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Effect of moisture content on the engineering properties of African yam bean (*Sphenostylis stenocarpa*) seed

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ABSTRACT

Purpose: This work was carried out to investigate the effect of moisture content on the engineering properties of African Yam Bean (*Sphenostylis stenocarpa*) seeds. **Research method:** Physical and mechanical properties of African Yam Bean seeds were evaluated. The physical and mechanical properties were evaluated at five moisture content levels of 8, 12, 16, 20 and 24% dry basis (d.b). **Findings:** From the physical properties, the average length, width, thickness, arithmetic mean diameter, geometric mean diameter and equivalent diameter were found to increase significantly (P≤0.05) with an increase in moisture content. The surface areas, volume, sphericity, aspect ratio, flakiness ratio, porosity, static angle of repose, dynamic angle of repose and static coefficient of friction of the seeds were also found to increase significantly (P≤0.05) with increasing seed moisture content. The mean results of seed densities showed a decrease in bulk density (0.840±0.045 to 0.806±0.074 g/cm^3) and true density (1.268±0.083 to 1.238±0.079 g/cm^3) with the increase in seed moisture content from 8% to 24 % (d.b). From the mechanical properties, the mean force, deformation, strain and energy for African yam bean seeds decreased significantly (P≤0.05) with the increase in moisture content. The mechanical properties evaluated showed a decrease in the force at peak (176.564±20.137 to 104.860±9.814 N), force at yield (168.548±24.049 to 84.694±53.464 N) and force at break (172.880±19.506 to 96.986±14.536 N) with the increase in seed moisture content from 8% to 24 % (d.b). **Research limitations:** No limitation to the report, yet, the study cannot claim to have exhausted all factors that influence engineering properties of African Yam Seed; thus, effects of other factors such as accessions, varieties, cultivars and species is recommended for further studies. **Originality/Value:** The results provide relevant data on efficient process handling and equipment design of the seeds to the engineers and designers.

INTRODUCTION

African yam bean (*Sphenostylis stenocarpa*) is an annual grain legume and has a pattern of growth similar to those of other grain legumes (Ameh, 2003). African yam bean is cultivated mainly for home consumption and only about 30% of the dry grain produced is sold (Osuagwu & Nwofia, 2014). It is a good source of protein, energy and the most culturally and economically important of the seven species in the genus *Sphenostylis* (Ojukwu *et al*., 2012). It is cultivated in South-Eastern Nigeria for its edible seeds, but cultivated in Central African Republic, Zaire, East Africa and Ethiopia for its tubers. Nutritionally, the African yam beans seed contains 62.6% carbohydrates, 21-29% protein and 2.5% fat. The grain is also high in Sulphur-containing amino acids (Ojukwu et al., 2012). In areas where it is grown for its seeds, the African yam bean has become an important substitute for animal protein and more widely-eaten cowpea (Ameh, 2007). Like cowpea, the seeds are contained in a pod, with each pod containing between ten and thirty seeds. The seeds of the African yam bean have a brown, black, white, grey or speckled bean-shaped appearance (Asoiro & Ani, 2011). The crop helps agriculturally to enrich the soil by its ability to fix nitrogen from the atmosphere. Studies have shown that the underutilized legumes are highly nutritious and are used as food, cover crops, green manure and natural fertilizers (Klu et al., 2000).

In Nigeria, the consumption of African yam bean seeds is restricted to the harvesting period, after which their availability in the rural market becomes scarce, as they are not cultivated in large quantities and their uses are limited (Ojukwu et al., 2012). This trend is not unconnected with the fact that there is hardly any food processor of African yam bean that possesses mechanized equipment for its harvesting, handling or processing. Most subsistence and small-scale producers perform the key operations manually which yields a product with poor quality and low nutrients. The design and fabrication of mechanical systems and associated equipment for handling, harvesting, processing, moving, aeration and storing the African yam bean seeds will be predicated on the determination of the engineering properties of the seeds. Asoiro and Ani (2011) investigated and reported the various post-harvest physical properties of African yam beans (*Sphenostylis stenocarpa*). The major diameter, intermediate diameter, minor diameter, and geometric mean diameter were determined as 8.1778 cm, 6.712 cm, 6.3025 cm and 7.0128 cm, respectively. The sphericity indicated that the bean shape (0.85933) is close to a sphere. The surface area and specific surface area were 77.404 cm^2 and 169.709 cm^2/cm^3, respectively. The static coefficient of friction on three different material surfaces varied from 0.114 to 0.196 on asbestos, from 0.097 to 0.1997 on aluminum, and from 0.1534 to 0.2049 on plywood. The angle of repose which was by the emptying method was 23.7750. The solid volume, bulk volume, solid density, bulk density, seed mass and porosity were 0.2387 cm^3, 7.6552 cm^3, 1.0179 g/cm^3, 1.0036 g/cm^3, 0.2362 g and 1.6805%, respectively. The moisture content varies from the range of 2.84% wb to 3.13% wb or a range of 2.93% d.b to 3.23% d.b. The data so generated there, because few researchers have worked on this study area, would be handy to overcome some of the handicaps which may be faced in the fabrication process of processing equipment.

