SOME ENGINEERING PROPERTIES OF SOYBEAN (*Glycine max*) SEEDS AS RELATED TO PRIMARY PROCESSING

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Abstract: Knowledge of physical properties of agricultural materials plays important roles in the design of post-harvest handling machines and processes. This study evaluated some physical properties of soybean seeds relevant to the design and development of equipment and machines for postharvest handling, processing and storage operations. The selected physical properties were evaluated at the seed moisture content of 8.02% ± 1.02 moisture level (db). The results showed mean values of geometric properties namely major diameter, intermediate diameter, minor diameter, geometric mean diameter, arithmetic mean diameter, surface area, sphericity and aspect ratio varied significantly ($p>0.05$). The ratio of bulk density to true density of the soybean seeds gave low porosity of 11.5%±0.32. The angle of repose was 28.5° ± 1.00, while the static coefficient of friction of the seeds was highest on plywood (0.44±0.02) and lowest 0.38±0.01 on the plastic surface. The result suggests that the highest static coefficient of friction on plywood surface could be attributed to the roughness of its surface, while the lowest coefficient of static friction on the plastic surface could be attributed to the smoothness of its surface.

Keywords: Soybean seeds; Moisture level; Engineering properties; Design and construction, Processing

INTRODUCTION

Soybean (*Glycine max* (L.) Merr.), one of the richest sources of plant protein among leguminous crops grown commercially worldwide, is the leading source of vegetable oil in the international market and accounts for about 20-24% of all fats and oil in the world (Adekanye and Olaoye, 2013; Gunda, 2017). It is a nutritious grain legume, with 40% protein, 35% total carbohydrate, 20% cholesterol-free oil and mineral content estimated at 1.7% potassium, 0.3% magnesium, 110 ppm iron, 50ppm zinc and 20 ppm copper (Manuwa, 2011). Valued for its wide edible varieties such as pure oil, margarine, processed foods, meat and milk substitutes and its flour (defatted or straight), soybean is a basic material for a wide range of protein foods (Nwachukwu *et al.*, 2006). It is good for soy-milk, soy-cheese, local magi (d*addawa*) and tom-brown, an infant weaning food (Fubara-Manuel *et al.*, 2014). Soymilk provides proteins and other nutrients to people in regions where the supply of animal milk is inadequate and especially important for infants and children who exhibit allergic reactions to dairy milk or for people with particular need for adequate protein in their diets (Iwe, 203; Fumen and Yiljep, 2005). Its composition compares favourably with those of cow's milk and human milk, with total solids of 8-10%, depending on the mixture ratio of water and bean in its processing, 3.6% protein, 2% fat, 2.9% carbohydrates, 0.5% ash (Islas-Rubio and Higuera-Ciapara, 2002).

Considering the increasing economic importance of food materials and the complexity of modern technologies for their production, harvesting and postharvest handling operations, there is need for comprehensive knowledge on physical properties of these materials (Chukwu and Sunmonu, 2010; Burubai and Amber, 2014). Physical properties of agricultural materials are those morphological attributes which when investigated are relevant to the engineering design and development of pre and postharvest handling equipment and machines for such materials. Most agricultural materials are irregular in shape and therefore, complete specifications of their form require an infinite number of measurements, which describe the physical state of a material at any given conditions and time. The number of these measurements increases with increase in the irregularity of the shape of the materials (Alonge and Omoniyi, 2012). Thus, numerous researchers have investigated the physical properties of different agricultural materials, amongst which are Bart-Plange *et al.* (2005) for maize; Heidarbeigi *et al.* (2008) for wild pistachio; Kilickan *et al.* (2010) for tef seed; Burubai *et al.* (2007) for african nutmeg; Burubai *et al.* (2014) for ngolgolo fruits; Abdullah *et al.* (2011) and Garnayak *et al.* (2008) for jatropha seeds, Gunda (2017) for cowpea and bambarnut seeds.

