Determination of Some Properties of Rice and Cowpea In Relation To Thresher Design

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Abstract-* Increasing rates of rice and cowpea production has helped in food sufficiency and sustainability in Nigeria. Handling and processing of these grain crops remain major problems in agricultural production chain and require urgent attention from stakeholders. Hence, this research focused on the determination of some grain properties that could enhance the design of crop processing machines. The outcome of the dimensional analysis showed that for optimum performance of the threshing machine the screen diameter must not be more than 3.66 mm and 6.44 mm for rice and cowpea respectively. For the two grain crops the rubber material recorded the highest coefficient of friction followed by wood while galvanize iron and mild steel had the least coefficient of friction to the grains. The terminal velocities of 6.54 m/s and 13.95 m/s were recorded for rice and cowpea grain respectively. This is due to the values of the projected area of the grains which are 5.23 and 43.70 mm^2 for rice and cowpea respectively, which directly affected the drag coefficient drag the grains. For rice, the mean rupture force for the major and intermediate axis was 35.404 N and 88.756 N respectively. The mean deflection for the major and the intermediate axis was determined to be 0.363 mm and 0.118 mm respectively. The mean rupture energy for the major and the intermediate was determined to be 0.010 Nm and 0.005 Nm respectively. Similarly, for cowpea, the mean rupture force for the major and intermediate axis was 60.634 N and 59.576 N respectively. The mean deflection for the major and the intermediate axis was determined to be 0.708 mm and 0.702 mm respectively. The mean rupture energy for the major and the intermediate was determined to be 0.024 Nm and 0.022 Nm respectively.

***Indexed Terms-* Aerodynamic, agricultural, crop processing, optimum performance, production.**

I. INTRODUCTION

Rice (*Oryza sativa*) is a stable food for majority of the world's population. More than 40% of the rice consumption in West Africa is imported, which represents 2.75 million tons per year [1]. Rice provides caloric nutritional needs and hence, grown in different environments where water is readily available for irrigation. Africa's emergence as a big rice importer is explained by the fact that during the last decade rice has become the most rapidly grown food in sub-Saharan Africa. Rice serves as an important staple food in the diet of an estimated 168 million Nigerians [2, 3]. In recent years, rice production in the country has been expanding at the rate of 6% per annum, with 70% of the production increase due mainly to land expansion and only 30% being attributed to an increase in productivity [4]. Cowpea {*Vigna unguiculata (L.) Walp*} is an annual, herbaceous and leguminous plant, with centre of origin and domestication reported to be in Africa [5]. Nigeria is the world largest producer and consumer of cowpea, producing 2.95 million metric tons in 2013 [5].

Threshing is the step in grain preparation after harvesting and before winnowing, which separates the loosened chaff from the grain. According to Agidi *et al*. [6] threshing is the process of loosening the edible part of grain (or other crop) from the scaly edible chaff that surrounds it. It is the step-in grain preparation after which after harvesting and before winnowing, which separates the loosened chaff from the grain. Threshing can be done by beating the grain using a flail on threshing floor. Threshing is one of the most important crop processing operations to separate the grains from the ear heads or the plants and to prepare it for market [7]. A number of small, medium, and large threshers have been in existence for quite a long time, but due to low or poor performance in comparison with the traditional methods, they have not been adopted to a significant extent. Some are hand-held threshers and pedal operated ones [8].

II. RESEARCH METHODOLOGY

A. Materials

To achieve the target of this research work, varieties of rice and cowpea were procured from a local farm in Akure, Ondo state, Nigeria. Random samples of 5 kg from raw rice and cowpea were taken to determine their optimum physical, aerodynamic and mechanical properties. The following materials were used when conducting the experiments on the selected samples to determine their properties that are useful in the design of thresher 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 20ºC with calibration of 250 ml ± 2 ml and a measuring cylinder with 100 ml; 20ºC) 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 (Figure 1). The sliding box was the equipment used to determine the angle of repose and the coefficient of friction (Figure 2). The Universal Testing Machine (UTM) Instron 6022 was used for compression loading for which rupture force and rupture energy were obtained. The apparatus used for the determination of the terminal velocity consists of an electric blower which discharge air blast into a transparent tapered tube used as a cyclone which is fixed at the outlet side of the blower through an elbow. A screen is fitted at the bottom of the transparent tapered tube of 8×4 cm cross section and a cyclone is fitted at the top of it 15 cm square cross section. A chock valve is built at the bottom of the cyclone to control the air flow rate. The chock valve was manually adjusted through the control lever.

