PHYSICAL PROPERTIES OF NEEM (*AZADIRACHTA INDICA*) SEEDS AND KERNELS RELEVANT IN THE DESIGN OF PROCESSING MACHINERIES

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Abstract

This study was undertaken to determine some physical properties of neem seeds and kernels such as axial dimensions, true density, bulk density, surface area, sphericity, moisture content, coefficient of friction, angle of repose and porosity that are relevant in the design of processing machineries. Results shows that the seeds and kernels have major, intermediate and minor diameter values of 13.64$\pm$1.15 mm, 6.80$\pm$0.41 mm and 5.54$\pm$0.44 mm and 9.32$\pm$1.13 mm, 4.32$\pm$0.63 mm and 3.38$\pm$0.35 mm respectively. The true density, bulk density, surface areas and the sphericity determined were 379.00$\pm$15.16 kg/m^3, 39.293$\pm$0.001 kg/m^3, 169.93$\pm$31.15 mm^2, 0.64$\pm$0.043 for the seed while for the kernel were 930.03$\pm$8.53 kg/m^3, 534.89$\pm$10.99 kg/m^3, 70.63$\pm$13.98 mm^2, 0.61$\pm$0.044 respectively at an average moisture content of 13.80 % for the seed and 11.9 % for the kernel on wet basis. The coefficient of friction determined on three different structural surfaces namely plywood, glass and mild steel for the seeds were 0.38, 0.42 and 0.33 respectively at an angle of repose of 34.52^o while that of the kernels were 0.49, 0.56 and 0.43 respectively at an angle of repose of 42.47°. The mean porosity obtained for the seed and kernel were 89.62 % and 42.47 % respectively.

Keywords: Diameter of Neem seeds and kernels, angle of repose, density (true and bulk), sphericity, porosity

1. Introduction

Neem (*azadirachta indica)* is an evergreen tree native to Asia, and tropical regions of Australia and Africa (Visvanathan et al., 1996). It belongs to the mahogany family (*meliacease*) and also one of the two species in the genus *Azadirachta*. The fruit is smooth olive-like drupe which varies in shape from elongated to oval to nearly roundish, its exocarp is thin and the bitter sweet pulp (mesocarp) is yellow-white and very fibrous having thickness between 0.3 - 0.5 cm, the white hard inner shell endocarp enclose one, rarely two or three elongated seed (kernels) having a brown seed coat that contain between 25 - 45 % neem oil. Neem is a large tree growing to about 25 m in height with semi-straight to straight trunk, 3 m in trunk and spreading branches forming a broad crown, starts fruiting after 3-5 years of planting. From the tenth year onwards it can produce up to 50 kg of fruits annually (Shruthi and Rahul, 2013). Orwa *et al.* (2009) reported that neem is a small to medium-sized tree, usually evergreen, up to 15 - 30 m tall, with a round, large crown up to 10 - 20 m in diameter; branches spreading; bole branchless for up to 7.5 m, up to 90 cm in diameter, sometimes fluted at base; bark moderately thick, with small, scattered tubercles, deeply fissured and flaking in old trees, dark grey outside and reddish inside, with colourless, sticky sap.

Neem, commonly referred to as ‘dogonyaro’ in Nigeria, is a plant that has found various uses in ecological, medicinal and agricultural sectors. Biological and pharmacological activities attributed to different parts and extracts of these plants include antiplasmodial, antitrypanosomal, antioxidant, anticancer, antibacterial, antiviral, larvicidal and fungicidal activities (Sunday and Atawody, 2009). Shruthi and Rahul (2013) reported that the neem tree has adaptability to a wide range of climatic and topographic factors. It thrives well in dry, stony shallow soils and even on soils having hard calcareous or clay pan, at a shallow depth. Neem tree requires little water and plenty of sunlight and rainfall in the range of 450 to 1200 mm with wide temperature range of 0 °C to 49 °C. However, it has been introduced successfully even in areas where the rainfall is as low as 150 to 250 mm. It grows on almost all types of soil including clayey, saline and alkaline soil, but does well on black cotton soils and deep well drained soil with good sub-soil water.

