Journal of Postharvest Technology
2019, **07**(2): 50-61
http://www.jpht.info

RESEARCH ARTICLE

Physical and mechanical properties of soya bean seeds in relation to the design of oil extractors

Tanko Bako[1]*, Ezekiel Ambo Mamai[2], Boman James Bature[3]

[1]Department of Agricultural and Environmental Engineering, University of Agriculture, Makurdi, Nigeria

[2]Department of Soil Science and Land Resource Management, Federal University, Wukari, Nigeria

[3]Department of Agricultural and Bio-Environmental Engineering, Nuhu Bamalli Polytechnic, Zaria, Nigeria

Received: 20.03.2019 Accepted: 21.04.2019

ABSTRACT

Physical and mechanical properties are very important in the design and manufacturing of processing machines. In this research work, the physical and mechanical properties of soya bean seeds were determined as design parameters for the development of an oil expeller for the crop. The physical properties determined were length, width, thickness, arithmetic mean diameter, geometric mean diameter, roundness, sphericity, aspect ratio, surface area, projected area, volume, moisture content, one thousand seed weight, bulk density, true density and porosity. The average seed length, width and thickness were found to be 6.67 ± 0.27, 5.60 ± 0.22 and 4.64 ± 0.24 mm respectively. The average arithmetic and geometric mean diameters were 5.64±0.19 and 5.58±0.17 mm respectively. The average roundness, sphericity and aspect ratio were 0.7879±0.023, 0.8359±0.021 and 0.8396±0.025 respectively. The mean surface area, projected area and volume were 97.66±32.58 mm^2, 29.34±3.47 mm^2 and 90.75±29.64 mm^3 respectively. The average moisture content was 7.34±0.32% dry basis and the thousand kernel weight was 104.88±0.53 g. The average bulk and true densities were 750.00 ± 3.28 and 1250.00 ± 4.45 kgm^{-3} respectively and the porosity was 40.02 ±0.061%. The mechanical properties determined in this study were angle of repose, coefficient of static friction, shear strength and compressive strength. The mean angle of repose was 27.00±0.37° while the mean coefficient of static friction on mild steel surface was 0.52±0.022. The mean shear strength and compressive strength of the seeds were 284.56±25.13 and 657.33±46.62 N/mm^2 respectively. These parameters would provide important and essential data for the efficient design of oil extractors.

Keywords: Soya bean, physical, mechanical, oil extractor, postharvest

Citation: Bako, T., Mamai, E.A., and Bature, B.J. 2019. Physical and mechanical properties of soya bean seeds in relation to the design of oil extractors. *Journal of Postharvest Technology*, **7**(2): 50-61.

INTRODUCTION

Soya bean (*Glycine max*) is a leguminous vegetable of the Pea family that grows in tropical, subtropical and temperate climates. Soya bean has a high protein content of 40% by weight, 32% carbohydrate, 20% fat, 5% minerals, and 3% fiber and other trace substances. It is used as sources of protein in human food, animal feed and in industries (Adekunle et al., 2006). Approximately, 85% of the world's soya bean crop is processed into soya bean meal and vegetable oil (Endres, 2001). Soya bean seed contains about 19% oil. According to their different uses, soya bean cultivars are classified as grain-type, which are conventional soybeans for oil and animal feeding, and food-type, which are those for human consumption in fermented foods like misso, tempeh and natto and non-fermented foods like tofu, soy flour and soy milk (Liu, 1999).

The soya bean shares the flaw of many plants from the Fabaceae family, namely it is prone to mechanical damage occurring during threshing, cleaning, drying, transportation, storage and processing. Knowledge of the physical and mechanical properties of soya bean seeds is therefore particularly important for the optimization of harvesting, drying, storing and

* *For correspondence:* T. Bako (Email: engbako@gmail.com; Phone: +234 7064190523)

ISSN: 2348-4330

processes (Rybinski et al., 2009). Unlike cereal grains, soya bean seeds have two cotyledons between which a gap may be formed if the water content is low. This leads to an increased susceptibility of the seeds to damage like, for example, breaking in half (Shahbazi et al., 2011).

In order to design equipment used for planting, harvesting, transporting, storage, processing and oil extraction of soya bean, there is need to know the various physical and mechanical properties of soya bean. The size, shape and mechanical behaviour of soya bean are important in designing of harvesting, separating, sizing, grinding and oil extraction machines. Bulk density, true density and porosity (the ratio of inter granular space to the total space occupied by the grain) are used in design of storage bins and silos, separation of desirable materials from impurities, cleaning and grading and quality evaluation of the products. The angle of repose is important in designing of storage and transporting structures. The static coefficient of friction of the grain against the various surfaces is also necessary in designing of conveying, transporting and storing structures.