Fig. 1. Electronic digital balance Fig. 2. Sliding box

B. Research Procedure

The grain dimensions (length, width and thickness), mass of thousand grain, volume, geometric mean diameter, arithmetic mean diameter, bulk and real densities, percent of sphericity, projected area, terminal velocity, drag coefficient, Reynold's number, angle of repose and coefficient of friction were measured and estimated. All the research procedures were replicated five times, the average values were recorded.

C. Physical Properties

The three principal dimensions namely, length (L), width (W), and thickness (T) were measured using a micrometer screw gauge reading to 0.01 mm. The size of the crop varieties in terms of length (L), width (W) and thickness (T) was used to calculate the volume (V), geometric mean diameter (Dg), arithmetic mean diameter (Da), sphericity (S), surface area (Af), porosity and area of transverse surface (At) of the individual seeds. The following equations according to EL–Raie et al. [9] and Soyoye et al. [10] were used to calculate the values of the above-mentioned properties:

1. Geometric maen diameter $\left(\mathrm{D_g}\right) = (\mathrm{LWT})^{1/3}$ (mm)
2. Arithemetic mean diameter $(\mathrm{D_a}) = \frac{(\mathrm{L+W+T})}{3}$ (mm)
3. Dimensional volume $(\mathrm{V}) = \frac{\pi}{6}\mathrm{LWT}\ (\mathrm{mm})^3$
4. Sphericity $(\emptyset) = \frac{(\mathrm{LWT})^{1/3}}{\mathrm{L}} \times 100\%$
5. Surface area $(\mathrm{A_f}) = \left(\mathrm{D_g}\right)^2\ (\mathrm{mm})^2$

The bulk density was determined using the standard test weight procedure. A standard container (beaker) of known weight and volume of 250 ml was filled with grains to the brim. The grains were then levelled by striking off the top of the container. The total weight of grains and cylinder was recorded. Bulk density was determined as the ratio of the mass of grains only to the volume occupied by the grains (250 ml).

$$\text{Bulk density } (\rho_b) = \frac{\text{Mass of grain (m)}}{\text{volume of grain (v)}}$$

For true density, 100 grains were picked at random from each sample and the mass determined. Toluene (C_7H_8) was poured into a measuring cylinder and the volume recorded. The already weighed grains were then poured into the cylinder and the volume of displaced toluene recorded. The true density was found as an average of the ratio of the mass of grains to the volume of toluene displaced by the grains. Toluene (C_7H_8) was used in place of water because it is absorbed by seeds to a lesser extent and its surface tension is low.

$$\text{True density } (\rho_t) = \frac{\text{Mass of grain (m)}}{\text{volume of displaced toluene (v)}}$$

The porosity of the grains was calculated from the values of the bulk and true densities using the mathematical expression;

$$\text{Porosity} = \left(1 - \frac{\text{bulk density}}{\text{true density}}\right) \times 100\%$$

D. Aerodynamic Properties

The wind tunnel was used to determine the terminal velocity of grains. A centrifugal fan powered by one horse power motor was used in the inlet of the wind tunnel to supply air flow. The air flow rate of the fan was controlled at the inlet by adjusting the velocity of the electric motor through an inverter set and a diaphragm. The final section of the wind tunnel consisted of a Plexiglas region where the terminal velocity of seed was measured. Each seed was placed in the center of the cross section of the wind tunnel on the screen. The air flow was then increased until the seed attained flotation point. At this moment, when the rotational movement of the seed was the lowest, the air velocity was measured using a hot-wire anemometer with an accuracy of 0.1 m s^{-1}. The terminal velocity of each seed was measured five (5) times and the mean calculated. In determining the terminal velocity at each moisture content level, five seeds were selected and used as five replications in the statistical analysis. The values of air density were taken as 1.206 kg m^{-3} at room temperature of 20^C. The object in free fall attains a constant terminal velocity (Vt) at the point where the net gravitational accelerating force (Fg) equals the resisting upward drag force (Fr). Under this condition where terminal velocity has been achieved, the air velocity will be equal to the terminal velocity (Vt).

