Determination of some Physical and Mechanical Properties of Cowpea and Groundnut and their Effects on the Design Analysis of a Planter

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Abstract - *The study of some physical and mechanical properties of these grain crops helps in proper dimensioning of agricultural machines and equipment for planting, harvesting, processing, packaging and storage. The mean values measured and recorded for length, width, thickness, geometric mean diameter, sphericity, surface area, bulk mass, bulk volume, bulk density, true density and porosity of cowpea and groundnut were 0.87 ± 0.054 cm, 0.654 ± 0.027 cm, 0.475 ± 0.026 cm, 0.646 ± 0.026 cm, 0.744 ± 0.029, 1.314 ± 0.105 cm^2, 17.08 ± 1.045 g, 24.700 ± 1.636 cm^3, 0.692 ± 0.024 g/cm^3, 0.419 ± 0.027 g/cm^3 and 12.837 ± 4.455 %; 1.512 ± 0.179 cm, 0.975 ± 0.072 cm, 0.915 ± 0.080 cm, 1.103 ± 0.071 cm, 0.736 ± 0.067, 3.837 ± 0.498 cm^2, 58.85 ± 4.61 g, 76.4 ± 4.067 cm^3, 0.769 ± 0.021 g/cm^3, 0.982 ± 0.071 g/cm^3 and 21.142 ± 7.532 % respectively. The mean compressive load at break and mean compressive stress at break for cowpea and groundnut were 1468.94 ± 673.28 N and 161.79 ± 74.16 MPa; 997.11 ± 431.56 N and 26.67 ± 11.54 MPa respectively. The properties determined helps in the designing and dimensioning of different parts of planter components such as hopper, metering unit, seed plate and delivery tube and also the angle of inclination and clearance of these parts to one another to minimize the seed damage. It also helps in choosing the right choice of materials for construction of some parts of the planter.*

***Key Words*: Cowpea, groundnut, physical properties, mechanical properties, planting equipment.**

1. INTRODUCTION

The cowpea (*Vigna unguiculata*) is one of the most economically and nutritionally important indigenous African grain legumes produced throughout the tropical and subtropical areas of the world. Cowpeas play a key role in the agriculture and food supply of Nigeria. Nigeria is the largest producer and consumer of cowpeas, accounting for about 45 percent of the world's cowpea production [1]. It provides protein to rural as well as the urban dwellers as a substitute for the animal protein. However, cowpea production is generally low as a result of some factors such as diseases and pest, drought, insect pest and weeds [1]. Agboola [2] reported that an average yield of 271.5 kg/ha from the vast area of 3.8 million hectares cultivated to cowpea in Nigeria. In addition, Singh and Jackai [3] further reported that with the use of improved technologies in cowpea production, yield of 1500-2000 kg/ha can be obtained on sole crops. Groundnut seeds (kernels) contain 40% to 50% fat, 20% to 50% protein and 10% to 20% carbohydrates [4, 5]. Groundnut is usually grown as a smallholder crop in the semi-arid tropics under rain fed conditions. It is an important crop in many countries where it is a good source of protein (25% to 34%), cooking oil (48% to 50%) and vitamins. The haulms are a good source of feed for livestock, especially during the dry season when fresh green grasses are not available. This serves as an additional source of income for farmers in the dry season when the fodder is in high demand [6]. Groundnut seeds are nutritional source of vitamin E, niacin, falacin, calcium, phosphorus, magnesium, zinc, iron, riboflavin, thiamine and potassium [4]. Groundnut kernels are consumed directly as raw, roasted or boiled kernels and oil extracted from the kernels is used as culinary oil. It is also used as animal feed (oil pressing, seeds, green materials and straw) and industrial raw material (oil cakes and fertilizer). The uses of groundnut plant make it an excellent cash crop for domestic markets as well as for foreign trade in several developing and developed countries [4]. Seed planter is a device that helps in the placement of seeds in a desired position, thereby assisting the farmers in saving time and money. The basic responsibility of a planter is to carry the seed, release and place the seed in the already opened furrow maintaining the required depth and intra row spacing, cover the seeds with soil and provide the adequate soil-seed firming conditions [7, 8]. The determination of some physical properties grains such as size, shape, axial dimensions, roundness and sphericity helps in the determination of the maximum size of seed plate diameter, the weight help in the material selection for the frame of the planter, the bulk density and moisture content helps to know the interaction between the seed and the material used for the hopper of the planter at maximum heat level [9]. The mechanical properties such as the angle of repose helps to ensure free flow of seed in the hopper [9], the terminal velocity helps to determine the flow of the seed in air between the point of discharge and impact on the soil. The shear stress and impact stress helps to determine the amount of pressure the seed plate should apply on the seed. These properties help in specifying the design considerations of planting equipment because it will be a waste of time, resources, effort and money if after fabricating, and the machine fails to deliver up to expectation.