Mordue and Alasdair (2000) reported that neem tree is now grown in most tropical and sub-tropical parts of the world for shade, for reforestation programmes and in plantations for the production of compound which have toxic, anti-feedant and repellent properties against insects. According to Subbalakshmi *et al.* (2012) neem can be propagated easily by seed, or 9 to 12 month-old neem seedlings can also be transplanted. Fresh fruit yield per neem tree ranges between 37 and 50 kg per year. Forty kg fruit yields nearly 24 kg of dry fruit (60 %), which in turn gives 11.52 kg of pulp (48 %), 1.1 kg of seed coat (4.5 %), 1 kg of husk (25 %) and 5.5 kg of kernel (23 %). The kernel gives about 2.5 kg of neem oil (45 %) and 3.0 kg of neem cake (55 %). Subbalakshmi *et al.* (2012) also reported that neem is known today as a natural product which has much to offer in solving global agricultural, environmental and public health problems of which researchers worldwide are now focusing on the importance of neem in the agricultural industry. The magical tree and hundreds of its active compounds are used to manufacture a number of products. Natural properties of neem do not have any toxic reactions, so they are helpful in plant protection and management. All the parts of neem like seed, flowers, bark, and leaf can be used to produce high quality product. Products derived from Neem tree act as powerful Insect Growth Regulators (IGR) and also help in controlling several nematodes and fungi.

According to Anya *et al.* (2013) Neem seed which contain between 25 - 45 % oil on dry matter basis is a non-edible type of oil that can be used in biodiesel production. Mature neem seeds contain between 40 – 60 % water on wet bases and are therefore, very liable to degrade after harvest (Bup *et al*., 2013). Neem oil is non- edible oil available in huge quantities in south Asia. Traditionally it has been used as fuel in lamps for lightening purposes in rural areas and is used on industrial scale for manufacturing of soaps, cosmetics, pharmaceutical and other non-edible products. The neem seed undergoes a number of operations during the process of extracting neem oil and its derivatives. Visvanathan et al., (1996) reported a linear decrease in bulk density, true density, and porosity of neem nut with a resultant increase in moisture content in the range between 7.6–21% wb. Bup *et al*., (2013) determined some physical properties of neem fruits, nuts and kernels in the fresh state in Northern Cameroon. Gupta and Das (1997) assessed various physical properties of sunflower seeds including porosity, bulk density, terminal velocity, angle of repose, coefficient of static and dynamic friction. Some engineering properties of almond seeds, such as rupture strength, sphericity were reported by Kalyoncu (1990). Aydın and Özcan, (2002) studied some physico-mechanic properties of terebinth (*Pistacia terebinthus L.*) fruits. Aydin, (2007) investigated moisture dependent engineering properties of peanut, such as axial dimensions, unit mass and volume, sphericity, true and bulk densities, porosity, terminal velocity, projected area, rupture strength and coefficient of dynamic friction on two structural surfaces.

Hence information on the physical properties and their dependence on the moisture content are paramount in the design and development of methods and processing equipment (Visvanathan et al., 1996).

Therefore, the aim of this study was to determine some physical properties of the neem seeds and kernels relevant to design and fabrication of agricultural processing machines.

2. Materials and Methods

2.1 Sampling and Sample Preparation

The neem seeds used in this study were purchased from Bida main market, Niger State, Nigeria. The seeds were cleaned manually to remove all foreign materials such as dust, dirt, stones and broken seeds. The sample was then poured into a polyethylene bag and the bag was sealed tightly. Fifty seeds were selected from the lot and their physical properties such as static coefficient of friction, angle of repose, axial dimensions, surface area, sphericity, porosity, moisture content and density (bulk and true) were measured. Decortication was done by carefully cracking the nuts with a stone and opening it with the hands to remove the kernels and it physical properties were also determined.

2.2 Determination of Moisture Content of Neem Seeds and Kernels

To determine the moisture content of the neem seeds and kernels, samples were randomly selected from the bulk samples. The mass of each of the selected sample was measured using an electronic weighing balance (Adventure AR 3130 with a sensitivity of 0.001 g and maximum capacity of 310 g) and placed in an oven (PBS 118SF) at 130°C to a constant mass (ASAE, 2003). Measurements were replicated thrice and the average moisture content was calculated on wet basis. The moisture content was calculated using the formular in equation 1 (ASAE, 2003, Orhevba *et al.*, 2013):

$$\text{MC (wb)} = \frac{W_2}{W_2} \times 100\ \% \qquad (1)$$

where: W_2= Mass of the sample before drying (g), W_1 = Mass of the sample after drying (g).

