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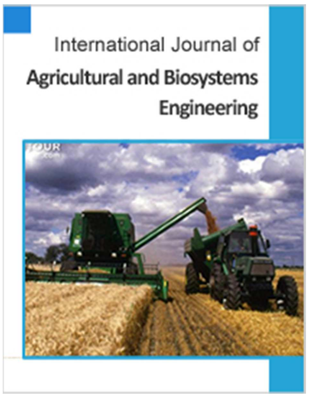

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Determination of Engineering Properties of Some Nigerian Local Grain Crops

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Abstract
Agricultural processing is the activity which is performed to maintain or improve the quality or change the form or characteristics of Agricultural products. Engineering Properties of food grains are useful in the design and operation of various equipment employ in the field of food processing. This study was conducted to investigate the engineering (physical and mechanical) properties of some selected food grains: rice, maize, soybean and cowpea. Some of these properties included; shape, size, density, weight, volume, hardness, moisture content, coefficient static friction, hardness, compressive and shear strength. Their properties were determined at three moisture content levels. To determine the mechanical properties, compression and three-point bending tests were conducted at 2.5mm/min. The mean length, thickness, width, geometric mean diameter, volume and density were obtained and the results were analyzed. It was observed that, by increasing moisture contents of the food grains tested, geometric mean diameter, sphericity, true density and angle of repose had an upward increment, whereas their bulk densities decreased. The average fracture force and energy obtained by compression test at vertical, horizontal and minor loading were 200.2N, 174.8N and 63.2N respectively for maize, and 100.8N, 56.4N and 57N respectively for cowpea.

1. Introduction

Nigeria has huge agricultural potential. It has 84 million ha of arable land of which only 40% is cultivated, it has 279 billion cubic meters of water, with a population of 167 million people being the most populous country in Africa. According to international food policy Research Institute, the value of agriculture in Nigeria at constant 2010 dollars by 2030 dollars was 99 billion dollars by 2030 [1]. Maize, Soybeans, Cowpea and Rice are agricultural materials that serve as food to both man and livestock and also serves as a by-product used in manufacturing industries. The global importance of grain crops to the human diet and moreover to the written history of man and agriculture cannot be over stated. More than 80% of Nigeria's food and agriculture produce constitutes grains, which are produced and consumed nationwide. The grains include Maize, sorghum (guinea corn), aches, rice wheat, millet, legumes etc. in spite of its nationwide production, the consumption demand for human, animal, industrial raw materials, seed stock, reserve and trade exchanging outstrips supply available [11].

Grains are the fruit of plants belonging to the grass family *Gramineae.* Cereal crops are energy dense, containing 10,000-15,000 Kj/Kg, about 10-20 times more energy than most succulent fruits and vegetables. Nutritionally, they are important sources of dietary protein, carbohydrates, the B complex of vitamin, Vitamin E, iron, trace minerals and fiber. It has been estimated that global cereal consumption directly provides about 50 percent of protein and energy necessary for human diet, with cereals providing an additional 25 percent of protein and energy via livestock intermediaries. Some cereals, notably wheat, contain that form gluten, which is essential for making leavened bread. Although dried cereal grains constitute living cells that respire, when kept in an appropriate environment, whole grains can be stored for many years, in 1996, world cereal production amounted to more than two billion metric tons [14]. Major cereal crops produced worldwide include wheat, rice, maize and barley. It is important to determine the physical and mechanical properties in order to enhance mechanization of both their planting and harvesting operation and hence the operation involved in processing of Agricultural materials. Information on physical and mechanical properties of agricultural products is needed in designing and adjustments of machines used during planting, harvesting, separating, cleaning, handling and storing of agricultural materials and converts them into food, feed and fodder. The properties which are useful during design must be known and determined at laboratory conditions [6]

The mechanical properties such as hardness, compressive strength, impact and shear strength and the rheological properties affect the various operations of agricultural processing. The development of satisfactory harvesting and processing method are greatly influenced by the mechanical properties of the product. Mechanical properties of the agricultural products are mostly conveniently measured with the force-deformation curve.