2. RESEARCH METHODOLOGY

While conducting the experiment to determine the physical and mechanical properties of cowpea and groundnut the following materials and apparatus were used:

Crops: 100 samples each of cowpea and groundnut were used. The cowpea used was IT 96 - 610 procured from IITA Ibadan (Figure 1) while the groundnut with the local name *kampala* was acquired from a local market in Ibadan (Figure 2).

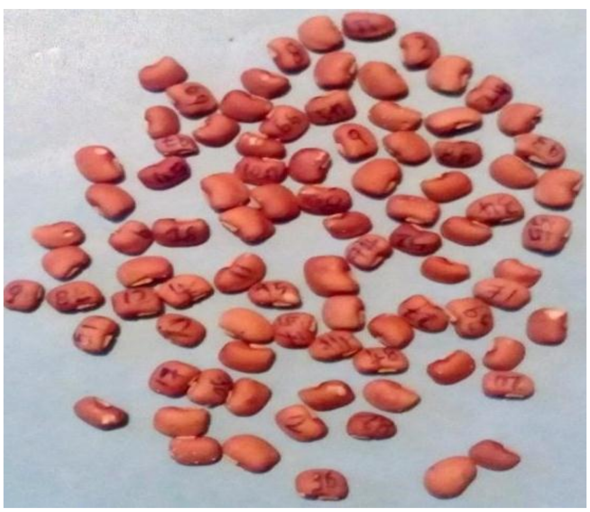

Fig -1: Cowpea (IT 96 - 610)

Fig -2: Groundnut (*Kampala*)

The following materials were used when conducting the experiments on the selected samples to determine their properties that are useful in the designing of planter components. A pair of vernier caliper was used to measure the axial dimensions of the samples including the length (L), breadth (B) and thickness (T). The model used is the Gilson Vernier Caliper with calibration of 20 cm with error of 0.05 mm. Two measuring cylinders (Spyrex EX 20^{o}C with calibration of 250 ml ± 2 ml and a measuring cylinder with 100 ml; 20^{o}C) were used to determine the bulk volume of the samples. The weighing balance used was The Electronic Digital Balance with model number BLC3002, Max weighing 310 g and readability 0.001 g. The sliding box was the equipment used to determine the angle of repose and the coefficient of friction. The Universal Testing Machine (UTM) Instron 6022 was used for compression loading for which rupture force and rupture energy were obtained.

2.2 Methods

The methods selected for this research work are those whose simplicity and practicability enjoy wide acceptability and above all exhibit high degrees of accuracy in accordance to Soyoye *et al*. [10].

2.2.1 Moisture content

The moisture content of the materials was determined using oven dry method, this was done to ascertain to know the moisture content at which the experiment was carried out. The weight of an empty container was measured and recorded as W_1, the material was poured in the container then measured and recorded as W_2. The oven was switched on and set at 105°C, the container with the material in it was placed inside the oven so as to remove the moisture in the material. The container was brought out of the oven at regular interval of one hour with the new weight measured and recorded. This is done until there was no more change in the weight of the previous hour and the present hour, this means the moisture has been completely removed and the weight at this point is recorded as W_3. The moisture content dry basis of the material was determined using the following relationship;

$$Moisture\ content = \frac{(W_2 - W_1)}{(W_3 - W_1)} \times 100\%$$

2.2.2 Size

A pair of digital vernier calipers was used to determine the dimensions such as length, width and thickness.

2.2.3 Geometric mean diameter

The geometric mean diameter (D_g) was determined using the following equation;

$$D_g = \sqrt[3]{(LWT)}$$

Where; L is the length, W is the width and T is the thickness.

2.2.4 Surface area

The surface area (S) was determined using the equation;

$$S = \pi D_g^2$$

2.2.5 Sphericity

It was determined using the equation;

$$\Phi = \frac{\sqrt[3]{(LWT)}}{L}$$

2.2.6 Bulk mass

The bulk mass was calculated using the weighing balance and the weighing can. The mass was measure in hundreds and the procedure was repeated ten (10) times so as to get the average.

