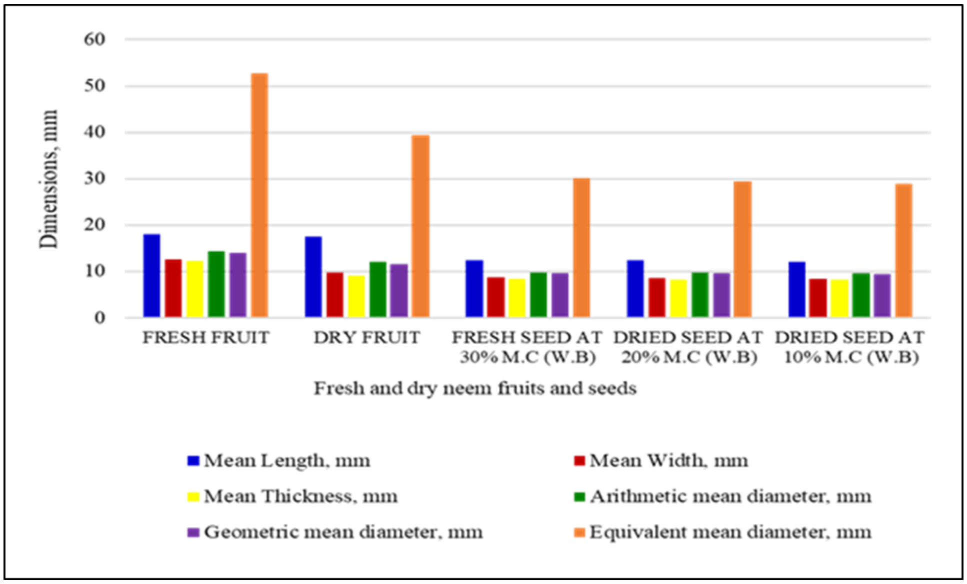

Figure 2. Dimensions of fresh and dry Neem fruits and seeds

Arithmetic mean diameter

The arithmetic means diameter showed a 0.001% level of significance with a -0.254 to 0.503 correlation and 0.9976 regression coefficient for dry and fresh neem seeds with the values of 9.57 (9.36 to 10.02) mm and 9.82 (9.52 to 10.02) mm showing an increase of 2.61 %. Likewise, for dry and fresh neem fruits, the values were 12.11 (11.5 to 12.44) mm and 14.30 (9.86 to 16.47) mm showing an increase of 18.08 %. The values obtained were higher than the values (11.02 ± 1.02 & 10.60 to 14.90 mm) for fresh neem fruits as mentioned by Nde et al., and Adedeji and Owolarafe [4, 12].

Geometric mean diameter

Dry and fresh neem fruits had a geometric mean diameter of 11.55 mm (10.90 to 11.93 mm) and 14.07 (9.54 to 16.24) mm with an increase of 21.82 %. Equally, for fresh and dry neem seeds, the values ranged between 9.41 (9.21 to 9.84) mm and 9.66 (9.42 to 9.87) mm with an increase of 2.66%. The level of significance, correlation, and regression coefficient was found to be 0.001%, -0.205 to 0.560 and 1. The values (10.70 ± 1.03 & 10.29 to 14.45 mm) reported by Nde et al., and Adedeji and Owolarafe [4, 12] were higher than the values obtained.

Equivalent mean diameter

The values of 39.32 (36.02 to 41.3) mm and 52.77 (29.49 to 65.44) mm with an increase of 34.29 % were obtained for equivalent mean diameter of the dry and fresh neem fruits. Correspondingly for fresh and dry neem seeds, the values were 28.87 (27.98 to 30.89) mm and 30.07 (28.94 to 31.08) mm with an increase of 4.16% which showed a 0.001% level of significance with the correlation of -0.216 to 0.515 and regression coefficient of 1.