2.3 Physical Dimensions of Seeds and Kernels

Samples of 50 seeds and 50 kernels were randomly selected. Each seed and kernel was measured for its major diameter (a), minor diameter (b, also known as width) and the intermediate diameter (c, also known as thickness) using a vernier calipers (Tricle Brand reading to 0.01mm). Each seed was placed between the outside jaws of the calliper to measure the major diameter along the major axis of the seed. The minor diameter (b) was measured such that it was perpendicular to the major diameter of the seed while the intermediate diameter (c) was measured perpendicular to the major diameter and parallel to the intermediate diameter. The physical dimensions of 50 kernels were also measured in a similar way as described for the seeds (ASAE, 2003).

2.4 Arithmetic Mean Diameter

The arithmetic mean diameter of the neem seeds and kernels were determined using the procedures reported by Aydin (2002); Anya (2013) in equation (2):

Arithmetic mean diameter $(D_a) = \frac{a+b+c}{3}$ (2)

where: a = major diameter (mm), b = minor diameter (mm) and c = intermediate diameter (mm) of the nuts or kernels.

2.5 Geometric Mean Diameter

The geometric mean diameter was determined from the physical dimensions (major diameter (a), minor diameter (b) and the intermediate diameter(c)) of the seeds and kernels. It was obtained from the relationship reported by Bup *et al.* (2013) and Orhevba *et al.* (2013) as given in equation (3):

Geometric mean diameter $\left(D_g\right) = (abc)^{\frac{1}{3}}$ (3)

2.6 Sphericity

Sphericity of the seeds and kernels were determined from the equation given below, which has been used by other researchers as Aydin, (2003). This is given by the relation (equation 4):

Sphericity $(\emptyset) = \frac{(a+b+c)^{\frac{1}{3}}}{a}$ (4)

where: a = major diameter (mm), b = minor diameter (mm) and c = intermediate diameter (mm) of the seed or kernel.

2.7 1000 Seed and Kernel Mass

Three samples of 100 seeds and 100 kernels were weighed and their average weights were determined. The average weight was then multiplied by 10 to obtain the 1000-unit mass for the seeds and kernels (Bup *et al*., 2013; Aydin, 2002).

2.8 Coefficient of Static Friction

Coefficients of static friction against plywood, glass and mild steel were determined for samples of seeds and kernels. An open (at both ends) rectangular wooden box of dimension 90 mm × 70 mm × 75 mm was placed on the inclined surface (plywood, glass or mild steel) whose angle of inclination was adjustable by means of a screw thread mechanism. The sample was then placed in the rectangular box and raised about 5 mm from the surface in order for the sample to be in contact with the surface. By gradually increasing the angle of inclination of the surface the sample just started to slide down. This angle between the surface and the horizontal was then measured, the tangent of which gave the coefficient of friction as stated in the Equation (5). Similar methods have been used by other researchers including Orhevba *et al*. (2013) and Francis (2012).

$$\text{Coefficient of static friction } (\mu) = tan\ \theta \tag{5}$$

where: θ = angle between the surface and the horizontal at which samples just start to slide down in degrees.

2.9 Determination of Angle of Repose

The angle of repose is the angle with the horizontal at which the material will stand when piled. This was determined by using a cylindrical container open at both ends. The cylinder was placed on a wooden table, filled with the seeds or kernels and raised slowly until it formed a cone of seeds. This was also done for the kernels. The angle of repose was calculated using the equation bellow which was adapted from the research by Idowu *et al*. (2012) given as;

$$\vartheta = tan^{-1}\left(\frac{2h}{d}\right) \tag{6}$$

where: h = Height of the cone formed by the seeds or kernels (cm)

d = Diameter of the base of the cone formed by the seeds or kernels (cm).

2.10 Determination of Bulk Density

In order to determine the bulk density for neem seeds, a container was filled with neem seed sample in excess. After filling the container of 51 mm in diameter and 375 mm in height, a flat ruler was passed across the top surface of the container to remove excess seeds. The sample was not compacted in any way. The container was weighed using an electronic balance (Adventurer

AR3130) with a precision of 0.001 g. The weight of the neem seeds was obtained by a difference. The process was replicated twice and the bulk density was calculated from the following relationship in equation 6 (Bup *et al.,* 2013; Aydin, 2002):

$$\text{Bulk density } (\rho_b) = \frac{m}{v} \qquad (7)$$

where: m = mass of neem seeds or kernels (g) and v = the volume of the container used (cm^3).