In the extraction of soya bean oil from seed, the soya beans are cracked, adjusted for moisture content, rolled into flakes and solvent extracted with commercial hexane (Hookgenkamp, 2005). Effective cracking of nut as reported by Eric et al. (2009) is dependent on the stiffness modulus and the sizes of nuts. Cracking of palm nut under repeated impact load with the objective of minimizing kernel breakage was modeled by koya (2006). The models were based on the conservation of energy impacted on the nut by a falling weight, on the kinetic energy of a moving nut and strain energy required in breaking the nut shell. Three parameters were identified by Ndukwu and Asoegwu, (2010) as influencing the performance of cracking operation, cracking speed, moisture content and the feed rate. The knowledge of compressive strength of grains is generally required by scientist, machine designers and processors in the development of appropriate machines for harvesting, milling, and oil extraction from the seed (Ajibola et al., 1990).

The four stages which influence the extraction/expression of oil are seed preparation, cooking, seed pressing and separation of solids from expressed oil. In order to design and develop methods and equipment for soya bean oil expression in the tropics, knowledge of physical and mechanical properties is necessary. Akinoso (2006) revealed that particle size of the seed, applied pressure, moisture content, heating duration and duration processing are identified factors influencing the yield and quality of oil seeds using hydraulic press. Mechanical compression was carried out with the aid of carver press. The result showed that raw soya bean required the highest pressure to reach the oil point and extruded soya bean. Also, increasing moisture content increased the oil point pressure for all the samples (Kamal-din and Appeloquist, 1995). The effect of hydro thermal treatment on mechanical oil expression from soya bean was also investigated. The report revealed that boiled splits soya bean produces high yield after drying to 7% moisture content and soaked split produces yield at 8% moisture content. Energy consumption decreases with an increase in moisture content in boiling treatment but temperature remained high in soaked beans (Singh and Bargala, 1990). Sakuniaran and Singh (1987) worked on oil expression characteristics of rape seed under uniaxial bulk compression and developed mathematical expression that correlates effects of moisture content, rates of deformation and pressure on oil expression characteristics. Oil recovery efficiency for degree of compression was found to be an exponential function of these factors.

Oil bearing crops are subjected to mechanical forces during oil extraction/expression process. These forces frequently result to deformation of the crops. Thus, the mechanical strength of the crops plays an important role in the oil extraction/expression process. Most agricultural products are visco-elastic in nature; they respond differently to tensile or compressive forces and also behave differently when they are subjected to vibration. Therefore, a fundamental knowledge of agricultural product behavior under mechanical forces is essential in determining the power requirement for different operations (Ozumba and

Obiakor, 2011). A rational approach to the design of agricultural machinery, equipment and facilities involves the knowledge of the engineering properties of the agricultural product concerned. Considering this, the knowledge of the mechanical properties (properties that have to do with the behaviour of agricultural products under applied forces) such as stress, strain, hardness and compressive strength is vital to engineers handling agricultural products (Chukwu and Sunmonu, 2010). Several researchers have investigated the physical and mechanical properties of some oil bearing crops considered relevant to the design of suitable machines and equipment for their production and processing; but a review of literature showed little information on the physical and mechanical properties of soya bean seeds, most especially, in relation to the design of an oil expeller. Therefore the objective of this study was to determine the physical and mechanical properties of soya bean seeds in relation to the design of an oil expeller. Soya bean processing industries select raw material based on weight, moisture, impurities and grain damage. Differences in physical and mechanical properties of soya bean cultivars are not taken into consideration in soya bean food processing. Information on these characteristics could help food industries obtain products with better functional, nutritional and sensory qualities with greater cost benefits. Soya bean is an important source of high-quality protein. Soya bean cultivars with high protein content allow the production of foods with superior nutritional value and yield, such as soy milk and tofu. To make superior nutritional value and yield products particularly rely on the in-depth knowledge of the physical and mechanical properties.

The soya bean kernels are commercialized at local, regional and international levels, indicating that demand is likely to increase. In other to have a good design of machine for handling, drying, cracking and processing knowledge of the engineering properties of the agricultural crop is necessary. Engineering properties of biological materials such as soya bean seed have unique characteristics which set them apart from other engineering materials. The irregular shape of most agricultural materials complicates the analysis of their behaviour. Also due to the increasing importance of agricultural products together with the complexity of modern technology for their production, processing and storage, a better knowledge of their engineering properties is necessary. The engineering properties of soya bean seeds are pre-requisites in the designing of equipment for handling, storage, mechanical extraction of oil and other processes. It is therefore essential to determine the relevant characteristics of soya bean seeds which appears to be lacking in literature. Therefore, this work will reveal the physical and mechanical properties of soya bean which will aid anyone with the knowledge of soya bean and its physical and mechanical properties..