The engineering properties of various agricultural products need to be understood and are very important to the design of machine structure, process and control. The engineering properties are physical, mechanical, thermal, electrical, optical, aerodynamic and hydrodynamic properties. All these properties are very useful in handling, storage, processing, preservation, quality evaluation distribution and marketing of crops. But in the course of this research, only the physical and mechanical properties were considered. To design equipment used in planting, storage, transportation, harvesting, processing, and oil extraction of agricultural oil seeds, it is necessary to know various physical and mechanical properties

(Bamgboye & Adebayo, 2012). The physical and mechanical properties are important in the sizing, separating, grinding, and oil extraction machines. As the true density, bulk density and porosity are used in the design of storage bins and silos, separation of desirable materials from impurities, cleaning and grading and quality evaluation of the products. The static friction coefficient of the grinding against the various surfaces is also necessary for designing conveying, transportation and storage structures. Moreover, moisture content, volume and density play important roles in numerous technological processes and in evaluating product quality during drying, and also in the design of silo and other storage structures (Olaniyan & Oje, 2002).

African yam bean seeds have a wide range of applications and have great potential. There is little information on the basic physical and mechanical properties of the seeds, which is an identified problem in the development of a new method of handling and processing the seeds. There is no equipment specifically designed and used in handling and processing African yam bean seeds. This is probably due to the lack of relevant data and information on the physical and mechanical properties of the seeds with different moisture contents. Therefore, this study aims to determine the effect of moisture content on some engineering properties of African yam bean seeds locally grown in Taraba State, Nigeria.

MATERIALS AND METHODS

Sample preparation

Fresh samples of the seeds were obtained from a local market in Jalingo, Taraba State, Nigeria. The seeds were manually clean to remove foreign materials and dirt. Hundreds of seeds were randomly selected for various experiments and conditioned to different moisture contents and their physical and mechanical properties were determined.

Moisture content determination

The initial moisture content (7.8% dry basis) of the seeds was determined using the standard hot air oven method at 105 °C±1 °C for 24 hours till there were no more changes in the weight. The initial moisture content (Dry basis) was obtained using Equation 1 (Mirzabe et al., 2016).

$$M_c = \frac{W_1 - W_2}{W_2} \quad (1)$$

Where; M_c = Moisture content (%), W_1 = Weight of seed before oven drying (g), W_2 = Weight of seed after oven drying (g).

Variation of moisture content

The samples (7.8% dry basis) were transferred to separate polythene bags and reconditioned to moisture content levels of 8%, 12%, 16%, 20% and 24%. A calculated amount of distilled water was added to each sample and the bags were sealed tightly. The samples were refrigerated for a week to enable the moisture to distribute uniformly throughout the samples. The prepared samples were then taken out of the refrigerator and placed at room temperature for about 2 hours. The samples of the preferred moisture contents were prepared by adding the pre-determined quantity of distilled water by using Equation 2 (Hazbavi, 2013; Audu et al., 2020).

$$Q = \frac{W_i(m_f - m_i)}{100 - m_f} \quad (2)$$

Where; Q = Mass of distilled water to be added (g), W_i = Initial mass of sample (g), m_i = Initial moisture content of the sample in dry basis (%), m_f = Final moisture content of the sample in dry basis (%).

Determination of physical properties

The physical properties of African yam bean seeds determined include; geometrical properties (size and shape), gravimetric properties and frictional properties.

Determination of size

A Mitutoyo absolute digimatic vernier caliper with 0.001 mm accuracy was used to measure the Length (major diameter), Width (intermediate diameter) and Thickness (minor diameter) of the seeds. The average of each measurement was taken as the reading for each of the samples (Dauda et al., 2015; Balami et al., 2016).