2.11 Determination of Surface Area

The surface area was determined by analogy using equation 7 (Francis, 2012).

$$S_a = \frac{\pi d a^2}{2a-d} \qquad (8)$$

where, $d = (bc)^{0.5}$

S_a = surface area (mm^2); $a =$ major diameter (mm); b = intermediate diameter (mm); $c =$ minor diameter (mm).

2.12 Determination of True Density

The true density was determined using the toluene displacement method. About 10 nuts of known mass were lowered into a measuring cylinder containing toluene. The true density of a seed is defined as the ratio of the mass of a sample of a seed to the solid volume occupied by the sample. The nut and kernel volume and their true densities were determined using the liquid displacement method. Toluene (C_7H_8) was used in place of water because it is absorbed by seeds to a lesser extent. Also, its surface tension is low; so that it fills even shallow dips in a seed and its dissolution power is low. The volume of toluene displaced by nuts was recorded. The ratio of mass to volume of the nuts was treated as true density (ρ_t) as given in equation 8 (Bup *et al.*, 2013; Aydin, 2003).

$$\text{True density } (\rho_t) = \frac{M}{V_t} \qquad (9)$$

where: $M =$ Mass of the neem seeds or kernels (g) ; V_t = Volume of toluene displaced (cm^3).

2.13 Determination of Porosity

The porosity (ε) values were calculated from the values of true density and bulk density using the relationship given in equation 9 (Aydin, 2007; Kalyoncu, 1990; Bup *et al.*, 2013)

$$\text{Porosity } (\varepsilon) = (1 - \frac{\rho_b}{\rho_t}) \times 100 \qquad (10)$$

where: ρ_b = bulk density (kg/m^3) and ρ_t = true density (kg/m^3).

3. Results and Discussion

The results of the physical properties of the nuts and kernels determined are presented in Tables 1 and 2 respectively.

The axial dimensions being the major diameter, intermediate diameter and the minor diameter of the seeds and kernels at the moisture contents of 13.8 and 11.9 % gave the values as shown in the Tables 1 and 2. These dimensions are important in the design of the cracking sieve, concave clearance between the sieve and the drum in the cracking unit and other apertures of the cracker. The Major diameter, intermediate diameter and the minor diameter of the seeds ranged between 11.21 to 17.50 mm, 5.11 to 8.72 mm and 3.12 to 8.0 mm respectively, these were 31.67 %, 36.47 % and 38.99 %, respectively greater than those of the kernels reported by Bup *et al.* (2013) which ranged from 10.12 to 11.34 mm, 3.55 to 4.55 mm and 3.10 to 4.19 mm respectively. The differences of 36 %, 29 % and 17 % for the major, intermediate and the minor diameters, respectively between the seeds and the kernels were also reported. The differences among the results of the seeds and kernels may be due to differences in the moisture contents. Other parameters applied were the arithmetic mean diameter, geometric mean diameter, surface area, sphericity, porosity, true density, bulk density, mass and 1000-unit mass. The results for sphericity indicated that the seeds were 4.69 % more spherical than the kernels. The neem seeds and kernels cannot be considered as spherical since their sphericity values were below 0.7 (Francis, 2012). The coefficients of static friction for the kernels are higher than those for the seeds by 22.45 %, 25 % and 23.26 % on the ply wood, glass and mild steel surfaces, respectively, which show similar variation with the results reported by Francis (2012) for *Jatropha curcas* seeds and kernels. This may be due to the low hardness and viscous nature of the surfaces of kernels, making it difficult for them to slide on the surfaces compared to the seeds. It also shows that surfaces for the gravitational flow of the kernels need to be inclined at greater angle compared to that for the seeds. Considering the three surfaces, coefficient of static friction was highest on glass, followed by plywood and galvanised steel as the lowest. This also agreed with the results of Francis (2012) for *Jatropha curcas* kernels and seeds.

Angle of repose was also higher for kernels than for the seeds, which can be attributed to the reason given above for the coefficient of static friction for the seeds and kernels. The viscous nature of the kernel surfaces created higher friction among the kernels leading to higher angle of repose (Francis, 2012). In decorticating the seeds, the principle is that the seeds need to be retained on the sieve for them to be decorticated while the kernels passes through the sieve after cracking to avoid being crushed. Hence, a sieve with circular holes will be needed to provide this condition for cracking using the physical dimensions.