MATERIALS AND METHODS

Physical properties of soya bean seeds were grouped into two namely: dimensional properties (length, width, thickness, arithmetic mean diameter, geometrical mean diameter, roundness, sphericity, aspect ratio, surface area, projected area and volume) and gravimetric properties (moisture content, one thousand seed weight, bulk density, true density and porosity). Mechanical properties of soya bean seeds were also grouped into two namely: frictional properties (angle of repose and coefficient of static friction) and strength properties (shear strength and compressive strength). These were evaluated as design parameters for the development of an oil expeller. They were determined following standard procedures.

Determination of Physical Properties of Soya Bean Seeds

Dimensional properties

In order to determine dimensions, one hundred soybeans were randomly selected. For each soya bean, the three principle dimensions, namely length, width and thickness were measured using a vernier caliper having the least count of 0.001 mm.

The length (L) was defined as the distance from the tip cap to kernel crown. Width (W) was defined as the widest point to point measurement taken parallel to the face of the kernel. Thickness (T) was defined as the measured distance between the two kernels faces as described by Pordesimo et al. (1990). Measurements were taken and the shape parameters were calculated.

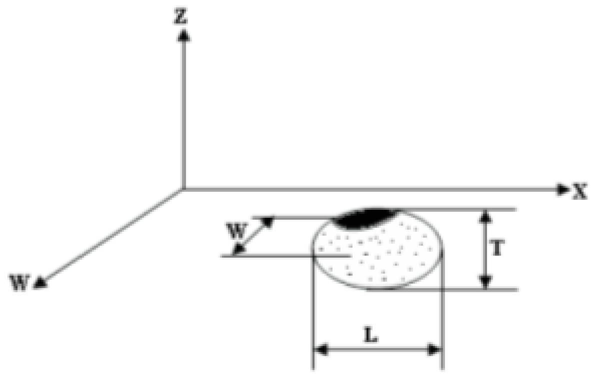

Figure 1: Characteristic dimensions of a soya bean seed

Arithmetic mean diameter: The arithmetic mean diameter (Da) of the seed was calculated using equation 1 given by Baryeh (2002).

$$Da = \frac{L+W+T}{3} \quad (1)$$

Geometric mean diameter: The geometric mean diameter (Dg) was determined from equation 2 given by Baryeh (2002).

$$Dg = (LWT)^{\frac{1}{3}} \quad (2)$$

Roundness: The roundness (R) was determined from equation 3 given by Baryeh (2002).

$$R = \frac{\left(\frac{W}{L}+\frac{T}{L}+\frac{T}{W}\right)}{3} \quad (3)$$

Sphericity: The sphericity (ϕ) was determined from equation 4 given by Mohsenin (1986) and Baryeh (2002).

$$\phi = \frac{Dg}{L} \quad (4)$$

Aspect ratio of seeds: The aspect ratio (Ra) was calculated from equation 5 given by Omobuwajo et al. (1999).

$$R_a = \frac{W}{L} \quad (5)$$

Surface area of seeds: The surface area (Sa) was obtained from equation 6 given by Baryeh (2002).

$$S_a = \pi D_g^2 \quad (6)$$

Projected area: The projected area (A_P) of the seeds was determined by the Equation 7 given by Mirzabe et al. (2013).

$$A_P = \frac{\pi WL}{4} \quad (7)$$

Volume of seeds: The computation of volume (V) of seeds was determined from equation 8 given by Mohsenin (1986).

$$V = \frac{\pi}{6} D_g^3 = \frac{\pi}{6} LWT \quad (8)$$

Gravimetric properties

Seed moisture content: A known weight of soya bean seeds was manually cleaned to remove foreign matter, dust, dirt, broken and immature seeds. The initial moisture content of the samples was determined before processing by oven drying at 105 °C for 72 h (Baryeh, 2002). Equation 9 was used to calculate the moisture content.

$$MC_{db} = \frac{w_1 - w_2}{w_2 - w_o} \times 100\% \quad (9)$$

Where; MC_{db} = Moisture content (% dry basis), w_0 = weight of container (g), w_1= Weight of fresh sample and container (g) and w_2= Weight of dry sample and container (g).