Arithmetic mean diameter (Da)

The arithmetic mean diameter of the African yam bean seed was determined from the Length (L), Width (W) and Thickness (T) using the relationship in Equation (3) as reported by Hazbavi (2013).

$$D_a = \frac{L+W+T}{3} \qquad (3)$$

Geometric mean diameter (D_g)

The geometric mean diameter of the African yam bean seed was determined from the Length (L), Width (W) and Thickness (T) using the relationship in Equation (4) as reported by Hazbavi (2013).

$$D_g = (LWT)^{\frac{1}{3}} \qquad (4)$$

Equivalent diameter (D_e)

The equivalent diameter of the African yam bean seed was determined from the Length (L), Width (W) and Thickness (T) using the relationship in Equation (5) as reported by Mirzabe *et al*. (2016).

$$D_e = \left[\frac{(T+W)^2}{4} L\right]^{\frac{1}{3}} \qquad (5)$$

Surface area (S_a)

Surface area is defined as the total area over the outside of the African yam bean seed. The surface area was determined by analogy using Equation 6 (Hazbavi, 2013).

$$S_a = \frac{\pi B L^2}{2L-B} \qquad (6)$$

But, $B = (WT)^{0.5}$

Where; S_a = Surface area (mm^2), L = Length (mm), W = Width (mm), T = Thickness (mm).

Specific surface area (S_S)

The specific surface area of African yam bean seed (S_S) in cm^2/cm^3 was calculated using Equation 7 according to Idowu et al. (2012).

$$S_s = \frac{S \times \rho_b}{M} \quad (7)$$

Where; S_s = Specific surface area (cm^2/cm^3), S = Surface area (cm^2), ρ_b = Bulk density of seeds (g/cm^3), M = Mass of one unit of seed (g).

Frontal area (F_a)

The frontal area and the related diameters are essential for the determination of terminal velocity, Reynold's number and drag coefficient. The frontal area was obtained using Equation 8 given by Idowu et al. (2012).

$$F_a = \frac{\pi}{4}(D_g)^2 \quad (8)$$

Transverse surface area (A_t)

Transverse surface was calculated from Equation 9.

$$A_t = \frac{\pi WT}{4} \quad (9)$$

Projected area (A_P)

The flat surface or projected area was determined from Equation 10.

$$A_P = \frac{\pi WL}{4} \quad (10)$$

Volume of seeds (V)

The volume of seeds was calculated using Equation 11 (Abano & Amoah, 2011; Hazbavi, 2013).

$$V = \frac{\pi B^2 L^2}{6(2L - B)} \quad (11)$$

But, $B = (WT)^{0.5}$

Determination of shape

Sphericity

This is a method to measure how close the material is to a sphere. The sphericity (∅) of African yam bean seed was calculated by using the values of the length, width and thickness of the seed from the expression in Equation 12 (Balami et al., 2016).

$$\emptyset = \frac{(LWT)^{\frac{1}{3}}}{L} \quad (12)$$

***Aspect* ratio**

The aspect ratio (R_a) of African yam bean seed at a natural flat position was calculated by using the following equations according to Werby and Mousa (2016).

$$R_a = \frac{W}{L} \quad (13)$$

Flakiness ratio

The flakiness ratio (F_r) is the ratio of the thickness to the width of a particle and was calculated by using the following Equation according to Mirzabe et al. (2016).

$$F_r = \frac{T}{W} \qquad (14)$$

Elongation ratio

Elongation ratio (E_r) is the ratio of the effective length to the width of a particle. It was calculated from Equation 15 (Mirzabe et al., 2016).

$$E_r = \frac{L}{W} \qquad (15)$$

Determination of gravimetric properties

Thousand seed mass

Hundreds of seeds weight was measured by counting 100 seeds and then weighed in the digital weighing balance of 0.001 g accuracy. The resulting value was multiplied by 10 to give the mass of 1000 seeds (Hazbavi, 2013).

Bulk density

The bulk density of African yam bean seed was determined by pouring the seed into a container of known weight and volume. The content was weighed with a digital balance with a sensitivity of 0.001 g and the bulk density was calculated using Equation 16 (Hazbavi, 2013).

$$\rho_b = \frac{W_s}{V_b} \qquad (16)$$

Where; ρ_b = Bulk density (g/cm^3), W_s = Weight of the sample (g), V_b = Bulk volume occupied by the sample (cm^3).

True density

The true density was determined according to the method described by Hazbavi (2013). The true volume of the seeds was determined using the liquid (kerosene) displacement method. Kerosene was poured into a measuring cylinder of 1000 cm^3 to one-half of its volume. Pre-weighed African yam bean seeds were filled inside the cylinder and the change in the level of kerosene in the measuring cylinder was recorded. The mass of each seed was obtained by using an electronic balance with a sensitivity of 0.001 g. The true density was calculated by using the relationship in Equation 17 (Hazbavi, 2013).

$$\rho_t = \frac{M_s}{V_t} \qquad (17)$$

Where; ρ_t = True density (g/cm^3), M_s = Mass of seed (g), V_t = True volume (cm^3).

Porosity

The Porosity of the bulk seed was computed from the values of the true density and bulk density of the seeds by using the relationship adopted by Hazbavi (2013).

$$P = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \qquad (18)$$

Where; P = Porosity, ρ_b = Bulk density, ρ_t = Solid density.