[3] measured physical characteristics of rice kernel including dimensions, true and bulk densities, and porosity in rough, brown and milled states t moisture content of 12% wet basis. Their results showed a reduction in kernel's bulk density from rough to milled condition. They also considered other characteristics such as porosity and density as the main parameters in heat and mass transfer phenomena and projected area and volume as basic parameter in crop drying and storage. [7] Determined various physical properties of rice at moisture content of 10% (w.b) and investigated the effect of two factors of temperature and moisture contents on rice kernels mechanical properties. Their results indicated that the mechanical properties are affected moisture content and temperature factors. [12] Investigated compression resistance of three rough rice varieties under quasi-static loading.

2. Methods

2.1. Sample Preparation and Procurement

The seed materials used for this research work were Rice *(Oryza Sativa)*, Maize *(Zea Mays)*, Cowpea *(Phaseolus Vulgaris)*, and Soybeans (*Glycine Max*) seeds. Theses grains were obtained from three geo-political regions (North, Western and middle belt) in Nigeria. Laboratory equipment used included measuring cylinder, weighing balance, micrometer screw gauge, sliding machine, vernier caliper, dryer, universal testing machine. In order to determine 1000-unit mass (m_{1000}), fifty (50) grains were selected randomly and weighed. True-density (Td), bulk-density (bd) and volume (V) were determined by use of displacement in liquid method.

2.2. Physical Properties Measurement

The physical properties such as length (L), width (W), thickness (T), mass (M), volume (V), true density (ρp), bulk density (ρd), depth of product (Dp), geometrical mean diameter (Dg), sphericity (ϕ), porosity (p), and surface area were measured using vernier calliper, weigh balance and measuring cylinder [9].

2.2.1. Size and Sphericity

The method of random sampling similar to that followed by [5] was used for seeds. Three principal dimensions namely; length, width and thickness were measured using a micro-screw gauge and vernier calliper (least count 0.01mm) for the geometric mean diameter (Dc) and sphericity (ϕ) as proposed by [10]; is given by Eq. (1).

Sphericity (ϕ);

$$(\phi) = \frac{(LWT)^{\frac{1}{3}}}{L} \times 100\% \cdot \quad (1)$$

2.2.2. Geometric Dimension

Geometric dimensions and mass of the rice, cowpea, soybeans and maize seeds were measured by vernier caliper and digital weighing balance with accuracy of 0.001 mm respectively at different moisture content. By use of those three dimensions, geometrical mean diameter (GMD), sphericity (ϕ) and surface area (S) of maize, cowpea, soybeans and rice were obtained using Eq. (2) below according to [10];

$$S = \lambda DP^2 \quad (2)$$

(Where; S = Surface area in cm^2)

DP was the geometric mean diameter, which was calculated using the relationship by

$$GMD = (LWT)^{0.03} \quad (3)$$

Hence,

$$S = \lambda(GMD)^2 \quad (4)$$

2.2.3. True Density and Bulk Density

True density (ρp) was determined by toluene displacement method as indicated with Eq. (5), and bulk density (ρb) was also determined using Eq. (6) [10].

$$(\rho p) = \frac{\text{Weight of the sample (g)}}{\text{Volume of water displaced (cm}^3\text{)}} \quad (5)$$

$$(\rho b) = \frac{\text{Weight of sample (g)}}{\text{Volume occupied (cm}^3\text{)}} \quad (6)$$

2.2.4. Porosity

The percentage void of an unconsolidated mass of material such as grain, silage, hay and grain can be determined by porosity tank method [4]. Porosity affects the angle of internal friction and the dynamic angle of repose. Materials with high values of porosity have high values of angle of friction and angle of repose. Porosity depends on the shape, dimension and roughness of the material surface. Porosity, which is also known as packing factor 'PF' may be calculated by using the relationship as described by [10]. as given by Eq. (7)

$$\text{Porosity} = \{1 - \frac{Bulk\ density}{True\ density} \times 100\%\} \quad (7)$$

2.2.5. Volume and Density

The volume of rice, cowpea, soybeans and maize seeds were obtained using water displacement method. A measuring cylinder of 100 ml was used; by dropping the grain in the measuring cylinder filled with a known volume of water which is equal to its own volume following Archimedes principle. The volume was then read directly from the cylinder. The average volume of the grains was then determined. The grains were initially weighed on the digital weighing balance to obtain their average mass. The density which is referred to as particle density in product is mass per unit volume is obtained from the Archimedes principle equation.