Thousand-grain weight: The 1000 unit mass (M1000) was determined using mettle electronic balance of accuracy of 0.01g. One thousand unit grains were carefully counted out from a cleaned sample of soya bean seeds and weighed in the balance. The measurements were replicated ten times (Sirisomboon et al., 2007).

Bulk density: The bulk density of the seeds was determined by filling a test tube of 20 ml volume with the seeds and the content weighed using an electronic balance of 0.01g sensitivity. The measurements were replicated ten times (Garnayak et al., 2008). The bulk density was calculated from the mass of the kernels and the volume of the container from equation 10 given by Garnayak et al. (2008).

$$\rho_b = \frac{M_1 - M_2}{V} \quad (10)$$

Where; ρ_b= bulk density (gcm^{-3}), M_1 =mass of filled container (g), M_2 = mass of empty container (g) and V = Volume of container (cm^3).

True density: The true density of the seeds was determined by water displacement method as described by Mohsenin (1986). 50 ml of distilled water was taken in a 100 ml measuring jar and pre-weighed soya bean grains was filled inside the jar and the change in the level of water in the measuring jar was recorded. The experiment was done as snappy as possible to minimize the absorption of water by the seeds. The measurements were replicated ten times. The true density was calculated as the ratio of the mass of seeds to the volume of water displaced as in equation 11 (Pradhan et al., 2013).

$$\rho_t = \frac{M}{V} \quad (11)$$

Where; ρ_t= True density (gcm^{-3}), M =Mass of seeds (g) and V = Volume of water displaced (cm^3).

Porosity: Porosity (ρ_o) is defined as the fraction of space in the bulk grain, which is not occupied by grain. Equation 12 was used to obtain the porosity (Mohsenin, 1986).

$$\rho_o = (1 - \frac{\rho_b}{\rho_t}) \times 100 \qquad (12)$$

Determination of Mechanical Properties of Soya Bean Seeds

Frictional properties

Angle of repose: This was determined by using an open-ended cylinder of 15 cm diameter and 30 cm height. The cylinder was placed at the centre of circular plate having a diameter of 70 cm and was filled with soya bean seeds, tapping during filling were done to obtain uniform packing. The cylinder was raised slowly until it formed a cone on the circular plate. The height H of the cone was recorded. The angle of repose θ was calculated using equation 13 (Umogbai, 2009; Davies, 2009).

$$\theta = \mathrm{Tan}^{-1}\left(\frac{2H}{D}\right) \qquad (13)$$

Where; θ = angle of repose (^{o}), H = vertical height of conical heap of grains (mm) and D = the diameter of base of cone formed (mm).

Coefficient of static friction: The coefficient of static friction for seed was determined against mild steel surface using the inclined plane method. This involves placing the soya bean seeds on adjustable tilting surface equipment with the surface formed using a mild steel sheet. Manually, the inclination of the plate was increased gradually until the specimen starts to slide down and at that point, the angle of tilt α in degree was read on a graduated scale (protractor). The angle of inclination with the horizontal was measured by a scale provided and was taken as an angle of internal friction and tangent of the angle was taken as co-efficient of friction between surface and soya bean seeds as in equation 14 (Umogbai, 2009).

$$\mu = \tan\alpha \qquad (14)$$

Where; µ = Coefficient of static friction (dimensionless) and α = Angle of inclination of material surface (^{o}).

Strength Properties

Shear strength: The shear strength was measured in double shear using a shear box consisting essentially of two fixed parallel hardened steel plates 6 mm apart, between which a third plate can slide freely in a close sliding fit. A series of holes with diameters ranging from 0.5 to 2 mm was drilled through the plates to accommodate grains of differing diameters. Shear force was applied to the grain specimens by mounting the shear box in the tension/compression testing machine. The sliding plate was loaded at a rate of 10mm min^{-1} and, as for the shear test; the applied force was measured by a strain-gauge load cell and a force -time record obtained up to the specimen failure. The shear failure stress (or ultimate shear strength), τ_s, of the specimen was calculated using equation 15 (Zareiforoush et al., 2010).

$$\tau_s = \frac{F_s}{2A} \qquad (15)$$

Where; τ_s = shear strength (N/mm^2), Fs = shear force at failure (N) and A = wall area of the specimen at the failure cross-section (mm^2).

Compressive strength: Compressive strength of the grain is considered as an important mechanical property in relation to the grain breakage. A universal testing machine (Testometric M500-100AT) was used to obtain the fracture force of the kernel. The slots were screwed to compress the kernel placed between them. The counter reading was taken immediately the first cracking sound was heard. Compressive strength was calculated by dividing the fracture force with the area in contact with the kernel using equation 16 (Craig et al., 2008).

$$\tau_c = \frac{F_c}{A} \qquad (16)$$

Where; τ_c = compressive strength (N/mm^2), Fc = compressive force at failure (N) and A = cross-sectional area defined by the length and width dimensions of the specimen (mm^2).