Determination of frictional properties

Static coefficient of friction

The static friction coefficient of African yam bean seeds was determined on five different surfaces (plywood, glass, plastics, stainless steel and mild steel) for all the samples. A cylinder of the height of 50 mm and diameter of 50 mm open at both the top and bottom was filled with the seeds after placing on an adjustable tilting surface. The cylinder was raised slightly so as not to touch the surfaces. The structural surface with the cylinder on its top was gradually raised until the cylinder just started to slide down. The angle of the surface made with the horizontal was taken. The friction coefficient (μ) was obtained using Equation (19) by finding the tangent of the angle (Hazbavi, 2013).

$$\mu = \tan\theta \qquad (19)$$

Where; μ = Static coefficient of friction, θ = Angle of inclination (degrees).

Static angle of repose

Flow-ability of African yam bean seeds was measured using the angle of repose that will be useful in material handling equipment. The static or filling angle of repose with the horizontal at which the material will stand when piled was determined using the open-ended cylinder method. A topless and bottomless cylinder of 5 cm diameter and 7 cm height was placed at the centre of a raised circular plate, having a diameter of 35 cm. The cylinder was filled with bean seeds and raised slowly until it formed a seed cone on the circular plate. The height and base (diameter) of the cone were measured. The static angle of repose was determined using Equation 20 (Galedar et al., 2010; Hazbavi, 2013; Aliyu et al., 2017).

$$\theta_s = \tan^{-1}\left(\frac{2H}{D}\right) \qquad (20)$$

Where; θ_s = Static angle of repose of the seed cone (Degrees), H = Height of cone formed (mm), D = Diameter of cone formed (mm).

Dynamic angle of repose

To determine the dynamic or emptying angle of repose, a fibre glass box of 20 × 20 × 20 cm, having a removable front panel was used. The box was filled with the African yam bean seed samples at the moisture content being investigated, and then the front panel quickly slid upwards allowing the samples to flow out and assume a natural heap. The dynamic angle of repose (θ_d) was obtained from measurements of the height of samples at two points (H_1 and H_2) in the sloping African yam bean seeds heap and the horizontal distance between two points (X_1 and X_2) using Equation 21 (Galedar et al., 2010).

$$\theta_d = \tan^{-1}\left[\frac{(H_2 - H_1)}{(X_2 - X_1)}\right] \qquad (21)$$

Determination of mechanical properties

Mechanical properties of African yam bean seeds were determined using the Universal Testing Machine. This machine has three main components, which are a stable forced and moving platform, a driving unit (AC electric motor, electronic variator and reduction unit) and a data acquisition (load cell, PC card and software) system. The machine was equipped with a load cell of 500 N at a compressive rate of 25 mm/min. The test type conducted was compression test and the parameters tested include: force at peak, deformation at peak, strain at peak, force at yield, deformation at yield, strain at yield, force at break, deformation at break, strain at break, energy at peak, yield and break.

Experimental design and statistical analysis

The experimental design for the statistical analysis follows a One-treatment effect (moisture content) in a Completely Randomized Design (CRD) with ten observations (replications) per experimental unit. All data collected were compared using One-way analysis of variance (ANOVA) at P≤0.05 and treatment means were separated using the F-LSD at P≤0.05. All the data were analyzed using the SPSS statistical software.

RESULTS AND DISCUSSION

Effects of moisture content on physical properties

Table 1. Results of the physical properties of African yam bean seeds.