2.2.7 Bulk volume

The bulk volume was determined using the displacement method. Toluene C_7H_8 was poured into the measuring cylinder to a certain level which was recorded. The bulk mass was then poured into the cylinder with toluene C_7H_8 in it. The volume of toluene in the cylinder rose. The new volume was recorded and subtracted from the initial volume. The volume obtained from the subtraction is the bulk volume for the bulk mass. The procedure was repeated ten (10) times.

2.2.8 Bulk density

The bulk density was determined mathematically by dividing the bulk mass by the bulk volume. The procedure was repeated ten (10) times.

$$Bulk\ Density = \frac{Bulk\ mass}{Bulk\ volume}$$

2.2.9 True density

The true density was determined by finding the individual density of 10 random samples from the bulk of 100. The mass and the volume of the ten samples were determined using the displacement method as done in the determination of the bulk density. The mass was divided by the volume to get the density for the 10 samples. The density was then divided by 10 so as to get the unity density. The procedure was repeated 3 times for the bulk 100 to get the average and the overall procedure was repeated 10 times [10].

2.2.10 Angle of repose

The angle of repose was determined using the sliding box provided in the Department of Agricultural and Environmental Engineering, Federal University of Technology Akure. The seed were placed randomly on the box and allowed to lie in their natural resting position. The angle was increased gradually till when the seed slides or rolls away. The angle at which the seed slide is recorded. The procedure was repeated for 100 samples and across different surface which are, mild steel, stainless steel and galvanized steel, all which was used in the determination of the coefficient of friction.

2.2.11 Coefficient of friction

The coefficient of friction over four surfaces (plywood, mild steel, stainless steel and galvanized steel) was determined using equation described by [11];

$$\mu = \tan \alpha$$

Where μ is the coefficient of friction and α is the angle of tilt.

2.2.12 Compression test

Compression tests were performed on seeds using the Monsanto Universal Testing Machine at National Centre for Agricultural Mechanization, (NCAM) Ilorin, Kwara State. Testing Conditions for the lnstron Machine were loading range: 0 – 500 N; chart speed – 50 rpm/mm; Crosshead speed – 1.5 mm/min. Each seed was placed between the compression plates of the tensonometer and compressed at a constant deformation rate of 1.25 mm/min. The applied forces at bio-yield and oil points and their corresponding deformations for each seed sample were read directly from the force-deformation curve. The mechanical behaviour of seed was expressed in terms of force required for maximum strength of the seed, energy required to deform the seed to initial rupture and seed specific deformation. The rupture force was determined as the force on the digital display when the seed under compression makes a clicking sound. Each process is often completed whenever the break point of the positioned seed is reached.

3. RESULTS AND DISCUSSION

The experiment was carried on cowpea and groundnut at moisture content (dry basis) of 20.49% and 10.92% respectively. Table 1 shows the summary of the results of the test and experiment carried out on the physical properties of 100 samples each of cowpea and groundnut. It shows the range, mean and standard deviation results of each property. The sizes of the materials in terms of horizontal (length), transversal (width) and vertical (thickness) dimensions were measured. The length, width and thickness of cowpea range from 0.758 cm to 1.015 cm, 0.591 cm to 0.717 cm and 0.407 cm to 0.571 cm respectively, the mean length, mean width and mean thickness was calculated to be 0.870 cm, 0.654 cm and 0.475 cm respectively (Table 1). These results were in accordance with that of IT716 (Cowpea) with average length, width and thickness of 0.864 cm, 0.621 cm and 0.505 cm measured by Faleye *et al.* [12], while the standard deviation of the length, width and thickness were 0.054, 0.027 and 0.026 respectively. Likewise for groundnut, the length, width and thickness range from 1.093 cm to 2.088 cm, 0.772 cm to 1.123 cm and 0.680 cm to 1.055 cm respectively, the mean length, mean width and mean thickness was calculated to be 1.512 cm, 0.975 cm and 0.915 cm, while the standard deviation of the length, width and thickness was calculated to be 0.719, 0.072 and 0.080 respectively (Table 1). The result was similar to the groundnut grains measured at 7.6% moisture content (dry basis) by Davies [13]. The above properties help in the design of the diameter of the metering plate of planter, the hopper and also the delivery tube. The geometric mean diameter for cowpea was calculated to range from 0.568 cm to 0.703 cm with the average and standard deviation of the geometric mean diameter determined to be 0.646 cm and 0.026 respectively. The geometric mean diameter for groundnut was calculated to range from 0.935 cm to 1.313 cm with the average and standard deviation of the geometric mean diameter determined to be 1.103 cm and 0.071 respectively. The result was close to the average geometric mean diameter of groundnut (1.271 cm ± 0.06) by Saeeid *et al.* [14]. This can also be used in the designing of the delivery tube of the planter. The sphericity for cowpea ranges from 0.693 to 0.825 with the average and standard deviation of the sphericity was determined to be 0.744 and 0.029 respectively. Likewise, the sphericity for groundnut ranges from 0.522 to 0.886, while the average and standard deviation of the sphericity determined to be 0.736 and 0.067 respectively. The result was similar to the one measured by Davies [13]. The surface area for cowpea was computed to range from 1.015 cm^2 to 1.553 cm^2 while the average and standard deviation of the surface area was calculated to be 1.314 cm^2 and 0.105 respectively. Similarly, the surface area for groundnut ranges from 2.747 cm^2 to 5.416 cm^2, while the average and standard deviation of the surface area determined to be 3.837 cm^2 and 0.498 respectively. This property helps in designing cups in the seed plate and also helps in the transfer of mass and energy between seeds. The bulk mass and bulk volume for cowpea was measured to range from 14.6 g to 18.8 g and 21.0 cm^3 to 26.0 cm^3 respectively while the average of the bulk mass and bulk volume was calculated to be 17.08 g and 24.7 cm^3 respectively, also standard deviation of the bulk mass and bulk volume was calculated to be 1.045 and 1.636 respectively. Similarly, the bulk mass and bulk volume for groundnut was measured to range from 51.8 g to 67.1 g and 70.0 cm^3 to 84.0 cm^3 respectively while the average of the bulk mass and bulk volume was calculated to be 58.85 g and 76.4 cm^3 respectively, also standard deviation of the bulk mass and bulk volume was calculated to be 4.61 and 4.067 respectively. The bulk mass and bulk volume helps to ascertain the distance between the tip of the delivery tube and the soil.