$$\text{Terminal velocity } (V_t) = \sqrt{\frac{(\rho_s - \rho_a)2mg}{\rho_s \rho_a A_p C_d}}$$

$$A_p = \frac{\pi}{4} LW$$

A_p is the projected area of the grains, C_d is the drag coefficient, ρ_s and ρ_a are densities of seed and air m is the mass of seed.

E. Mechanical Properties

The angle of repose was determined by using a topless and bottomless cylinder of 150 mm diameter and 220 mm height. A removable circular plate was placed under the cylinder, the sample was poured into the cylinder and then the cylinder was slowly raised allowing the sample to form a cone on the circular plate (Figure 3). The height of cone was measured and the angle of repose calculated by dividing the height of the cone by the radius of the circular plate. Sezer et al. [11] used this method to determine angle of repose for indent corn and Davies [12] used the same method for groundnut.

Fig. 3. Forming angle of repose for rice

A. Compressive Loading of Seeds

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.

III. RESULTS AND DISCUSSION

The data in Tables 1 and 2 show the geometric mean diameter, arithmetic mean diameter and sphericity of the rice grains**.** These dimensions are considered in selecting and designing a suitable size of screen perforations and in the determination proper method for grading and separation of grains. The dimensional results showed that for optimum performance of the threshing machine, the screen diameter must not be more than 3.66 mm and 6.44 mm for rice and cowpea respectively.

The data presented in Table 3 shows the values of coefficient static friction. For the two grain crops the rubber material recorded the highest coefficient of friction followed by wood while galvanize iron and mild steel had the least coefficient of friction to the grains. The results confirmed that galvanize and mild steel are the best choice of materials to be used in the design of the hopper of the threshing machines. The data can be utilized to assess the optimum side inclination of seed hopper in threshing machine, planting machine, silos and storage containers to allow easy sliding.

Tables 4 and 5 show the results of the aerodynamic properties of rice and cowpea. The tables revealed a variation in terminal velocity for the varieties of the crop due to the variation in particle mass, air and particle density. The terminal velocities of 6.54 m/s and 13.95 m/s were recorded for rice and cowpea grain respectively. This is due to the values of the projected area of the grains which are 5.23 and 43.70 mm^2 for rice and cowpea respectively, which directly affected the drag coefficient drag the grains. Hence, the difference in terminal velocity offers the possibility of separating such materials from each other in an air stream and it can be utilized in designing threshing screen, threshing chamber and cleaning unit of a threshing machine.

The compression test was carried out on rice and cowpea seeds at two different axes which are the major (M_A) and intermediate (I_A) axes. Five tests were carried out on each axis. The results from the tests are as shown in Tables 6 and 7. For rice, the mean rupture force for the major and intermediate axis was 35.404 N and 88.756 N respectively. The mean deflection for the major and the intermediate axis was determined to be 0.363 mm and 0.118 mm respectively. The mean rupture energy for the major and the intermediate was determined to be 0.010 Nm and 0.005 Nm respectively. Similarly, for cowpea, the mean rupture force for the major and intermediate axis was 60.634 N and 59.576 N respectively. The mean deflection for the major and the intermediate axis was determined to be 0.708 mm and 0.702 mm respectively. The mean rupture energy for the major and the intermediate was determined to be 0.024 Nm and 0.022 Nm respectively. The implication of these results in thresher design is that the impact and rubbing forces resulting from the impact of the beating spikes around the cylinder on the grains must not be greater than the peak force of the grains concerned. For rice grains a spike impact force of 35 ± 0.5 N is recommended. While an impact force of 59 ± 0.5 N is recommended for cowpea grains. These forces can be achieved by proper regulation of the rotational speed of the spike to reduce the impact effects on the grains.