Properties	Moisture content				
	8%(db)	12%(db)	16%(db)	20%(db)	24%(db)
Geometrical Properties					
Size					
Length (mm)	7.603±0.66	8.211±0.42	8.237±0.28	9.152±0.81	9.722±0.35
Width (mm)	5.755±0.56	6.415±0.46	6.712±0.73	8.108±0.76	8.681±0.69
Thickness (mm)	4.705±0.14	5.706±0.26	6.102±0.44	7.380±0.58	7.990±0.27
Arithmetic Mean Diameter (mm)	6.021±0.81	6.777±0.93	7.017±0.76	8.213±0.55	8.798±0.68
Geometric Mean Diameter (mm)	5.905±0.43	6.698±0.38	6.961±0.61	8.181±0.66	8.769±0.27
Equivalent Diameter (mm)	5.925±0.33	6.706±0.42	6.967±0.15	8.187±0.55	8.774±0.21
Surface Area (mm^2)	94.475±6.32	123.552±5.84	135.406±8.55	192.598±6.05	222.476±4.63
Specific Surface Area (cm^2/cm^3)	3.354±0.85	4.185±0.97	4.497±0.64	5.887±0.77	6.580±0.92
Frontal Surface Area (mm^2)	27.383±3.32	35.240±2.88	38.061±4.21	52.571±5.11	60.396±4.33
Transverse Surface Area (mm^2)	21.266±3.18	28.749±3.46	32.167±2.85	46.996±4.63	54.476±6.08
Projected Area (mm^2)	34.365±2.87	41.370±3.56	43.422±5.70	58.280±6.13	66.285±4.24
Volume (mm^3)	81.935±3.21	124.584±5.33	144.427±4.86	248.305±6.15	308.810± 9.26
Shape					
Sphericity	0.777±0.073	0.816±0.053	0.845±0.092	0.894±0.069	0.902±0.085
Aspect Ratio	0.757±0.052	0.781±0.019	0.815±0.073	0.886±0.025	0.893±0.066
Flakiness Ratio	0.818±0.026	0.889±0.041	0.909±0.038	0.910±0.021	0.920±0.054
Elongation Ratio	1.321±0.212	1.280±0.091	1.227±0.104	1.129±0.124	1.120±0.214
Gravimetric Properties					
Thousand Seed Mass, M1000 (g)	236.6±7.81	245.9±9.24	248.7±5.96	266.3±6.88	272.5±5.78
Bulk Density, ρ_b (g/cm^3)	0.840±0.045	0.833±0.057	0.826±0.078	0.814±0.063	0.806±0.074
True Density, ρ_t (g/cm^3)	1.268±0.083	1.260±0.097	1.252±0.068	1.243±0.088	1.238±0.079
Porosity, P (%)	33.75±3.55	33.89±2.72	34.03±4.17	34.51±2.30	34.89±3.80
Frictional Properties					
Angle of Repose (θ)					
Static Angle of Repose (Deg.)	5.597±1.26	5.622±0.85	5.824±1.32	5.878±1.05	5.962±0.97
Dynamic Angle of Repose (Deg.)	22.132±2.16	23.006±1.95	23.775±3.17	24.502±2.31	25.212±4.08
Coefficient of Static Friction (μ) on Various Structural Surfaces					
Glass	0.249±0.043	0.264±0.061	0.277±0.017	0.291±0.041	0.295±0.091
Stainless Steel Sheet	0.268±0.012	0.273±0.027	0.281±0.014	0.294±0.036	0.298±0.037
Mild Steel Sheet	0.298±0.026	0.315±0.052	0.319±0.023	0.328±0.072	0.334±0.054
Wood	0.325±0.033	0.341±0.058	0.356±0.025	0.360±0.035	0.365±0.019
Plastic Sheet	0.342±0.030	0.353±0.039	0.359±0.044	0.363±0.083	0.366±0.038

A summary of the results obtained for the physical properties of African yam bean seed at different moisture content is shown in Table 1. As it can be seen, the average length (L), width (W), thickness (T), arithmetic mean diameter (D_a), geometric mean diameter (D_g) and equivalent diameter (D_e) was found to increase with the increase in moisture content. With increasing moisture content from 8% to 24% (d.b), the length (L), width (W), thickness (T), arithmetic mean diameter (D_a), geometric mean diameter (D_g) and equivalent diameter (D_e) of the seeds increased significantly (P≤0.05) from 7.603±0.66 to 9.722±0.35 mm, 5.755±0.56 to 8.681±0.69 mm, 4.705±0.14 to 7.990±0.27 mm, 6.021±0.81 to 8.798±0.68 mm, 5.905±0.43 to 8.769±0.27 mm and 5.925±0.33 to 8.774±0.21 mm, respectively. The increase in dimensions could be attributed to the expansion of the seeds as a result of moisture absorption in the intracellular spaces inside the seeds (Sologubik et al., 2013). These dimensions are important in determining the aperture size of machines, particularly for the separation of different materials. The major axis is indicative of the natural rest position of the material and hence in the application of compressive force to induce mechanical fracture. Also, this dimension will be useful in applying shearing force during slicing (Owolarafe & Shotonde, 2004). The average values obtained from this study compares satisfactorily with that reported by Asoiro and Ani (2011).

The surface areas and volume of the seeds were also found to increase with the increase in moisture content. With increasing moisture content from 8% to 24 % (d.b), the surface area (S), specific surface area (S_S), frontal surface area (F_a), transverse surface area (A_t), projected area (A_P) and volume (V) of the African yam bean seeds increased significantly (P≤0.05) from 94.475±6.32 to 222.476±4.63 mm^2, 3.354±0.85 to 6.580±0.92 mm^2, 27.383±3.32 to 60.396±4.33 mm^2, 21.266±3.18 to 54.476±6.08 mm^2, 34.365±2.87 to 66.285±4.24 mm^2 and 81.935±3.21 to 308.810± 9.26 mm^3, respectively. The increase in surface areas and volume could be attributed to the expansion of the seeds as a result increase in dimensions.