Statistical analysis

In the present study, the results are expressed as mean and standard deviation (S.D.) of various determinations.

RESULTS AND DISCUSSION

Physical Properties

A summary of the results for the physical properties measured and determined is shown in Table 1. The average moisture content was calculated as 7.34±0.32% dry basis and all the other experiments were conducted at this moisture content. The moisture content is very important as it influences the size, shape and angle of repose of the seeds; which in turn determine the hopper capacity and the free flow of the seeds.

It was observed that the longitudinal dimension or Length (L) of the seeds ranged from 6.0 to 7.2 mm with the mean value as 6.67 ± 0.27 mm, the width (W) varied from 5.0 to 6.1 mm with the mean value as 5.60 ± 0.22 mm and the seed thickness (T) varied from 4.1 to 5.4 mm with the mean value as 4.64 ± 0.24 mm. Although, Mohsenin (1986) had effectively highlighted the imperativeness of the axial dimensions in machine design, the comparison of the data with existing work on the other seeds can be sufficient in making symmetrical projections towards process equipment adaptation. It is seen from Table 1 that the arithmetic mean diameter (Da) and geometrical mean diameter (Dg) of the kernels varied from 5.03 to 6.23 mm with the mean value of 5.64±0.19 mm and 4.97 to 6.19 mm with the mean value of 5.58±0.17 mm, respectively.

The results showed that roundness (R) of the seeds ranged from 0.7789 to 0.8275 with the mean value of 0.7879±0.023, sphericity (ϕ) varied from 0.8289 to 0.8597 with the mean value of 0.8359±0.021 and aspect ratio (Ra) ranged from 0.8333 to 0.8472 with the mean value of 0.8396±0.025. Garnayak et al. (2008) considered any grain, fruit and seed as spherical when the sphericity value is above 70%, thus, the high sphericity of the soya bean seeds is indicative of the shape towards being a sphere. The lower sphericity values thus suggest that the kernels tend towards a cylindrical shape (Omobuwajo et al., 2000). The aspect ratio is an indicator of a tendency toward an oblong shape (Heidarbeigi et al., 2009). Thus, the lower values of the aspect ratio and sphericity generally indicate a likely difficulty in getting the kernels to roll than that of peas like spheroid grains. They can, however, slide on their flat surfaces. This tendency to either roll or slide should be necessary in the design of hoppers for milling process. However, the surface area (Sa) ranged from 77.70 to 120.37 mm^2 with the mean value of 97.66±32.58 mm^2, the projected area (A_P) ranged from 23.56 to 34.49 mm^2 with the mean value of 29.34±3.47 mm^2 and the seed volume (V) varied from 64.40 to 124.18 mm^3 with the mean value of 90.75±29.64 mm^3. The surface area is a relevant tool in determining the shape of the seeds. This will actually be an indication of the way the kernels will behave on oscillating surfaces during processing. The projected area of the particle is generally indicative of its pattern of behavior in a flowing fluid such as air, as well as the ease of separating extraneous materials from the particle during cleaning by pneumatic means (Omobuwajo et al., 1999). The values of the dimensions of the soya bean seeds are useful in the calculation of the amount of seeds that will be crushed at the feed end portion of the machine. It also assists in determining the total force that will be required to express the oil based on the number of seeds to be processed per batch.

Table 1. Physical properties of soybean seeds

Physical Properties	Unit	Minimum	Maximum	Mean	Standard Deviation
Dimensional Properties					
Length (L)	mm	6.0	7.2	6.67	0.27
Width (W)	mm	5.0	6.1	5.60	0.22
Thickness (T)	mm	4.1	5.4	4.64	0.24
Arithmetic mean diameter (Da)	mm	5.03	6.23	5.64	0.19
Geometrical mean diameter (Dg)	mm	4.97	6.19	5.58	0.17
Roundness (R)	-	0.7789	0.8275	0.7879	0.023
Sphericity (ϕ)	-	0.8289	0.8597	0.8359	0.021
Aspect ratio (Ra)	-	0.8333	0.8472	0.8396	0.025
Surface area (Sa)	mm^2	77.70	120.37	97.66	32.58
Projected area (A_P)	mm^2	23.56	34.49	29.34	3.47
Volume (V)	mm^3	64.40	124.18	90.75	29.64
Gravimetric Properties					
Moisture content (Mc)	%	6.98	7.59	7.34	0.32
One thousand seed weight (M1000)	g	104.28	105.62	104.88	0.53
Bulk density (ρ_b)	kgm^{-3}	748.23	752.14	750.00	3.28
True density (ρ_t)	kgm^{-3}	1246.18	1255.92	1250.00	4.45
Porosity (ρ_o)	%	39.96	40.11	40.02	0.061