2.2.6. Weight

This was carried out by weighing the seeds on a precision digital weighing balance; reading to 0.01 (g) calibrations. The experiment was carried out at room temperature.

2.2.7. Angle of Repose

The angle of repose was determined by using a special tilting table fabricated in the department of Agricultural Engineering used along with a topless and bottomless box of dimension 150 x 100 x 20 mm^3 filled with rice, beans, soybeans and maize seeds and places on the adjustable tilting surface or inclined plane apparatus (Figures 3 and 4). The stainless steel, ply wood, galvanized, was place after the other and the experiment was repeated ten times to find the mean value of the repose angle. Allowing the seeds to flow and assumed a natural slope.

The dynamic angles of repose of loosely packed materials are normally higher than those of closely packed material. Angle of repose and frictional properties of the agricultural materials play an important role in selection of design of hoppers, storage bins and other equipment like grain extractor. According to [8] as given in Eq. (8),

$$F = \mu \tan QR \quad (8)$$

Therefore, the coefficient of static friction would be calculated by Eq. (9),

$$\frac{F}{N} = U \quad (9)$$

2.2.8. Coefficient of Static Friction

The coefficient of static friction of rice, beans, soybeans and maize seeds were determined in respect to four surfaces, which are plywood, mild steel, stainless steel and glass using the inclined plane apparatus. The table was gently raised and the angle of inclination to the horizontal at which the seeds started sliding was read (Figure 1) off the protractor attached to the apparatus. The coefficient of static friction was calculated as the tangent of this angle. [5] and [2] used similar method in determining angle of repose.

***Figure 1.** Tilting box.*

2.2.9. Moisture Content

The moisture content (MC) of Rice, Beans, Soybeans and Maize seeds were obtained as shown in Eq. (10) below. The ratio of the weight of water present in the seeds to the dry weight of the seeds.

$$MC = \frac{weight\ of\ water}{weight\ of\ dry\ seed} \times 100\% \quad (10)$$

The direct method was used, that is the oven dry method. The initial weight of the seeds were weighed and known, the weight of the can was also weighed and known, then the seeds and the can were placed in the oven at a temperature of 75°C for 16 hours to get the first moisture content. The seeds were then dried for 24 hours at the same temperature of 105°C, the moisture content was recorded. The third moisture content of the seeds was also determined after oven- dried for 48 hours at the same temperature of 105°C [10].

2.3. Measurement of Mechanical Properties

A Testometric machine (Model 1186) equipped with a 5000N compression load was used to carry out the mechanical properties of rice, beans, maize and soybeans at vertical, horizontal and minor axis (Figure 2). A compression test was performed on the seeds using the Monsanto Universal Testing Machine. Testing Conditions for the Testron Machine were loading range: 0.0-5000 N with chart speed of 25mm/min. Each seed was placed between the compression plates of the machine. The seed was compressed at a constant deformation rate of 1.25mm/min. the applied forces at bio-yield and their corresponding deformation for each seed samples were read directly from the force deformation curve (Figure 3). The mechanical behaviour of the seeds was expressed in term of force required for maximum strength of the seed, energy required to deform the seed to initial rupture and seeds specific deformation. The rupture force was determined as the force on the digital display when the seed under compression made a clicking sound. Each process was often completed whenever the break point of the positioned seed was reached.

Figure 2. Testron machine with seed placement.