The average values of sphericity, aspect ratio and flakiness ratio increase with increasing seed moisture content while the elongation ratio decreased with increasing seed moisture content. With increasing moisture content from 8% to 24 % (d.b), the sphericity, aspect ratio and flakiness ratio of the African yam bean seeds increased significantly (P≤0.05) from 0.777±0.073 to 0.902±0.085, 0.757±0.052 to 0.893±0.066 and 0.818±0.026 to 0.920±0.054, respectively. Generally, in the present study, the African yam bean seed is treated as an equivalent sphere. Considering the high aspect ratio (which relates the seeds width to length) and sphericity, it may be deduced that African yam bean seeds would roll on flat surfaces. This tendency to either roll or slide is very important in the design of hoppers, dehulling and thresher equipment for the seed because most of flat seeds slide easier than spherical seeds, which roll on structural surfaces (Sharma et al., 2011). Furthermore, the shape indices indicated that the African yam bean seed may be treated as a sphere for an analytical prediction of its drying behavior.

The mass of 1000 seeds was found to increase from 236.6±7.81 to 272.5±5.78 g as moisture content increased from 8% to 24% (d.b). This parameter is useful in determining the equivalent diameter that can be used in the theoretical estimation of seed volume and in cleaning using aerodynamic forces. The mean values of the bulk density and true density were found to decrease significantly (P≤0.05) with the increase in seed moisture content. With increasing moisture content from 8% to 24 % (d.b), the bulk density decreased from 0.840±0.045 to 0.806±0.074 g/cm^3 and the true density decreased from 1.268±0.083 to 1.238±0.079 g/cm^3. The decrease in seed densities with the increase in moisture content shows that the increase in mass resulting from the moisture gain of the sample is lower than the accompanying volumetric expansion of the seeds (Sologubik et al., 2013). Based on the true density value, there is a tendency for African yam bean seeds to be partially submerged in water. These properties may be useful in the separation and transportation of the seed by hydrodynamic means. The porosity of African yam bean seed increased from 33.75±3.55 to 34.89±3.80% with an increase in moisture content from 8% to 24% (d.b). This could be attributed to the expansion and swelling of seeds that might have resulted in more voids space between the seeds and increased the bulk volume. This is also exhibited in the reduction of bulk density with an increase in moisture content.

The static and dynamic angle of repose were found to increase significantly (P≤0.05) with increasing seed moisture content. With increasing moisture content from 8% to 24 % (d.b), the static angle of repose increased from 5.597±1.26 to 5.962±0.97° and the dynamic angle of repose increased from 22.132±2.16 to 25.212±4.08°. At higher moisture content seeds might tend to stick together due to the plasticity effect (stickiness) over the surface of the seeds resulting in better stability and less flow ability thereby increasing the angle of repose. The angle of repose is of paramount importance in designing hopper openings, side wall slopes of storage bins and bulk transporting of seeds using chutes (Irtwange & Igbeka, 2002). Therefore, the moisture content of seeds should be taken into account while designing such types of equipment and structures.

The static coefficient of friction of the seed was found to increase significantly (P≤0.05) as moisture level increased for all contact surfaces. The static coefficient of friction increased from 0.249±0.043 to 0.295±0.091, 0.268±0.012 to 0.298±0.037, 0.298±0.026 to 0.334±0.054, 0.325±0.033 to 0.365±0.019 and 0.342±0.030 to 0.366±0.038 for glass, stainless steel, mild steel, wood and plastic sheet, respectively, as the moisture content increases from 8% to 24% (d.b). This is due to the increased adhesion between the seed and the material surfaces at higher moisture values. The design and the dimension of hoppers, bunker silos and other bulk solid storage and handling structures should ensure non-arching (avoid stoppage of the flow of bulk solids) phenomena. The coefficient of mobility represents the freedom of motion of a substance and is inversely related to the coefficient of friction (tangent of angle of internal friction) (Irtwange & Igbeka, 2002). The higher the coefficient of friction the lower the mobility coefficient hence requiring a larger hopper opening, larger hopper side wall slope and a steeper angle of inclination in inclined grain transporting equipment like chutes (Elaskar et al., 2001; Irtwange & Igbeka, 2002) to avoid immature flow (where some depth of granular particles remain stationary) and the arching phenomena to ensure a fully developed sliding flow. The average values obtained from this study compares satisfactorily with that reported by Asoiro and Ani (2011).

Table 2. Results of the mechanical properties of African yam bean seeds.