To design and fabricate appropriate indigenous equipment and machines for planting, harvesting and postharvest handling of any particular agricultural material, there is need for adequate knowledge of such properties as shape, axial dimensions, arithmetic mean diameter, geometric mean diameter, surface area, sphericity, aspect ratio, thousand grain mass and volume, bulk density, true density, porosity, angle of repose and static coefficient of friction

(Unal *et al.*, 2006; Kibar *et al.*, 2014; Opadotun *et al.*, 2015). The size and shape of a grain material, for instance, are important in its electrostatic separation from undesirable materials and in the development of sizing and grading equipment and machines (Heidarbeigi *et al.*, 2009). The shape of the material is important for an analytical prediction of its drying behavior (Isik and Unal, 2007).The bulk density, true density and porosity can be useful in sizing grain hoppers and storage facilities as well as affecting the rate of heat and mass transfer of moisture during aeration and drying processes. Grain bed with low porosity will have greater resistance to water vapor escape during drying process, which may require higher power to drive the aeration fans. The resistance of bulk grain to airflow also is in part a function of the porosity and the kernel size (Heidarbeigi *et al.*, 2009).

The angle of repose and coefficient of friction are important properties in designing equipment for solid flow and storage structures. The coefficient of friction (static and dynamic) of the grain on commonly used bin wall materials such as galvanized steel, plywood and concrete surfaces is important in designing storage bins, hoppers, chutes, screw conveyors, forage harvesters, and threshers (Altuntaş and Yildiz, 2007; Ixtaina *et al.*, 2008). The angle of repose is an important property in determining the maximum angle of a pile of grain with the horizontal plane, as well as the filling of a flat storage facility when grain is not piled at a uniform bed depth but rather is peaked (Heidarbeigi *et al.*, 2009).

The objective of this research was to determine some physical properties of soybean seeds to establish a convenient reference data for the mechanization and processing of soybeans.

MATERIALS AND METHODS

The study was conducted in 2017 in the Department of Agricultural and Bio-environmental Engineering Technology, Samaru College of Agriculture, Ahmadu Bello University, Zaria, Nigeria.

Material Collection and Preparation

A sample of soybean seeds, locally referred to as *waken-soya* (Hausa) was used in this study. The sample was sourced from Samaru market in Sabon-Gari Local Government Area of Kaduna state. The seed sample was prepared by winnowing and hand picking to remove dust and chaff, stones, pieces of stalks, animal droppings as well as broken and immature seeds.

Experimental procedures

To determine the selected physical properties of the soybean seeds, the moisture content of the seeds was determined. At the basis of this moisture content, the physical properties were determined under three subheadings namely geometric properties, gravimetric properties and frictional properties.

Determination Moisture content

To evaluate the selected physical properties at a given moisture content, three samples of soybean seeds, each weighing 50g, were oven dried at 103°C for 24hr (Unal *et al.*, 2006). The hot dried seed samples were cooled in desiccators after which they were reweighed, using an electronic balance at 0.01g accuracy, to determine the moisture loss. The moisture content was determined using the expression in Equation (1).

$$M_{db} = \frac{Wi - Wf}{Wf} \times 100 \quad (1)$$

Where,
M_{db} = Moisture content (%db), W_i = initial weight of sample before drying (g), W_f = final weight of sample after drying (g).

Determination of Geometric Properties

Using 50 randomly picked seeds from a 500g mass of seeds, the dimensions of the three principal axes namely major diameter (a), intermediate diameter (b) and minor diameter (c) were measured, using a vernier caliper with an accuracy of 0.01 mm. Mean values of the three axial dimensions were used to determine the geometric mean diameter (D_g), arithmetic mean diameter (D_a), surface area (A_S), sphericity (φ) and aspect (R_a) of the seeds (Simonyan *et al.*, 2013; Ogunsina, 2014; Burubai and Amber, 2014; Yisa *et al.*, 2016).