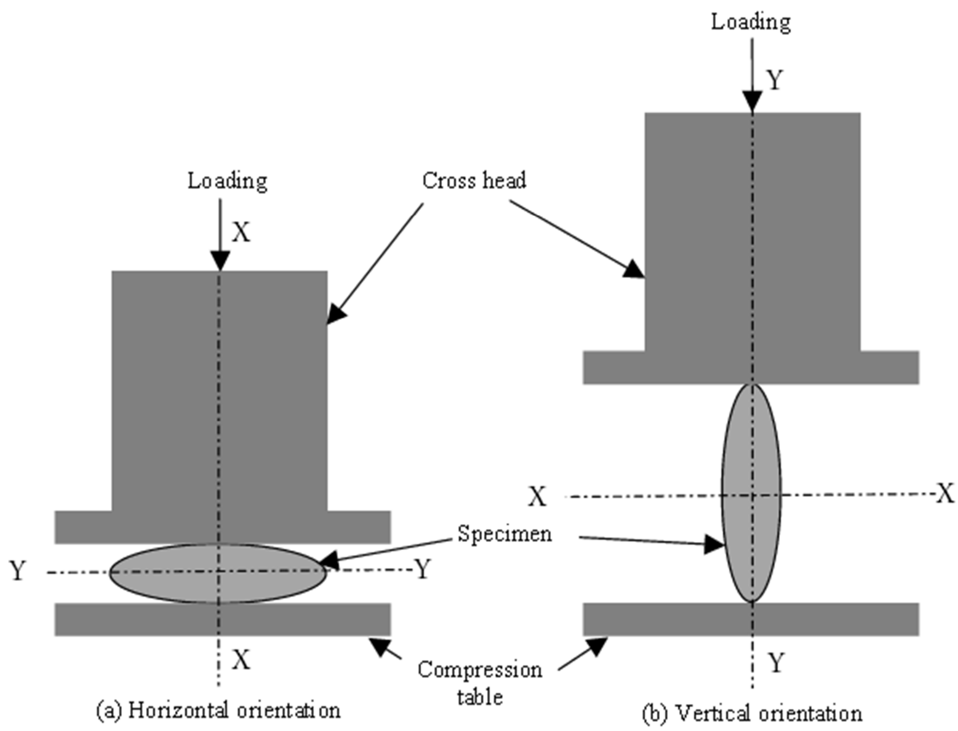

Figure 3. Mechanism of loading of materials.

The maximum shear strength is expressed by Eq. (11) below;

$$\delta s\ S = \frac{Fmax}{A} \quad (11)$$

The indices that determine the compression behaviour of plant materials are modulus of elasticity and compression energy. The linear portion of the force-displacement curve is used to determine the modulus of elasticity in compression, which is given by Eq. (12);

$$\sigma_c = \frac{F_c/A}{\nabla L/d} = \frac{F_c \cdot d}{A \nabla L} \quad (12)$$

Where σ_c is the modulus of elasticity in compression,

F_c is the compression force, (N)

∇L is the transverse deformation due to compressive force, (m)

d is the diameter of the grain at the point of compression, (m)

3. Result

3.1. Physical Properties

Length, Thickness, Width, Density, Geometric Mean and Volume

The length, thickness, width, density, Geometric mean and volume of rice, beans, soybeans and maize was affected by the different moisture levels present in the materials (maize, cowpea, soybeans and rice).

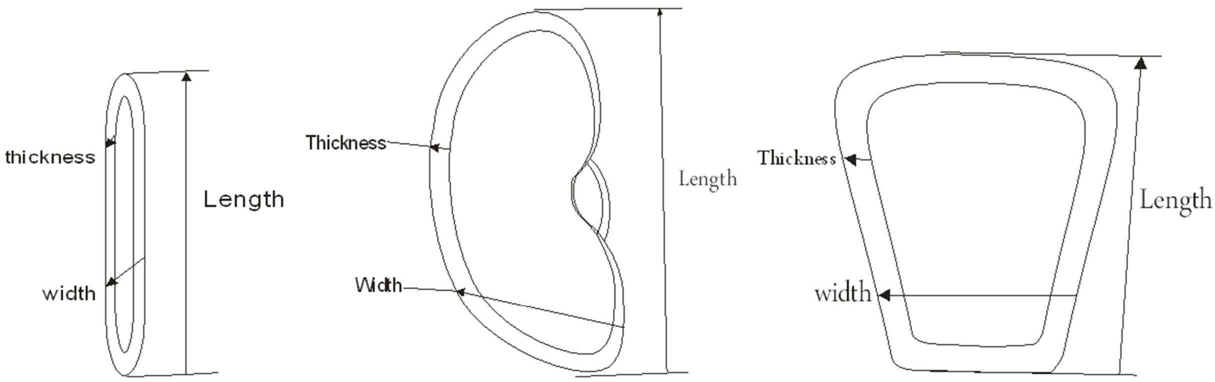

Figure 4. *Length, Breadth and Thickness of rice, cowpea and maize.*

Table 1. *Result on mean dimension and distribution of grains at 3% at dry base (db).*