Table 2. Engineering properties of fresh and dry neem fruits

Properties	Fresh neem fruits		Dry neem fruits	
	Mean	CV (%)	Mean	CV (%)
Physical properties				
Length, mm	18.10 ± 1.033	5.707	17.55 ± 0.511	2.916
Width, mm	12.63 ± 0.929	7.356	9.707 ± 0.524	5.399
Thickness, mm	12.18 ± 0.968	7.947	9.066 ± 0.591	6.525
Arithmetic mean diameter, mm	14.30 ± 0.658	4.601	12.11 ± 0.308	2.545
Geometric mean diameter, mm	14.07 ± 0.649	4.613	11.55 ± 0.336	2.916
Equivalent mean diameter, mm	52.77 ± 3.392	6.428	39.32 ± 1.700	4.323
Sphericity, %	77.7 ± .041	5.277	65.830 ± 2.199	3.340
Surface area, mm^2	621.92 ± 0.970	0.156	419.267 ± 24.202	5.772
Volume, mm^3	8750.48 ± 3.040	0.0347	4850.243 ± 415.580	8.568
Aspect ratio, %	69.8 ± 0.049	7.020	55.294 ± 3.882	7.021
Frontal surface area, mm^2	179.54 ± 19.149	10.665	133.701 ± 6.820	5.101
Cross sectional area, mm^2	160.68 ± 12.440	7.742	115.176 ± 5.8071	5.041
Shape index, mm^2	187.53 ± 15.877	15.877	122.365 ± 7.388	6.038
Moisture content, % (w.b)	38		15	
One thousand mass, g	1200 ±16.971		720 ± 20.086	
Bulk Density, kg/m^{-3}	659.84		350.30	
True Density, kg/m^{-3}	929.33		666.66	
Porosity, %	28.99		47.455	
Frictional properties				
Angle of repose	42.80		34.38	
Coefficient of friction				
A) Rubber sheet	0.65		0.667	
B) Cardboard	0.86		0.783	
C) Stainless steel	0.70		0.733	
D) Galvanized iron steel	0.76		0.764	
Mechanical properties				
Compressive strength, N	264.87		412.02	
Aerodynamic properties				
Terminal velocity, m/s	223.16		130.55	

Sphericity

An increase of 18.03 % of Sphericity was obtained for dry and fresh neem fruits with values of 65.83(63.242 to 69.31) % and 77.7 (70.24 to 79.22) %. Similarly, fresh and dry neem seeds showed values of 77.7 (76.17 to 78.93) % and 78.07 (75.74 to 81.68) % with an increase of 0.48%. It showed a correlation and regression coefficient of -0.20722 to 0.5342 and 0.1356 with a 0.1% level of significance. Results showed parallel trends of variations of moisture content with sphericity as seen in fenugreek seeds (*Trigonellafoenum-graceum* L.) mentioned by Altuntaş et al., [33]. The value (71.91 ± 3.46% for fresh neem fruits) given by Adedeji and Owolarafe [12] was lower than the value obtained.

Surface area

The correlation value of -0.209 to 0.5164 was obtained for the surface area of the dry and fresh neem seeds with values of 278.10 (266.77 to 304.04) mm^2 and 293.50 (279.01 to 306.41) mm^2 showing an increase of 5.54% with 0.001% level of significance, -0.2099 to 0.5164 correlation and 0.9926 regression coefficient. Dry and fresh neem fruits with values of 419.26 (373.08 to 446.92) mm^2 and 621.92 (286.2 to 828.5) mm^2 showed an increase of 48.33 %. The values were higher than the values of fresh neem fruits and seeds (332.70 to 665.97 and 117.06 to 279.14 mm^2) reported by Nde et al., [4].

Volume

The level of significance, correlation, and regression coefficient of 0.001%, -0.218 to 0.518, and 1 were obtained for the volume of the dry and fresh neem seeds with the values of 2617.87 (2458.97 to 2991.78) mm^3 and 2838.48 (2629.99 to 3026.93) mm^3 an increase of 8.42%. Likewise, for dry and fresh neem fruits, the values were 4850.24 (4066.69 to 5331.9) mm^3 and 8750.5 (2731.98 to 13455.75) mm^3 with an increase of 80.41%.

Aspect ratio

The Aspect ratio of the dry and fresh neem fruits was 55.29 (49.36 to 61.32) % and 69.8 (59.23 to 71.61) % with an increase of 26.24 %. Correspondingly, dry and fresh neem seeds showed an increase of 1.07% with values of 69.85 (66.11 to 73.25) % and 70.6 (65.76 to 74.69) % having a correlation and regression coefficient of -0.183 to 0.429 and 0.402 with no significance. The value obtained for fresh neem fruits was higher than the value (61.94 ± 4.68 %) mentioned by Nde et al., [4].