Geometric mean diameter (D_g)

Computing the mean values of the tri-axial dimensions, the geometric mean diameter of the seeds was determined using the expression in Equation (2).

$$D_g = \sqrt[3]{(abc)} \quad (2)$$

Arithmetic mean diameter (D_a)

Mean values of the three principal axes (a, b and c) were used to determine the arithmetic mean diameter as expressed in Equation (3).

$$D_a = \frac{(a+b+c)}{3} \quad (3)$$

Surface Area (A_s)

Surface area is an important property related to size and shape of a biomaterial. It is useful in estimating the amount of packaging space and the rate of heating and cooling during drying (Heidarbeigi *et al.*, 2009; Burubai and Amba, 2014). The surface of the seeds was determined as expressed in Equation (4).

$$A_s = \pi(D_g)^2 \quad (4)$$

Where,
As = surface area (mm²) , D_g = geometric mean diameter (mm)

Sphericity (φ)

Sphericity is a property relevant to fluid flow, heat and mass transfer calculations. It expresses the characteristic shape of a solid object relative to that of a sphere of same volume (Heidarbeigi *et al.*, 2009; Burubai and Amber, 2014). It was determined as expressed in Equation (5).

$$\varphi = \frac{\sqrt[3]{(abc)}}{a} \quad (5)$$

Aspect ratio (R_a)

It is a property that determines also the shape of agricultural materials (Burubai and Amber, 2014). It was calculated by use of the expression in Equation (6).

$$R_a = \frac{b}{a} \times 100 \quad (6)$$

Determination of Gravimetric Properties

Properties such as 1000 seed mass (m_s) and volume (v_s) of 1000 seed mass, and bulk seed mass (m_b) and volume (v_b) were measured. Mean values of the measurements were used to determine the true density, bulk density and porosity of the seeds (Jibril et al., 2016; Gunda, 2017).

True density (ρt)

The true or solid density of the seeds was determined by dividing the solid mass (ms) by the solid volume (vs) of the seeds. One thousand seed weight (M_{1000}) was obtained by weighing 100 seeds on an electronic balance of 0.001g accuracy. The mass was multiplied by 10 to give the mass of 1000 seeds (m_s). Similarly, 100 seeds were submerged into kerosene in a cylinder. Multiplying the volume of kerosene displaced by 10, gave the volume of 1000 soybean seeds (Jibril *et al.*, 2016). The true density was calculated using the expression in Equation (7).

$$\rho t = \frac{ms}{vs} g/cm^3 \quad (7)$$

Where,

ρt = true density (g/cm^3), ms = mass of 1000 seeds (g), vs = volume of 1000 seeds (cm^3).

Bulk density (ρB)

To determine the bulk density, a measuring cylinder with a volume of 1000 cm^3 was used. Measuring the mass of the cylinder, the cylinder was filled with soybean seeds to the brim. The top was tapped to settle the seeds well in the spaces. The measuring cylinder with soybean seeds was weighed. Subtracting the weight of empty cylinder from the weight of cylinder and seeds, the bulk mass of seeds was given as m_b. The bulk volume (v_b) of the seeds was the same as the volume of the cylinder (Ndukwu and Adama, 2012). Bulk density was determined by the expression in Equation (8).

$$\rho b = \frac{mb}{vb} \ (g/cm^3) \quad (8)$$

Where,

ρb = bulk density (g/cm^3), m_b = bulk mass of seeds (g), V_b = volume of seeds (cm^3).

Porosity (ε)

Heidarbeigi *et al.* (2009) defined porosity as the ratio of inter-granular space to the total space occupied by the seeds in store or container. Using the values of true density and bulk density, the porosity of the seeds was determined as expressed in Equation (9).

$$\varepsilon = (1 - \frac{\rho b}{\rho t}) \times 100 \quad (9)$$

Where,

ε = porosity (%), ρb = bulk density (g/cm^3), ρt = true density (g/cm^3).

Determination of Frictional Properties

The two frictional properties of the seeds determined were angle of repose and coefficient of static friction against three different structural material surfaces (plywood, plastic and galvanized iron).