The average moisture content (Mc) was 7.34±0.32%, although the moisture content varied between 6.98 and 7.59%. The thousand kernel weight (M1000) ranged from 104.28 to 105.62 g with the mean value of 104.88±0.53 g. One point worthy of note however that is the one thousand seed weight is a function of the individual mass (weight) of the seed/kernel/grain of the crops. Weight is an important parameter to be used in the design of cleaning grains using aerodynamic forces (Oje and Ugbor, 1991). The bulk density (ρ_b) of kernels ranged from 748.23 to 752.14 kgm^{-3} with mean value of 750.00 ± 3.28 kgm^{-3}, the true density (ρ_t) value varied from 1246.18 to 1255.92 kgm^{-3} with mean value of 1250.00 ± 4.45 kgm^{-3} and the porosity (ρ_o) of the kernels varied from 39.96 to 40.11% with the mean value as 40.02 ±0.061%. The value of true density indicates that, the kernel density is higher than water, which is the important property in case of food grains during wet cleaning, as kernels do not float on water. The densities are useful in the theoretical calculation of the capacity of the expeller.

Overall, handling losses during cleaning and oil expression will be affected by the size and shape of soya bean seeds. According to Olayanju (2002), if the screen hole is too big, it may result in uncleaned seeds and if the screen hole is too small, it may lead to reduced efficiency. If the oil barrel clearance is too big, it may result in partial crushing of seeds and if it is too small, it may lead to excessive choking of the discharge section as the seeds are crushed. For optimum performance of the cleaner and oil expeller, the size of perforations and barrel clearance have to be carefully selected (Olayanju, 2002). The obtained results from the dimensional properties determination are therefore very important. The sphericity will be useful in handling operations such as conveying and discharge from chutes. Since the seeds are to be transferred from one placement unit to the other, the sphericity value obtained will be taken into consideration for designing the slope of the transfer unit. The bulk density is important in calculating thermal properties in heat transfer processes, in determining Reynolds number in pneumatic and hydraulic handling of the material, in separating the product from undesirable materials and in predicting physical structures and chemical composition (Olayanju, 2002). The porosity gives knowledge of the percentage void of the soya bean seeds and is important in heat and airflow studies.

Mechanical Properties

A summary of the results for the mechanical properties determined is shown in Table 2. The mechanical properties include the frictional and strength properties. The frictional properties examined for the kernels are the angle of repose (θ) and the coefficient of static friction (μ).

Table 2. Mechanical properties of soybean seeds

Mechanical Properties	Unit	Minimum	Maximum	Mean	Standard Deviation
Frictional Properties					
Angle of repose (θ)	Degrees	25.98	27.36	27.00	0.37
Coefficient of static friction (μ)	-	0.51	0.54	0.52	0.022
Strength Properties					
Shear strength (τ_s)	N/mm^2	248.92	331.67	284.56	25.13
Compressive strength (τ_c)	N/mm^2	571.08	760.54	657.33	46.62

Essentially, the mean angle of repose was 27.00±0.37^o, although the angle of repose varied from 25.98 to 27.36^o. This phenomenon is imperative in food grain processing, particularly in the designing of hopper for milling equipment. The angle of repose will determine the angle at which chutes must be positioned in order to achieve consistent flow of materials through the chute. To ensure free flow, an angle of repose which is modestly higher than the average angle of repose (27.00±0.37^o) obtained for the soya bean seeds would be used. The co-efficient of static friction on mild steel surface found ranged from 0.51

to 0.54 with the mean value of 0.52±0.022. The knowledge of the coefficient of friction will be useful during the calculations of the various forces required to translate and compress the seeds as well as the frictional force resulting from the motion of the screw.