Parameters	Maize	Cowpea	Soy Beans	Rice
Length, mm	11.160±0.620	10.539±0.561	7.350±0.362	11.022±0.575
Width, mm	4.478±0.254	7.361±0.370	6.154±0.328	3.281±0.236
Geometric diameter, mm	7.757±0.432	7.753±0.400	6.033±0.311	4.293±0.217
Volume, cm^3	0.470±0.080	0.460±0.010	0.237±0.006	0.033±0.002
Density, g/cm^3	3.280±0.235	2.210±0.060	1.743±0.101	

Coefficient of Friction

Table 2. *Shows the result of mean value for coefficient of friction of maize, rice, cowpea and soybeans on plywood, stainless steel, mild steel and glass.*

Material	Cowpea	Rice	soya Beans	Maize
Wood	0.456	0.273	0.330	0.426
Stainless Steel	0.637	0.449	0.581	0.781
Mild Steel	0.606	0.436	0.485	0.669
Glass	0.309	0.082	0.300	0.386

3.2. Mechanical Property Test

Compression on crops was determined using testron testing machine. The materials were loaded in three axes, The material is placed horizontally, vertically and on minor axis between the testron machine plate, hence the force is applied to cause fracture from which the force at peak, deflection at peak, strain at peak, force yield, deflection yield, strain yield, force yield, deflection at yield and strain.

Table 3. *Mean value for Mechanical Properties of maize and cowpea obtained at three-point bending test.*

(a). Axial loading compression Test

Materials	Force @ peak (N)	Def. @Peak (mm)	Strain @Peak (%)	Force @Yield (N)	Def. @yield (mm)	Strain@ Yield (%)	Def. @Break (mm)	Strain @Break
Maize	63.200	0.487	11.248	402.800	0.274	6.325	0.595	13.749
cowpea	57.000	0.226	3.464	36.800	0.100	1.5527	0.426	6.524

(b). Vertical loading compression Test

Materials	Force @ peak (N)	Def. @Peak (mm)	Strain @Peak (%)	Force @Yield (N)	Def. @yield (mm)	Strain@ Yield (%)	Def. @Break (mm)	Strain @Break
Maize	200.200	1.246	11.043	53.200	0.469	4.158	1.545	13.697
cowpea	100.800	1.113	10.357	35.600	0.102	0.953	1.556	14.486

(c). Horizontal Loading Compression Test

Materials	Force @ peak (N)	Def. @Peak (mm)	Strain @Peak (%)	Force @Yield (N)	Def. @yield (mm)	Strain@ Yield (%)	Def. @Break (mm)	Strain @Break
Maize	174.800	1.756	16.354	40.600	0.662	6.166	1.964	18.285
cowpea	56.400	0.589	7.385	21.800	0.084	1.050	0.753	9.443

4. Discussion

4.1. Effect of Moisture Content on Length, Width, Thickness and Geometric Diameter

The variations in length, width, thickness and geometric diameter of grains are in respect with moisture content. All dimensions increase with the grains moisture content up to 26% moisture content. Beyond 26% moisture content, there is no appreciable dimensional change. The grain probably retain some tiny air voids as they absorb water and these are replaced water, beyond 26% moisture content there making sphericity of soybeans to increase linearly with grain moisture content up to 25% (db). In Figure 4, the grain displayed no dimensional changes. The grains surface area increases with increasing moisture content, however, it was found that the surface area of soybeans increase linearly with grain moisture content. The sphericity decreases with increasing moisture content up to 26% and shows no increase with moisture content beyond that.