Angle of repose (θ)

To determine the angle of repose for soybean seeds, a topless and bottomless cylindrical hollow frame made of plywood and a circular wooden platform of known diameter was used. The hollow frame was placed on the platform and filled with soybean seeds. Lifting up the frame slowly, the seeds fell in a pile or heap on the platform, assuming a natural slope (Orhevba *et al.*, 2016). Using the height (H) of pile of seeds and the diameter (D) of spread of the seeds, the angle of repose was determined as expressed in Equation (10).

$$\theta = \tan^{-1}(\frac{2H}{D}) \quad (10)$$

Coefficient of static friction (μ)

The coefficient of static friction of the seeds was determined against three different material surfaces, namely plywood, plastic and galvanized iron. This involved the use of a topless and bottomless hollow metal cube and an adjustable titling surface. Placing the hollow metal cube on the adjustable tilting surface and filling it to the brim with soybean seeds, the inclined surface was tilted until the samples began to move leaving an inclined surface. The angle of inclination with the horizontal base was measured by a scale provided and taken as an angle of internal friction (α), while the tangent of the angle was taken as coefficient of friction (μ) between the material surface and the seeds (Varnamkhasti *et al.*, 2008; Jibril *et al.*, 2016). The coefficient of static friction was determined as expressed in Equation (11).

$$\mu_s = \tan\alpha \quad (11)$$

Where,

μ_s = coefficient of static friction,
α = angle of internal friction (°).

Statistical Analysis

In computation and comparison of the data generated from this study, mean, standard deviation and coefficient of variation were applied, using SPSS 11.5 for Windows (Chukwu and Sunmonu, 2010). A t-test was used to determine significance in differences between means.

RESULTS AND DISCUSSION

A summary of the results of determined physical properties of soybean seeds at 8.02% $\pm$ 1.02 % moisture content (db) is presented in Tables1, 2 and 3, and discussed under three subheadings namely geometric, gravimetric and frictional properties.

Table1: Mean geometric properties

PP	No/Qty	Max	Min	Mean (μ)	SD (σ)	CV (%)
M	50	9.04	7.0	8.02	1.02	1.27
a	50	6.73	4.64	5.69	1.05	18.77
b	50	6.64	4.59	5.62	1.04	17.97
c	50	7.00	4.67	5.84	1.17	19.98
D_g		6.89	4.63	5.76	1.13	19.59
D_a		6.89	4.63	5.76	1.13	19.59
A_s		149	67	108	1.34	19.31
φ.		0.78	0.68	0.73	0.54	13.44
R_a		99	99	99	0.15	18.71

Geometric Properties of Soybean Seeds

The measurements taken for major, intermediate and minor diameters of soybean seeds gave values in the range of 4.64-6.73 mm, 4.59-6.64 mm and 4.67-7.00 mm, with mean values of 5.61 mm$\pm$ 1.05, 5.76 mm $\pm$ 1.04 and 5.83 mm $\pm$ 1.17, respectively. These values were found to be much closer to earlier reported values of 7.41 mm, 5.34 mm, 4.50 mm for soybean seeds as reported by