Properties	Moisture content				
	8% (db)	12% (db)	16% (db)	20% (db)	24% (db)
Force at Peak (N)	176.564±20.137	118.452±76.791	110.560±55.044	107.710±32.430	104.860±9.814
Deformation at Peak (mm)	1.358±0.245	1.056±0.355	0.784±0.132	0.732±0.182	0.679±0.231
Strain at Peak (%)	15.767±5.303	11.805±2.133	11.362±1.917	10.672±2.655	9.982±3.393
Energy at Peak (N.m)	0.072±0.019	0.059±0.026	0.030±0.023	0.028±0.018	0.025±0.012
Force at Yield (N)	168.548±24.049	107.010±59.952	102.878±11.318	93.786±32.391	84.694±53.464
Deformation at Yield (mm)	1.322±0.304	1.004±0.251	0.757±0.173	0.666±0.237	0.574±0.300
Strain at Yield (%)	14.991±3.754	11.499±2.640	10.968±2.512	9.702±3.462	8.435±4.411
Energy at Yield (N.m)	0.069±0.024	0.050±0.013	0.024±0.013	0.022±0.016	0.019±0.018
Force at Break (N)	172.880±19.506	117.692±77.272	109.462±43.140	103.773±34.790	96.986±14.536
Deformation at Break (mm)	1.411±0.259	1.065±0.369	0.780±0.131	0.756±0.172	0.680±0.230
Strain at Break (%)	15.899±5.505	12.273±2.250	11.577±1.627	11.117±2.648	9.994±3.378
Energy at Break (N.m)	0.078±0.021	0.060±0.028	0.036±0.013	0.030±0.015	0.025±0.012

Effects of moisture content on mechanical properties

According to the results (Table 2), the force, deformation, strain and energy for African yam bean seeds decreased with an increase in moisture content. It can also be observed that the force required to cause a given deformation decreased as the moisture content increased. This may be because at higher moisture content, the seed became softer and required less force. With increasing moisture content from 8% to 24 % (d.b), the force at peak, force at yield and force at break were found to decrease significantly (P≤0.05) from 176.564±20.137 to 104.860±9.814 N, 168.548±24.049 to 84.694±53.464 N and 172.880±19.506 to 96.986±14.536 N, respectively. The small rupture forces at higher moisture content might have resulted from the fact that the seed became more sensitive to rupture at high moisture.

CONCLUSION

The variation in the moisture content increased the linear dimensions, arithmetic mean diameter, geometric mean diameter, equivalent diameter, surface areas, volume, sphericity, aspect ratio, flakiness ratio, porosity, static angle of repose, dynamic angle of repose and static coefficient of friction along the five surfaces, but decreased the bulk density and true density. The variation in the moisture content also decreased the mechanical properties. Statistical analyses (P≤0.05) revealed that the variation in the moisture content had a significant effect on the physical properties and the mechanical properties. The effects of other factors such as accessions, varieties, cultivars and species, and development of predictive models for engineering properties of African yam bean is recommended for further studies.

Conflict of interest

The authors have no conflict of interest to report.

REFERENCES

Abano, E.E. & Amoah, K.K. (2011). Effect of moisture content on the physical properties of Tiger nut (*Cyperus esculentus*). *Asian Journal of Agricultural Research*, *5*(1), 56-66. http://doi.org/10.3923/ajar.2011.56.66

Aliyu, M., Balami, A.A., Dauda, S.M., Mohammed, I.S. & Abdulfatai, Y. (2017). Engineering properties of Luffa (*L. cylindrica*) seed relevant to the processing machineries. *Agricultural Engineering International: CIGR Journal*, *19*(3), 47-55. http://www.cigrjournal.org.

Ameh, G.I. (2003). Seedling morphology and growth analysis studies of African yam bean, *Sphenostylis Stenocarpa* (Hoechst. Ex. A. Rich.) Harms. Unpublished PhD Thesis, Department of Botany, University of Nigeria, Nsukka. 146pp.

Ameh, G.I. (2007). Proximate and mineral composition of seed and tuber of african yam bean, *Sphenostylis Stenocarpa* (Hoechst. Ex. A. Rich.) Harms. *ASSET - An International Journal, ASSET Series B*, *6*(1), 1-10.

Audu, J., Aremu, A.K. & Ogunlade, C.A. (2020). Development of a neural network model for and identifying bulk Cowpea seeds variety using its electrical properties. *LAUTECH Journal of Engineering and Technology*, *14*(2), 65-79.

Asoiro, F.U. & Ani, A.O. (2011). Determination of some physical properties of African yam beans. *The Pacific Journal of Science and Technology*, *12*(1), 374-380. http://www.akamaiuniversity.us/PJST.htm.

Balami, A.A., Dauda, S.M., Lawal, A. & Ahmad, D. (2016). Some engineering properties of palmyra palm tree (*Borassus aethiopum*) germinating shoot. *Agricultural Engineering International: CIGR Journal*, *18*(1), 58-69. http://www.cigrjournal.org.