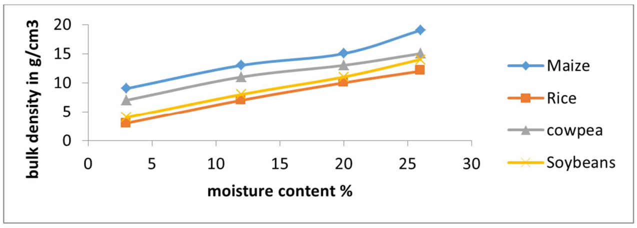

Figure 5. *Variation of bulk density of grains with moisture contents.*

4.2. Coefficient Static Friction

The static coefficient of friction for maize, cowpea, soybeans and rice determined with respect to stainless, glass, plywood and galvanized sheet surfaces increased with increasing moisture content. The coefficient of friction at all moisture contents considered is highest on plywood followed by galvanized iron and stainless steel. The mean coefficient of friction of Rice, Cowpea, Soybeans and Maize has shown in Table 2. The grains also become rougher and possibly, sticker on the surface as the moisture content increases, making the coefficient of friction increased. Figure 5 shows the variation of true density with moisture content. Increase in moisture content of the grain, increases the weight hence increases the true density of the material. Figure 6 also showed that increase in water content of the grain increases the porosity of the grain.

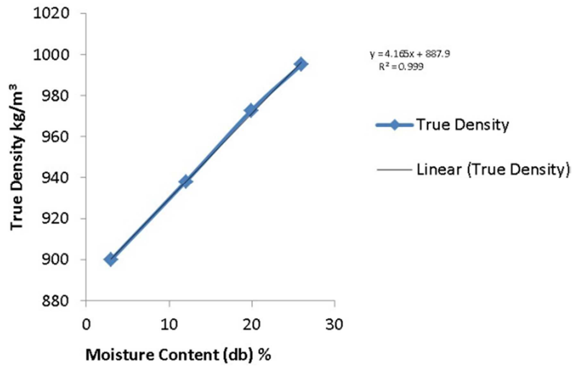

Figure 6. *Variation of true density of with MC.*

Increase in moisture content of the grain, increases the weight hence increases the true density of the material

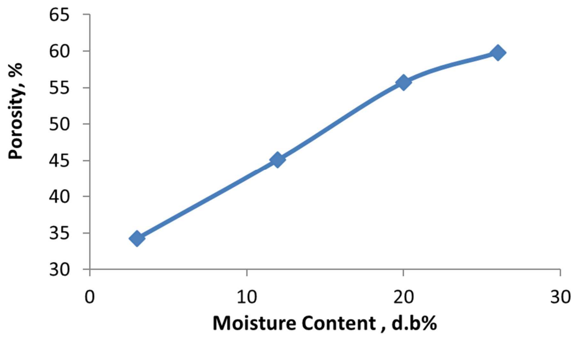

Figure 7. *Variation of grain porosity with MC.*

Increase in moisture content of the grain increases the porosity of the grain.

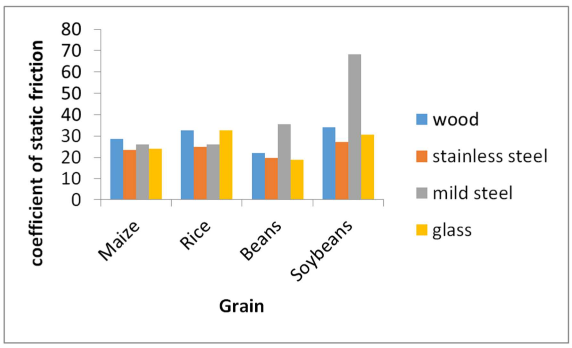

Figure 8. *Variation of coefficient of static friction with grains.*

The grain becomes rougher and possibly stickier on the surface as the moisture content increases, hence increases the coefficient of static friction

4.3. Angle of Repose

The angle of repose for maize, beans, soybeans and rice determined with respect to stainless, plywood and mild steel and glass sheet surfaces increased with increasing moisture content. The angle of repose increases with increase in coefficient of friction and grain moisture content. The variation is similar to that of [13] for cumin seeds and [6] for guna seed, however, exhibit a linear increase in angle of repose with increase in moisture content. The differences could be due to difference in the surface roughness of grain as they get wet. Angle of repose is a useful parameter for optimum design of hoppers. The inclination angle of hopper wall should be larger than the grain angle of repose to ensure the continuous flow of grain by gravitational force at yield, force at break, deflection at break, strain at break were determined