Polat *et al.* (2006) and 10.50 mm, 9.48 mm and 8.50 mm for bambara nut seeds (Mpotokwane *et al.*, 2008). According to Ogunsina (2014), these values smaller in size when compared with other crop seeds such as cashew, almond, pistachio, filbertnut seeds and cashew nuts and kernels which mean major diameter, intermediate diameter and minor diameter were 32.24mm, 23.23mm and 17.02mm (Oloso and Clarke, 1993); 25.49m, 17.03mm and 13.12mm (Aydin, 2003); 16.86mm, 12.10mm and 11.81mm (Kashaninejad *et al.*, 2004), and 25.32mm, 20.54mm and 17.93mm (Pliestic *et al.*, 2006), respectively. Mean values of the tri-axial dimensions were used to estimate the values of geometric mean diameter, arithmetic mean diameter, surface area, sphericity and aspect ratio. The values were found to be 5.76 mm$\pm$1.13, 5.76 mm $\pm$ 1.13, 108 mm $\pm$ 1.34, 0.73$\pm$0.54 and 99%$\pm$0.15, respectively. Similar investigations on the dimensional properties for various agricultural materials have been carried out (Asoiro *et al.,* 2012; Ogunsina, 2014). Knowledge of the difference in size of grain crops plays an important role in the selection of sieve or screen size in the design of cleaning and separating equipment and in the design of augers and barrels for effective oil extraction from palm kernel seeds (Gbadamosi, 2006). The tri-axial dimensional parameters of agricultural materials also play important roles in the design of processing and handling equipment and machines as they are useful in determining the aperture size of machines, particularly in separation of materials as well as estimating the sizes of machine components (Davies, 2011).

Geometric mean diameter of biomaterials have been found useful in determining the mean diameter of the materials as well as the diameter of sieve holes of threshing and cleaning machines (Isa and Olajide, 2015).

Comparing the surface area of 108±1.34 of the studied soybean seeds to the surface area of 687.94mm^2 and 252mm^2 for smarouba fruit and kernel, 447.9mm^2 and 898.4 for bitter kola nut and shell, 1584.80-2455.90 mm^2 and 737.37- 1378.90mm^2 for gbafilo fruit and nut (Davies and Zibokere, 2011; Davies, 2015), the surface area of soybean seeds was relatively smaller. Surface area of biological materials affects air stream velocity during separation of materials from unwanted materials in pneumatic separators or pneumatic conveyors (Asoiro *et al.*, 2011). Considering the mean sphericity of the soybean seeds at 0.73±0.54, the result suggests that soybean seeds will tend to roll when placed on an inclined platform. The ability of any grain, nut or fruit to either roll or slide depends on the sphericity as well as aspect ratio (Davies, 2009). A seed, nut, fruit or any grain crop is considered a sphere if its Sphericity approaches unity or one hundred percent (Garnayak *et al.*, 2008; Davies, 2015). Sphericity is an essential property of grain crops which is useful in the design of hoppers for cleaning machines, design of drying and storage facilities such as grain silos (Gbadamosi, 2006).

Table 2: Mean gravimetric properties

Ph.Pr.	No/Qty	Max	Min	Mean (μ)	SD (σ)	CV (%)
M	50	9.04	7.0	8.02	1.02	1.27
m_s	50	0.18	0.15	0.17	0.02	9.88
v_s	50	0.19	0.16	0.18	0.02	9.62
m_b	500	35.34	33.75	34.55	0.71	2.07
V_b	500	42.07	40.18	41.13	0.98	2.39
ρT		0.95	0.94	0.95	0.01	1.09
$\rho B.$		0.84	0.84	0.84	0.02	1.90
$\varepsilon.$		12	11	11.50	0.32	3.44

Gravimetric Properties of Soybean Seeds

The result in Table2 gave mean values of true density, bulk density and porosity of the soybean seeds as 0.95gmm^{-3} $\pm$0.01, 0.84gmm^{-3}$\pm$0.02 and 11.5% $\pm$ 0.32, with corresponding coefficients of variation at 1.09, 1.90 and 3.44, respectively. Both densities were lower than unity, implying that soybean seeds are less dense than water (1000 g/cm^3). This suggests that the seeds will tend to float when placed in water, hence water can be used to convey or separate the seeds from other heavier objects (Gbadamosi, 2006). Both true density and bulk density play important roles in determining the storage capacity of grain materials.

Comparing the porosity (11.5%) of soybean seed with the porosity of common beans, cowpea and yard-long beans in the range of 49-53.5% (Ndukwu and Adama, 2012), 51.03-31.48% for *prosopis Africana* seeds (Asoiro *et al.*, 2012) and 34.10-68.00% for hog plum fruit and nut (Davies, 2015), soybean seeds were considered less porous. This implies difficulty in the flow of heated drying air stream through a pile seeds on a drying platform. Materials with low porosity have less pore spaces and hence dry slowly. To achieve effective aeration of less porous materials, high power fans and motors are needed to pass air through the pore spaces (Asoiro *et al.*, 2012; Davies, 2015).