The strength properties examined for the kernels are the shear strength (τ_s) and the compressive strength (τ_c). The shear strength and compressive strength of the kernels varied from 248.92 to 331.67 N/mm^2 with the mean value of 284.56±25.13 N/mm^2 and 571.08 to 760.54 N/mm^2 with the mean value of 657.33±46.62 N/mm^2, respectively. In designing food processing machines, the knowledge of these properties has been emphasized by Adebayo (2004) when he carried out carried a compression test on Dura varieties of the palm nut in order to determine the force required for cracking the palm nut. The compressive strengths for minor, major and intermediate axis are 396.20 ± 49.40 N/mm^2, 216.30 ± 23.92 N/mm^2 and 262.4 ± 174.80 N/mm^2 respectively for the white almond. These parameters are important in designing of machines for processing biomaterials, particularly in the design of a cracking machine for extraction of nut from the kernel. These parameters also give the energy requirement and consideration governing equipment selection in size reduction operation (Orhevba et al., 2013). Overall, the mechanical properties determined give an indication of the shear strength and compressive strength of soya bean seeds. They also provide useful information about the energy and the force required to crush and expel oil from the seeds at the feed end portion of the machine as well as the deformation of the seeds.

CONCLUSION

The physical and mechanical properties of soya bean seeds in relation to the design of an oil expeller for the crop have been determined. The average seed length, width and thickness were found to be 6.67 ± 0.27, 5.60 ± 0.22 and 4.64 ± 0.24 mm respectively. The average arithmetic and geometric mean diameters were 5.64±0.19 and 5.58±0.17 mm respectively. The average roundness, sphericity and aspect ratio were 0.7879±0.023, 0.8359±0.021 and 0.8396±0.025 respectively. The mean surface area, projected area and volume were 97.66±32.58 mm^2, 29.34±3.47 mm^2 and 90.75±29.64 mm^3 respectively. The average moisture content was 7.34±0.32% dry basis and the thousand kernel weight was 104.88±0.53 g. The average bulk and true densities were 750.00 ± 3.28 and 1250.00 ± 4.45 kgm^{-3} respectively and the porosity was 40.02 ±0.06%. The mean angle of repose was 27.00±0.37^o while the mean coefficient of static friction on mild steel surface was 0.52±0.022. The mean shear strength and compressive strength of the seeds were 284.56±25.13 and 657.33±46.62 N/mm^2 respectively. These parameters will serve as inputs for the efficient design of oil extractors for soya bean seeds.

REFERENCES

Adebayo, A.A. 2004. Development and Performance Evaluation of a Motorized Palm Nut Cracker. Proceedings of the Nigerian Institution of Agricultural Engineers (NIAE), 26: 326-330.

Adekunle, A.A., Fatunbi, A.O., Asire, J.A. and Abikoye, J.O. 2006. Growing Soybean Commercially in Nigeria- An Illustrated Edition. IITA – Research to Marvish Africa. CGIAR.

Ajibola, O.O., Eniyomi, S.E., Fasina, O.O. and Adeeko, K.T.A. 1990. Mechanical Expression of Oil from Melon Seed. Journal of Agricultural Engineering Research, 45: 45-53.

Akinoso, R. 2006. Effects of Moisture Content, Roasting Duration and Temperature on Yield and Quality of Palm Kernel (Elaeis guineensis) and Sesame (Sesamum indicum) Oils. Unpublished Ph.D Thesis, University of Ibadan. Nigeria. PP. 273-280.

Baryeh, A.E. 2002. Physical properties of millet. Journal of Food Engineering, Elsevier Science Limited, 5: 139-146.

Chukwu, O. and Sunmonu, M.O. 2010. Determination of Selected Engineering Properties of Cowpea (Vigna unguiculata) related to Design of Processing Machines. International Journal of Engineering and Technology, 2(6): 373-378.

Craig, F.M., Marvin, J.P., Arthur, D.B., Kameron, P., Garrison, E.K. and Patrick, J.M. 2008. Compressive Strength of Wheat Endosperm: Analysis of Endosperm Bricks. Cereal Chemistry, 85(3): 351-358.

Davies, R.M. 2009. Some physical properties of groundnut grains. Research Journal of Applied Science, Engineering and Technology, 1(2): 10-13.

Endres, J.G. 2001. Soy Protein Products. Champaign-Urbana, IL AOCS Publishing. pp. 43 – 44. ISBN 1 – 893997 – 27-8

Eric, K.G., Simons, A. and Elias, K.A. 2009. The Determination of some Design Parameters for Palmnut Crackers. European Journal of Scientific Research, 38(2): 315 – 327.

Garnayak, D.K., Pradhan, R.C. Nalk, S.N. and Bhatnagar, N. 2008. Moisture-dependent physical properties of Jatropha seed. Industrial Crops and Products, 27: 127-129.

Heidarbeigi, K., Ahmadi, H., Kheiralipour, K. and Tabatabaeefar, A. 2009. Some Physical and Mechanical Properties of Khinjuk. Pakistan Journal of Nutrition, 8 (1): 74-77.