Table -1: Physical Properties of cowpea and groundnut

Property	Cowpea Range	Cowpea Average	Cowpea (SD)	Groundnut Range	Groundnut Average	Groundnut (SD)
Length (cm)	0.758 - 1.015	0.87	0.054	1.093 - 2.088	1.512	0.179
Width (cm)	0.591 - 0.717	0.654	0.027	0.772 - 1.123	0.975	0.072
Thickness (cm)	0.407 - 0.571	0.475	0.026	0.680 - 1.055	0.915	0.08
Geometric Mean Diameter (cm)	0.568 - 0.703	0.646	0.026	0.935 - 1.313	1.103	0.071
Sphericity	0.693 - 0.825	0.744	0.029	0.522 - 0.886	0.736	0.067
Surface Area (cm^2)	1.015 - 1.553	1.314	0.105	2.747 - 5.416	3.837	0.498
Bulk Mass (g)	14.6 -18.8	17.08	1.045	51.8 - 67.1	58.85	4.61
Bulk Volume (cm^3)	21.0 - 26.0	24.7	1.636	70 - 84	76.4	4.067
Bulk Density (g/cm^3)	0.650 - 0.726	0.692	0.024	0.730 - 0.799	0.769	0.021
True Density (g/cm^3)	0.38 - 0.453	0.419	0.027	0.832 - 1.038	0.982	0.071
Porosity (%)	7.298 - 20.73	12.837	4.455	5.039 - 26.789	21.142	7.532

Table -2: Angle of Repose

Surface	Number of Samples	Cowpea Range (°)	Cowpea Average (°)	Cowpea Standard Deviation	Groundnut Range (°)	Groundnut Average (°)	Groundnut Standard Deviation
Plywood	100	11 - 40	23.675	5.555	4 – 35	12.825	5.975
Stainless Steel	100	9 - 35	24.72	5.591	5 – 30	12.11	5.501
Mild Steel	100	8 - 50	28.4	9.126	5 – 27	14.81	4.915
Galvanized Steel	100	11 - 47	28.115	7.496	5 – 34	14.995	6.296

Table -3: Co-efficient of Friction

Surface	Cowpea Range	Cowpea Average	Cowpea Standard Deviation	Groundnut Range	Groundnut Average	Groundnut Standard Deviation
Plywood	0.194 - 0.840	0.444	0.118	0.070 - 0.700	0.231	0.116
Stainless Steel	0.158 - 0.700	0.465	0.116	0.087 - 0.577	0.217	0.104
Mild Steel	0.141 - 1.192	0.559	0.213	0.086 - 0.510	0.267	0.093
Galvanized Steel	0.194 - 1.073	0.546	0.17	0.089 -0.675	0.271	0.123