Table3: Mean frictional properties

Ph.Pr.	No/Qty	Max	Min	Mean (μ)	SD (σ)	CV (%)
M	50	9.04	7.0	8.02	1.02	1.27
θ.	500	30	27	28.50	1.00	2.00
μ_s	500					
Plw		0.45	0.42	0.44	0.02	3.64
Plg		0.39	0.37	0.38	0.01	2.63
Gli		0.44	0.42	0.43	0.01	2.33

Frictional Properties of Soybean Seeds

In Table3, the result showed that the angle of repose between the seeds and the horizontal plane of the wooden platform ranged between 27 ° and 30 °, with a mean value of 28. 50 ° ±1.00, and a corresponding coefficient of variation at 2.00. Comparing this value with the angles of repose for bitter kolanut seed (21. 9 °) and shell (33. 7 °) as reported by Davies (2015), 21.58 -22. 72 ° for *prosopis Africana* seeds (Asoiro *et al.*, 2012) and 38. 5 ° for *neem* seeds (Balogun *et al.*, 2015), the angle of repose for soybean seeds was found to be closer in range. Angle of repose is an essential property for determining flow ability of biomaterials; the lower the angle of repose, the less cohesive the biomaterials are, hence, the easier the flow of the materials. The angle of repose is also needed in the determination of the relative size of length (diameter) and height of an appropriate storage structure for grain materials (Gbadamosi, 2006).

The coefficients of static friction between soybean seeds and surfaces of plywood, plastic glass and galvanized iron were in the range of 0.42-0.45, 0.37-0.39 and 0.42-0.44, with mean values of 0.44 ± 0.02, 0.38 ± 0.01 and 0.43 ± 0.01, respectively. The highest coefficient of static friction (0.44 ± 0.02) was on the plywood surface, while the lowest coefficient of static friction (0.38 ± 0.01) was on the plastic glass. The relatively higher coefficient of static friction on the plywood surface could be attributed to the roughness of its surface while the relatively lower value recorded on the plastic glass could be attributed to the smoothness of the glass surface. This property determines how a pile of seeds or grain will flow on structural material surfaces. Static coefficient of friction is a design parameter needed in determining the steepness of storage containers, hoppers or any loading or unloading devices for grain crops (Asoiro *et al.*, 2012).

CONCLUSIONS

Some physical properties of soybean seeds which are likely to be useful in the design and development of postharvest handling, processing and storage equipment and machines were evaluated in this study. From the results it can be concluded that:

1. The mean geometric properties namely major diameter, intermediate diameter, minor diameter, geometric mean diameter, arithmetic mean diameter,

surface area, sphericity and aspect ratio varied significantly ($p>0.05$).

2. The ratio bulk density to true density of the investigated seeds gave low porosity of 11.5%±0.32.

3. The angle of repose was 28.5$^{\circ}\pm 1.00$, while the static coefficient of friction of the seeds was highest on plywood (0.44±0.02) and lowest 0.38±0.01 on the plastic surface.

4. The highest static coefficient of friction was observed with plywood surface, while the least was noticed with glass.

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Nomenclature

Ph.Pr Physical property
a Major diameter, mm
b Intermediate diameter, mm
c Minor diaeter, mm
D_g Geometric mean diameter, mm
D_a Arithmetic mean diameter, mm
A_s Surface area, m^2
φ Sphericty
R_a Aspect ratio, %
ρt True density, g/cm^3
ρb Bulk density, g/cm^3
ε. Porosity
θ Angle of repose, degree (°)
μ_s Static coefficient of friction
Plw Plywood
Plg Plastic glass
Gli Galvanized iron

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