Frontal surface area

The Frontal surface area of the dry and fresh neem fruits had a correlation and regression coefficient of -0.259 to 0.697 and 0.9854 with a 0.01% level of significance with the values of 133.70 (121.47 to 143.79) mm^2 and 179.54 (85.92 to 236.3) mm^2 with an increase of 34.29 %. In the same way for dry and fresh neem seeds, the values were 80.28 (75.99 to 90.33) mm^2 and 84.98 (78.08 to 90.09) mm^2 with an increase of 5.85%.

Cross sectional area

Dry and fresh neem fruits had Cross-sectional area of 115.18 (103.81 to 121.54) mm^2 and 160.68 (76.41 to 213.05) mm^2 with an increase of 39.50 %. Similarly, an increase of 47% was observed for dry and fresh neem seeds with the values of 71.86 (69.31 to 78.86) mm^2 and 75.79 (71.24 to 78.81) mm^2 having a 0.001 % level of significance followed by a correlation and regression coefficient of -0.205 to 0.673 and 0.9979.

Shape index

The correlation and regression coefficient of -0.170 to 0.483 and 0.9991 were obtained for the shape index of the dry and fresh neem seeds with values of 83.94 (79.15 to 92.55) mm^2 and 88.88 (83.93 to 94.38) mm^2 showing an increase of 5.88% with 0.01% level of significance. Dry and fresh neem fruits with values of 122.36 (108.38 to 133.97) mm^2 and 187.53 (83.67 to 250.7) mm^2 showed an increase of 53.16 %.

Table 3. Engineering properties of neem seeds at different moisture content

Properties	Fresh seeds at 30% (w.b)		Dried seeds at 20% (w.b)		Dried seeds at 10% (w.b)	
	Mean	CV (%)	Mean	CV (%)	Mean	CV (%)
Length, mm	12.386 ± 0.30	2.427	12.34 ± 0.2242	1.816	12.1 ± 0.08	0.710
Width, mm	8.74 ± 0.280	3.2095	8.574 ± 0.317	3.698	8.45 ± 0.30	3.591
Thickness, mm	8.35 ± 0.046	0.556	8.2 ± 0.050	0.616	8.15 ± 0.04	0.602
Arithmetic mean diameter, mm	9.825 ± 0.142	1.445	9.707 ± 0.157	1.626	9.56 ± 0.11	1.231
Geometric mean diameter, mm	9.667 ± 0.137	1.420	9.538 ± 0.157	1.651	9.41 ± 0.12	1.375
Equivalent mean diameter, mm	30.070 ± 0.64	2.1599	29.472 ± 0.740	2.514	28.8 ± 0.60	2.090
Sphericity, %	78.079 ± 1.60	2.06	77.254 ± 1.059	1.371	77.7 ± 1.09	1.408
Surface area, mm^2	293.50± 8.31	2.834	285.74 ± 9.46	3.313	278.1 ± 7.6	2.752
Volume, mm^3	2838.4 ± 120.3	4.241	2726.86 ± 135.99	4.987	2617.874± 108.17	4.132
Aspect ratio, %	70.59 ± 0.274	3.88	69.4 ± 0.023	3.428	69.8 ± 0.02	3.648
Frontal surface area, mm^2	84.98 ± 3.558	4.186	83.129 ± 3.949	4.751	80.2 ± 2.95	3.677
Cross sectional area, mm^2	75.79 ± 2.178	2.874	73.989 ± 2.418	3.268	71.8 ± 1.77	2.465
Shape index, mm^2	88.88 ± 3.207	3.608	86.285 ± 3.674	4.259	83.9 ± 3.22	3.837
Moisture content, % (w.b)	30		20		10	
One thousand mass, g	460 ±10.64		350 ± 5.71		276.7 ± 9.03	
Bulk Density, kg/m^{-3}	186.76		159.520		157.639	
True Density, kg/m^{-3}	752.14		720.14		730.14	
Porosity, %	75.16		77.84		78.40	
Using rectangular container,						
Bulk Density, kg/m^{-3}	349.15		338.432		311.653	
True Density, kg/m^{-3}	752.14		720.14		730.14	
Porosity, %	53.57		53.004		57.31	
Frictional properties						
Angle of repose, ∘	32.54		30.42		30.29	
Coefficient of friction,						
A) Rubber sheet	0.22		0.21		0.21	
B) Cardboard	0.36		0.35		0.35	
C) Stainless steel	0.305		0.31		0.31	
D) Galvanized iron steel	0.314		0.325		0.327	
Mechanical properties						
Compressive strength, N	39.24		73.575		107.91	
Aerodynamic properties						
Terminal velocity, m/s	114.90		109.17		108.25	