Hookgenkamp, H.W. 2005. Soy Protein and Formulated Meat Products. Nallingford. Oxon, UK: CABI Publishing. Pp. 14. ISBN 0 – 85199 -864-x.

Kamal-Eldin, A. and Appelquist, L.A. 1995. The Effects of Extraction Methods on Sesame Oil Stability. Journal of the American Oil Chemists’ Society, 72(8): 967-969.

Koya, O.A. 2006. Palm nut Under Repeated Impact Load. Journal of Applied Science, 6(2): 2471 – 2475.

Liu, K. 1999. Soybeans: chemistry, technology and utilization. New York: Klewer Academic press. 532pp.

Mirzabe, A.H., Khazaei, J., Chegini, G.R. and Gholami, O. 2013. Some physical properties of almond nut and kernel and modeling dimensional properties. Agricultural Engineering International: CIGR Journal, 15(2): 256－265.

Mohsenin, N.N. 1986. Physical Properties of Plant and Animal Materials (Handbook). (2nd ed.). Gordon and Breach Science Publishers, New York, PP. 616-681.

Ndukwu, M.C. and Asoegwu, S.N. 2010. Functional Performance of a Vertical shaft Centrifugal Palmnut Cracker. Research in Agricultural Engineering, 56(2): 77 – 83.

Oje, K. and Ugbor, E.C. 1991. Some physical properties of oil bean seed. Journal of Oil Bean Seeds, 50: 305-313.

Olayanju, T. M. A. 2002. Design, Fabrication and Evaluation of a Beniseed (Sesanum indicum L.) Oil Expeller. Ph.D Thesis, Department of Agricultural Engineering, University of Ibadan, Ibadan, Nigeria.

Omobuwajo, T.O., Akande, E.A. and Sanni, L.A. 1999. Selected Physical, Mechanical and Aerodynamic Properties of African Breadfruit (Treculia africana) Seeds. Journal of Food Engineering, 40: 241-244.

Omobuwajo, T.O., Sanni, L.A. and Olajide, J.O. 2000. Physical properties of ackee apple (Blighia sapida) seeds. Journal of Food Engineering, 45: 43-48.

Orhevba, B.A., Idah, P.A., Adebayo, S.E. and Nwankwo, C.C. 2013. Determination of Some Engineering Properties of Dika Nuts (Irvingia gabonensis) at Two Misture Contents Levels as Relevant to its Processing. International Journal of Engineering Research and Applications (IJERA), 3(2): 182-188.

Ozumba, I.C. and Obiakor, S.I. 2011. Fracture Resistance of Palm Kernel Seed to Compressive Loading. Journal of Stored Products and Postharvest Research, 2(13): 248-253.

Pordesimo, L.O., Anantheswaran, R.C., Fleischmann, A.M., Lin, Y.E. and Hanna, M.A. 1990. Physical Properties as Indicators of Popping Characteristics of Microwave Popcorn. Journal of Food Sciences, 55(5): 1352-1355.

Pradhan, R.C, Said, P.P. and Singh, S. 2013. Physical Properties of Bottle Gourd Seeds. Agricultural Engineering International: CIGR Journal, 15(1):106-115.

Rybinski, W., Szot, B., Rusinek, R. and Bocianowski, J. 2009. Estimation of geometric and mechanical properties of seeds of Polish cultivars and lines representing selected species of pulse crops. International Agrophysics, 23: 257–267.

Shahbazi, F., Saffar, A. and Analooei, M. 2011. Mechanical Damage to Pinto Beans as Affected by Moisture Content and Impact Energy. Agricultural Engineering International: CIGR Journal, 13(2): 1–8.

Singh, J. and Bargala, P.C. 1990. Effects of Hydro-Thermal Treatment on Mechanical Oil Expression from Soybean. Journal of Food Science and Technology, India, 27: 86-88.

Sirisomboon, P., Kitchaiya, P., Pholpho, T. and Mahuttanyavanitch, W. 2007. Physical and mechanical properties of Jatropha curcas L. fruits, nuts and kernels. Biosystems Engineering, 97: 201-207.

Sukuniaran, C.R. and Singh, B.P.N. 1987. Oil Expression Characteristics of Rapeseed. Journal of Food Science and Technology, India, 24(l): 11-16.

Umogbai, V.I. 2009. Development of Angle of Friction Measuring Device. Journal of Engineering Science and Technology, 4(1): 116-121.

Zareiforoush, H., Mohtasebi, S.S., Tavakoli, H. and Alizadeh, M.R. 2010. Effect of loading rate on mechanical properties of rice (Oryza sativa L) straw. Australian Journal of Crop Science, 4(3):190-195.