4.4. Mechanical Properties

Mechanical properties of selected grains (maize, rice, cowpea and soybeans) were known by subjecting them to compression. Compression is the act of determining the behaviour of materials under a compressive load. Compression tests were conducted by loading the test specimen between two plates and then applying a force to the specimen by moving the crossheads together. The compression test was used to determine elastic limit, proportionality limit, yield point, yield strength and compressive strength. The force- deformation characteristics are exhibited by the grains under compressive loading force front. The most important of the compressive curve was the first local maximum point, which was selected as the rupture force. There was a decrease in the force after rupture occurred in the specimen and this point was denoted as the rupture point. Compression on crops was determined using testron testing machine. The materials were loaded in three axes, The material is placed horizontally, vertically and on minor axis between the testron machine plate, hence the force is applied to cause fracture from which the force at peak, deflection at peak, strain at peak, force yield, deflection yield, strain yield, force yield, deflection at yield and strain (Table 3).

In this research, five tests were carry out on maize and cowpea at three different loading; vertically, horizontally and axially. The graph shows five different lines, with each line representing result graph for each seed

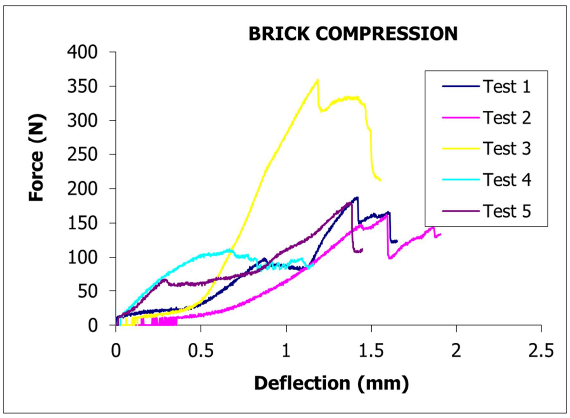

Figure 9. *Compression test on maize grains seed when placed vertically.*

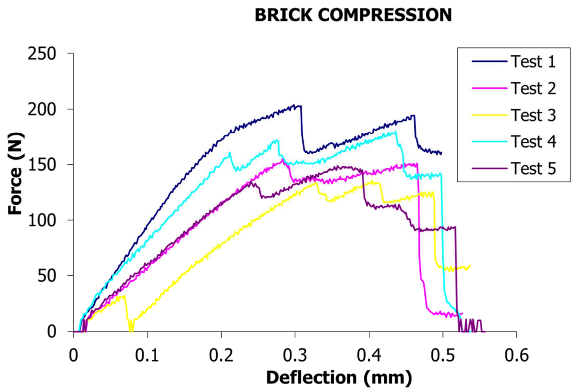

Figure 10. *Compression test of five (5) sample of Maize grains seed horizontally.*