Bulk density

The average bulk density of dry and fresh neem fruits was 350.30 and 659.84 kg/m^{-3}. It showed an increase of 88.36% in BD. Correspondingly for dry and fresh neem seeds having a regression coefficient of 0.7982, the values were 157.64 and 186.76 kg/m^{-3} with an increase of 18.47% in BD. The values of bulk density for fresh neem fruits and seeds were higher than the values (633 and 240 kg/m^{-3} for fresh neem fruits and seeds) given by . Solanki et al., [11]. The values were higher for fresh neem fruits and lower for fresh neem seeds when compared to the values (628.06 and 572.88 kg/m^{-3}) reported by Nde et al., [4]. Density values play a vital role in designing silos and in grading neem of seeds Taser et al., [34].

True density

An increase of 39.40% was obtained for the average true density of dry and fresh neem fruits with values of 666.66 and 929.33 kg/m^{-3}. Also for dry and fresh neem seeds with a 0.451 regression coefficient, the values were 720.14 and 752.14 kg/m^{-3} with an increase of 4.44%. Fresh neem fruits and seeds showed more true density than dry neem fruits and seeds due to an increase in moisture content and size. The true density of fresh neem fruits was lower than values (980 and 581 kg/m^{-3}) for fresh neem fruits and seeds) reported by Solanki et al., [11]. The value (1085.50 kg/m^{-3}) mentioned for fresh neem seeds by Nde et al., [4] was higher than the values obtained.

Porosity

It showed a decrease of 63.67% in porosity when comparing the values of 47.45 and 28.99% for dry and fresh neem fruits. The average porosity of dry and fresh neem seeds was 78.40 and 75.16% with a decrease of 4.31% and showed a regression coefficient of 0.8751. The porosity of fresh neem fruits was lower and fresh neem seeds were higher than the values (35.4 and 58.7 % for fresh neem fruits and seeds) stated by Solanki et al., [11] and similar trends of variations of increase in porosity with the decrease in moisture content was reported by Nde et al., [4].

Color

Table 4 represents the color value of fresh and dry neem fruits and seeds. The dry and fresh neem fruits showed color value L*, a*, b*, c*, h* and ΔE) of (16.0, 3.0, 3.2, 4.3, 46.5 and 84.1) and (43.7, 9.9, 26.7, 28.4, 69.6 and 63.1) with an increase of 173.12% in L*, 230% in a*, 734.37% in b*, 560.46% in c*, 50.77% in h* and decrease of 33.28% in ΔE. Similarly, for dry and fresh neem seeds, the values were (29.3, 5.7, 10.1, 11.6, 60.8, and 79.3) and (37.3, 9.3, 24.7, 26.4, 69.36, and 68.0) with an increase of 27.30% in L*, 63.16% in a*, 144.55% in b*, 127.59% in c*, 14.08% in h* and decrease of 16.62% in ΔE. A decrease in color value was due to the drying. A graphical representation of color value is given in figure 3.

Table 4. Color value of fresh and dried Neem seeds

Samples	L*	a*	b*	c*	h*	ΔE
Fresh fruits	43.7	9.9	26.7	28.4	69.6	63.1
Dry fruits	16.0	3.0	3.2	4.3	46.5	84.1
Fresh seeds 30% m.c (w.b)	37.3	9.3	24.7	26.4	69.3	68.0
Dried seeds at 20% m.c (w.b)	23.3	11.4	17.0	17.0	20.5	56.2
Dried seeds at 10% m.c (w.b)	29.3	5.7	10.1	11.6	60.8	79.3

Frictional properties
Angle of repose
An increase of 24.49% was observed for dry and fresh neem fruits with the value of 34.38 and 42.80. Likewise, for dry and fresh neem seeds, the values were 30.29 and 32.54 with an increase of 7.43% followed by a regression coefficient of 0.7932. The values of fresh neem fruit were higher than the values of fresh neem seed which stated that slopes for feeding units should be more for depulping units when compared to decorticator. The angle of repose of neem fruits was closely similar to the values (40.32 and 37.53 for fresh neem fruits and seeds) given by Solanki et al., [11].