Bamgboye, I.A. & Adebayo, S. (2012). Seed moisture dependent on physical and mechanical properties of *Jatropha curcas*. *Journal of Agricultural Technology*, *8*(1), 13-26.

Dauda, S.M., Ahmad, D., Khalina, A. & Jamarei, O. (2015). Effect of cutting speed on cutting torque and cutting power of varying kenaf-stem diameters at different moisture contents. *Pertanika Journal of Tropical Agricultural Science, 38*(4), 549-561.

Elaskar, S.A., Godoy, L.A. Mateo, D. & Seeber, G. (2001). An Experimental Study of the Gravity Flow of Sorghum. *Journal of Agricultural Engineering Research*, 79(1), 65-71. http://doi.org/10.1006/jaer.2000.0665

Galedar, M.N., Tabatabaeefar, A., Jafari, A., Sharifi, A., Mohtasebi, S.S. & Fadaei, H. (2010). Moisture dependent geometric and mechanical properties of wild pistachio (*Pistacia vera* L.) nut and kernel. *International Journal of Food Properties*, *13*(6), 1323-1338. http://doi.org/10.1080/10942910903062099

Hazbavi, I. (2013). Moisture dependent physico-mechanical properties of Iranian okra (*Ablemoschus esculentus* L.) Seed. *African Journal of Biotechnology*, *12*(42), 6098-6106. http://doi.org/10.5897/AJB2013.12888

Idowu, D.O., Abegunrin, T.P., Ola, F.A., Adediran, A.A. & Olaniran, J.A. (2012). Measurement of some engineering properties of sandbox seeds (*Hura crepitans*). *Agriculture and Biology Journal of North America*, *3*(8), 318-325. http://doi.org/10.5251/abjna.2012.3.8.318.325

Irtwange, S.V. & Igbeka, J.C. (2002). Flow properties of African yam bean (*Sphenostylis stenocarpa*) as affected by accession and moisture content. *Transaction of the American Society of Agricultural Engineers (ASAE)*, *45*, 1063-1070. http://doi.org/10.13031/2013.9915

Klu, G.Y., Bansa, D., Kumaga, F.K., Aboagye, L.M., Benett-Lartey, S.O. & Gamedoagbao, D.K. (2000). The African yam bean (*Sphenostylis stenocarpa*): A neglected crop in Ghana. *West African Journal of Applied Ecology*, *1*(1), 53-60. http://doi.org/10.4314/wajae.v1i1.40570

Mirzabe, A.H., Taheri, M., Pouyesh, A. & Bavani, N.B. (2016). Moisture content on some engineering properties of celery (*Apium graveolens L*) seeds. *Agricultural Engineering International: CIGR Journal*, *18*(2), 243-259.

Ojukwu, M., Olawuni, I.A., Ibeabuchi, C. & Amandikwa, C. (2012). Physical, proximate and functional properties of "Nsama", a local variety of African yam bean (*Sphenostylis stenocarpa*) grown in southern states in Nigeria. *African Journal of Food Science and Technology*, *3*(10), 260-267.

Olaniyan, A.M. & Oje, K. (2002). Some aspects of the mechanical properties of Shea nut. *Biosystems Engineering*, *81*, 413-420. http://doi.org/10.1006/bioe.2002.0049

Osuagwu, A.N. & Nwofia, G.E. (2014). Effects of spent engine oil on the germination ability of eleven accessories of African yam bean seeds (*Sphenostylis stenocarpa* Hochst ex. A. Rich) Harms. *IOSR Journal of Agriculture and Veterinary Science*, *7*(1), 59-62.

Owolarafe, O.K. & Shotonde, H.O. (2004). Some physical properties of fresh okro fruit. *Journal of Food Engineering*, *63*, 299-302. http://doi.org/10.1016/j.jfoodeng.2003.08.002

Sharma, V., Das, L., Pradhan, R., Naik, S., Bhatnagar, N. & Kureel, R. (2011). Physical properties of tung seed: an industrial oil yielding crop. *Industrial Crops and Products*, *33*(2), 440-444. http://doi.org/10.1016/j.indcrop.2010.10.031

Sologubik, C., Campañone, L. Pagano, A. & Gely, M. (2013). Effect of moisture content on some physical properties of barley. *Industrial Crops and Products*, *43*(1), 762-767. http://doi.org/10.1016/j.indcrop.2012.08.019

Werby, R.A. & Mousa, A.M. (2016). Some physical and mechanical properties of Jatropha fruits. *Misr Journal of Agricultural Engineering*, *33*(2), 475-490. http://doi.org/10.21608/mjae.2016.97971