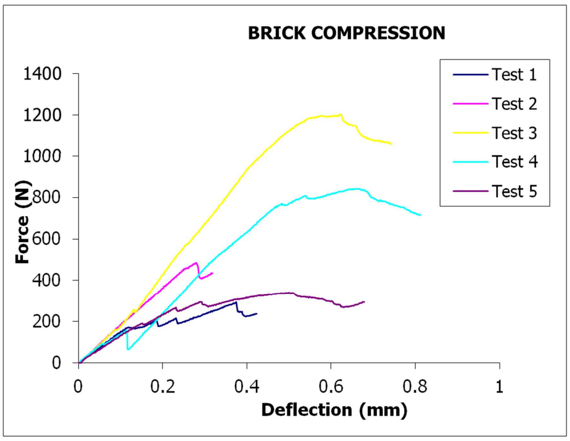

Figure 11. *Compression graph of axial loading of maize.*

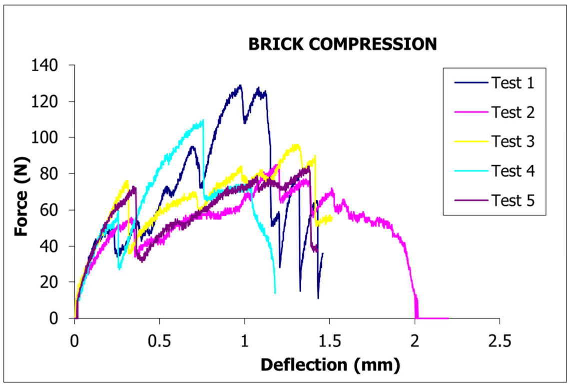

Figure 12. *Compression test graph for cowpea when places vertically.*

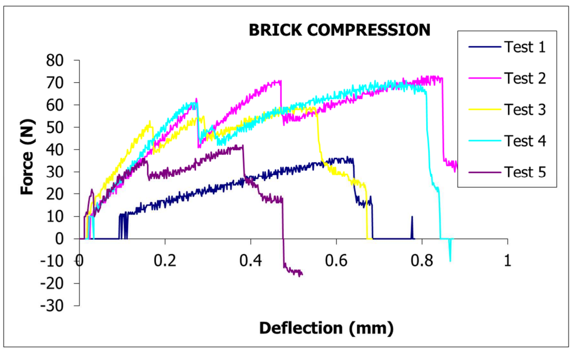

Figure 13. *Compression graph for horizontal loading in cowpea seed.*

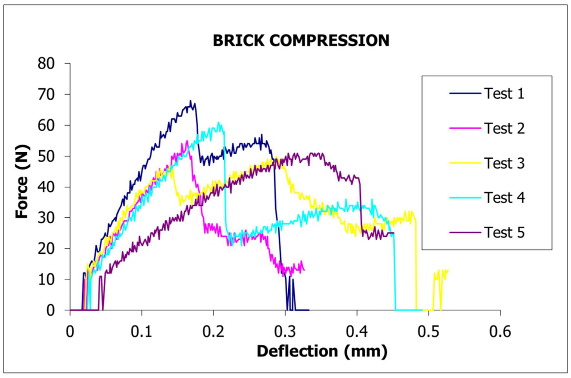

Figure 14. *Compression graph of axial loading of cowpe.*

None of mechanical properties obtained by three-point bending test were significantly affected when MC was increased from 12 to 16% (w.b). hence, the mean values of fracture force, fracture energy, specific fracture energy and bending strength were 21.43N, 4.13J×10^{-3}, 339.54Jm^{-2}, and 20.43MPa, respectively at the range of MC in this research (12% to 26%, w.b).

5. Conclusion

This work focused on some physical and mechanical properties of maize, soybeans, cowpea and rice based on the results and discussion of my experiment the following conclusions could be made: all the dimensions of maize, soybeans, beans and rice increased with increase in moisture content. The length, width, thickness, arithmetic mean diameter, and geometric mean diameter of the maize, soybeans, beans and rice increased linearly with increase of moisture content. The 1000-seed mass increases linearly with increase in moisture content.

Sphericity, volume, and surface area increased linearly with increase in moisture content. True density was higher than bulk density at all grains moisture content studied. Bulk density slightly decreased linearly with increase of moisture content but the true density porosity increased with increase in moisture content. The angle of repose and static coefficient was highest for wood, followed by galvanized and stainless for the material tested. The load-deflection behaviour for the maize, soybeans, beans and rice was presented. Compressive load at rupture and at yield depend largely on contact area, that is the largely the contact area the smaller the load applied to it.

Nomenclatures

w.b	Wet basis
V	Volume
Db	Dry basis
Pb	Bulk density (g/cm^3))
Pp	True density (g/cm^3)
D_p	Depth of product
ϕ	Sphericity
P	Porosity
Td	True density
L	Length (m)
W	Width (m)
T	Thickness (m)
S	Surface area (cm^2)
U	Coefficient of static friction
N	Newton
F_c	compression force

Greek Symbols

ϕ	Sphericity
σ_c	modulus of elasticity in compression,

Abbreviations

Mpa	Micro Pascal
°C	Degree Centigrade
MC	Moisture Content

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