The compression test was carried out on 8 samples of cowpea and 8 samples of groundnut, the test results was plotted on a graph of compressive stress (MPa) against compressive strain (mm/mm) (Figures 3 and 4). For cowpea, the mean compressive stress at break and mean compressive strain at break was determined to be approximately 161.79 MPa and 4.05 mm/mm respectively while the standard deviation for compressive stress at break and standard deviation for compressive strain at break was determined to be approximately 74.16 MPa and 1.01 mm/mm respectively. Other test result include mean compressive load (force) at break 1468.94 ± 673.28 N, this is similar to the result recorded for intermediate axis of almond seed (1379.20 ± 823.15 N) recorded by Sunmonu *et al.* [15]. For groundnut, the mean compressive stress at break and mean compressive strain at break was determined to be approximately 26.67 MPa and 2.23 mm/mm respectively while the standard deviation for compressive stress at break and standard deviation for compressive strain at break was determined to be approximately 11.54 MPa and 0.28 mm/mm respectively. Other test result include mean compressive load (force) at break 997.11 ± 431.56 N.

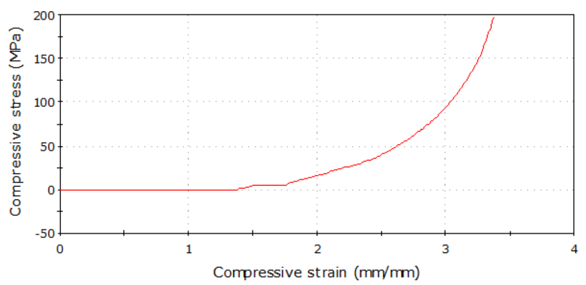

Fig -3: Compression graph for cowpea

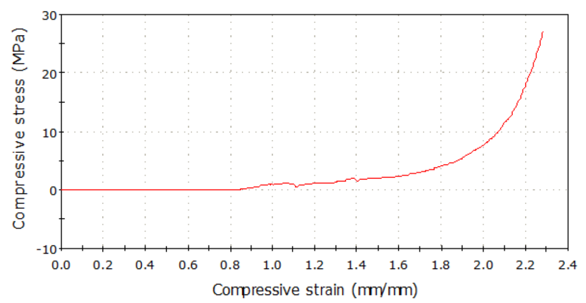

Fig -4: Compression graph for groundnut

4. CONCLUSIONS

This work examined some physical and mechanical properties of cowpea and groundnut in relation to planter design. This will help in determining the dimensions of the planter components such as hopper, metering unit, and delivery tube and also the angle of inclination and clearance of these components to one another. It also helps in choosing the right choice of designing geometry for some parts of the planter. The following conclusions were drawn from the results and discussions of this experiment:

1. The mean angle of repose of cowpea over plywood, stainless steel, mild steel and galvanized steel is 23.68°, 24.72°, 28.40° and 28.12° respectively while for groundnut is 12.83°, 12.11°, 14.81° and 15.0° respectively. To ensure free flow of seed, the hopper should be fixed at a higher angle than that of the seeds.
2. When designing the diameter of seed metering device the average minimum diameter to use for cowpea and groundnut are 0.646 cm and 1.103 cm respectively, this is based on the seed size. This is also used in determining the number of cells on the seed metering roller.
3. The bulk density of cowpea and groundnut is 0.692 g/cm^3 and 0.769 g/cm^3; this is useful in estimating the volume of hopper to be used for the planter.
4. In order to avoid unsteady flow of seed when designing the delivery tube which results in irregular spacing of seeds along the row, the average minimum diameter of the delivery tube should be 0.646 cm and 1.103 cm for cowpea and groundnut respectively.
5. The mean coefficient of friction of cowpea over plywood, stainless steel, mild steel and galvanized steel is 0.444, 0.465, 0.559 and 0.546 respectively while for groundnut is 0.231, 0.217, 0.267, and 0.271 respectively. It is recommended to use stainless steel for the seed hopper because it has a low mean coefficient of friction for both cowpea and groundnut which means the seeds tend to roll better on it. Because of high cost of stainless steel, mild steel can be used.
6. The average porosity of cowpea (12.84 %) is low compared to average porosity of groundnut (21.14 %) hence to allow proper flow of air in the soil, when designing furrow opener for cowpea, it should not cut too deep into the soil.
7. The compressive load at break of cowpea and groundnut is 1468.94 N and 997.11 N respectively. This helps to know the amount of force the seeds can withstand before breaking, this also aids in the designing of the clearance between seed plates in other to prevent breaking of the seed during operation.

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