Table 1: Physical properties of the seeds at 13.8% moisture content

Properties	N	Minimum	Maximum	Mean	Nuts
M.D (mm)	50	11.21	17.50	13.64	13.64±1.15
I.D (mm)	50	5.11	8.72	6.80	6.80±0.41
MN.D (mm)	50	3.12	8.00	5.54	5.54±0.44
G.M.D (mm)	50	6.41	9.84	7.97	7.97±0.74
A.M.D (mm)	50	6.97	10.38	8.66	8.66±0.65
Mass (g)	3	30.112	30.114	30.113	30.113±0.001
T.D (kg/m^3)	3	360.91	398.00	379.00	379.00±15.16
Sphericity	50	0.54	0.72	0.64	0.64±0.043
S.A (mm^2)	50	128.95	257.08	169.93	169.93±31.15
1000 mass (g)	3	203.53	203.67	203.62	203.62±0.11
B.D (kg/m^3)	3	39.293	39.293	39.293	39.293±0.01
Porosity (%)	3	89.11	90.13	89.62	89.62±0.41
Coefficient of friction on various surfaces					
Wood	3	0.37	0.39	0.38	0.38±0.0082
Glass	3	0.42	0.43	0.42	0.42±0.0058
Stainless steel	3	0.32	0.34	0.33	0.33±0.0082
Angle of repose	3	33.93°	35.34°	34.52°	34.52° ±0.60°

N = Number of Observation, M.D = Major dia., I.D = Intermediate dia., MN.D = Minor dia., G.M.D = Geometric Mean dia., A.M.D = Arithmetic Mean dia., T.D = True density, S.A = Surface Area, B.D = Bulk Density.

Table 2: Physical properties of the Kernels at 11.9 % moisture content

Properties	N	Minimum	Maximum	Mean	Kernel
M.D (mm)	50	7.45	12.56	9.32	9.32±1.13
I.D (mm)	50	3.3	5.5	4.32	4.32±0.63
MN.D (mm)	50	2.4	5.8	3.38	3.38±0.35
G.M.D (mm)	50	4.03	6.46	5.12	5.12±0.50
A.M.D (mm)	50	4.58	7.15	5.68	5.68±0.54
Mass (g)	3	39.21	40.11	39.82	39.82±0.43
T.D (kg/m^3)	3	918.33	938.42	930.03	930.03±8.53
Sphericity	50	0.54	0.73	0.61	0.61±0.044
S.A (mm^2)	50	43.66	110.89	70.63	70.63±13.98
1000 mass (g)	3	110.35	110.38	110.37	110.37±0.013
B.D (kg/m^3)	3	521.47	548.40	534.89	534.89±10.99
Porosity (%)	3	40.28	44.43	42.47	42.47±0.42
Coefficient of friction on various surfaces					
Wood	3	0.42	0.55	0.49	0.49±0.056
Glass	3	0.53	0.60	0.56	0.56±0.029
Stainless steel	3	0.40	0.45	0.43	0.43±0.021
Angle of repose	3	39.60°	40.82°	40.31°	40.31° ±0.52°

N = Number of Observation, M.D = Major dia., I.D = Intermediate dia., MN.D = Minor dia., G.M.D = Geometric Mean dia., A.M.D = Arithmetic Mean dia., T.D = True density, S.A = Surface Area, B.D = Bulk Density.

4. Conclusion

Some physical properties of the neem seed and kernel at moisture contents of 13.8 and 11.9 % were determined which are useful as design parameters for the designing of agricultural processing machine. The Major, intermediate and minor diameters of the neem seeds ranged between 11.21 to 17.50 mm, 5.11 to 8.72 mm and 3.12 to 8.0 mm respectively, while that of the kernel ranged between 10.12 to 11.34 mm, 3.55 to 4.55 mm and 3.10 to 4.19 mm respectively. The sphericity of the seed was 4.69% more spherical than the kernels. The coefficients of friction for the neem kernel on the three different surfaces were higher than those for the seeds by 0.11, 0.14 and 0.10 respectively. The angle of repose of the kernel was higher by 5.79° than for the seeds. The porosity for the kernel was 47.15% less than that of the seed. This information is useful to designers of agricultural processing machines.

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