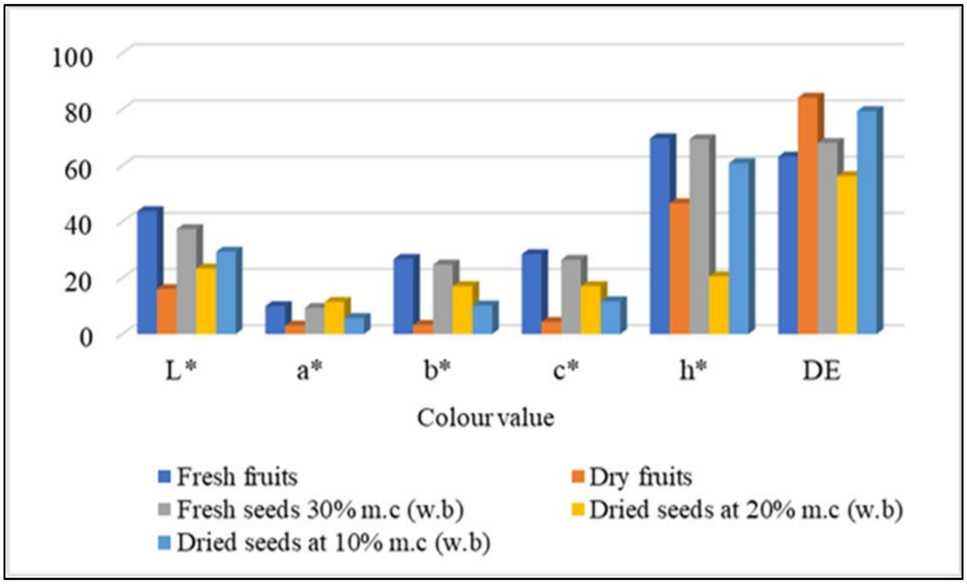

Figure 3. Colour value of fresh and dry Neem fruits and seeds

Coefficient of friction
The highest coefficient of friction value for dry and fresh neem fruits was found on cardboard surfaces (0.78 and 0.86) followed by galvanized iron steel (0.76 and 0.76), stainless steel (0.73 and 0.70), and rubber sheets (0.67 and 0.65) respectively. Similarly, for fresh and dry neem seeds a negligible change in the coefficient of friction was obtained at all the surfaces with regression coefficients ranging between 0.75 to 0.862. An increase in the coefficient of friction was observed while the increase in moisture content and increase in moisture weight might be a reason. Similar studies done by Solanki et al., [11] reported the highest coefficient of friction for wood followed by aluminum.

Mechanical properties
The compressive strength of dry and fresh neem fruits was 412.02 and 264.87 N respectively with a decrease of 55.55%. The dry neem seeds recorded the highest compressive strength of 107.91 N compared to fresh neem seeds with 39.24 N with a 175% decrease with a regression coefficient of 1. Dry neem fruits and seeds had more compressive strength than fresh neem fruits and seeds. Results were observed higher for fresh and dry neem seeds (20.5 and 14.7N) as reported by Solanki et al., [11].

Aerodynamic properties
The fresh neem fruits registered a terminal velocity of 223.16 m s^{-1}, whereas it was found to be 130.55 m s^{-1} for dry neem fruits. In the same way, fresh neem seed had the highest terminal velocity

of 114.90 m s^{-1} than dry neem seed (108.25 m s^{-1}) with 0.851 as the regression coefficient. The mean values were higher than the values reported by Solanki et al., [11] as the formula method was used to calculate the terminal velocity for dry and fresh neem seeds.

Conclusion

The engineering properties of neem seeds and fruits were evaluated as a function of the moisture content, in the range of 10% to 30% w.b. The principal dimensions of seeds (length, width, and thickness), arithmetic mean diameter, geometric diameter, surface area, volume, equivalent mean diameter aspect ratio, frontal surface area, cross sectional area, shape index, bulk density, true density, angle of repose and terminal velocity decreased linearly as increasing the seed moisture content. An increase in moisture content yields a decrease in bulk and true density.

The coefficient of friction, porosity, and compressive strength increases with an increase in moisture content, it could be attributed to the seeds' morphological and physiological characteristics. The color value of neem seeds decreased as the moisture content decreased and this was due to the drying. The comparison of the data of the seeds at different moisture content can be important for the design and adaptation of equipment for transporting, storage, and processing.

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