Table 1. Basic Geometric Properties of Rice

Properties	Test I	Test II	Test III	Test IV	Test V	Average
Length (L) (mm)	7.45	7.64	7.30	7.27	7.11	7.35
Width (w) (mm)	2.99	2.60	2.83	2.83	2.54	2.76
Thickness (T) (mm)	2.35	2.48	2.40	2.45	2.39	2.41
Geometric mean diameter (Dg) (mm)	3.74	3.67	3.67	3.69	3.51	3.66
Arithmetic mean diameter (Da) (mm)	4.26	4.24	4.18	4.18	4.01	4.18
Percent of sphericity (S) %	50.21	47.98	50.33	50.81	49.34	49.73

Table 2. Basic Geometric Properties of cowpea

Properties	Test I	Test II	Test III	Test IV	Test V	Average
Length (L) (mm)	8.15	8.43	8.59	7.72	8.87	8.35
Width (w) (mm)	6.61	6.80	6.78	6.20	6.86	6.65
Thickness (T) (mm)	5.29	4.14	5.58	4.59	4.56	4.83
Geometric mean diameter (Dg) (mm)	6.58	6.19	6.88	6.03	6.52	6.44
Arithmetic mean diameter (Da) (mm)	6.68	6.46	6.98	6.17	6.76	6.61
Percent of sphericity (S) %	80.74	73.44	80.04	78.16	73.53	77.18

Table 3. Coefficient of Static Friction

Crop	Plywood	Galv. iron	Rubber	Mild steel
Rice	0.46	0.43	0.53	0.42
cowpea	0.47	0.44	0.64	0.44

Table 4. Aerodynamic Properties of Rice

	Test I	Test II	Test III	Test IV	Test V	Average
Projected area of the particle	5.52	5.06	5.34	5.45	4.77	5.23
Drag coefficient	0.57	0.48	0.63	0.55	0.49	0.54
Terminal velocity (m/s)	6.35	6.50	6.47	6.77	6.60	6.54

Table 5. Aerodynamic Properties of Beans

	Test I	Test II	Test III	Test IV	Test V	Average
Projected area of the particle	42.32	45.03	45.75	37.60	47.80	43.70
Drag coefficient	0.447	0.452	0.450	0.453	0.449	0.450
Terminal velocity	13.80	14.05	14.30	13.35	14.26	13.95

Table 6. Results of compression tests on rice seeds

S/N		1	2	3	4	5	Min	Max	Mean	S. D
Force at Peak	M_A	29.310	29.730	55.570	24.290	38.120	24.290	55.570	35.404	12.318
(N)	I_A	98.380	91.930	81.650	95.230	76.590	76.590	98.380	88.756	9.262
	M_A	0.268	0.251	0.621	0.237	0.439	0.237	0.621	0.363	0.166

Deflection at Peak (mm)	I_a	0.120	0.112	0.122	0.119	0.119	0.112	0.122	0.118	0.004
Force at Break (N)	M_A	28.630	26.740	38.500	24.290	37.980	24.290	38.500	31.228	6.586
	I_A	98.380	91.930	81.650	95.230	76.590	76.590	98.380	88.756	9.262
Deflection at Break (mm)	M_A	0.285	0.270	0.835	0.237	0.453	0.237	0.835	0.416	0.249
	I_A	0.120	0.112	0.122	0.119	0.119	0.112	0.122	0.118	0.004

Table 7. Results of compression tests on cowpea seeds

S/N		1	2	3	4	5	Min	Max	Mean	S. D
Force at Peak (N)	M_A	44.160	54.630	65.990	59.030	79.360	44.160	79.360	60.634	13.128
	I_A	50.960	96.430	38.820	37.490	74.180	37.490	96.430	59.576	25.320
Deflection at Peak (mm)	M_A	0.464	0.709	0.648	0.762	0.955	0.464	0.955	0.708	0.178
	I_a	0.419	1.158	0.387	0.577	0.970	0.387	1.157	0.702	0.344
Force at Break (N)	M_A	33.280	54.500	45.200	54.790	79.050	33.280	79.050	53.364	16.831
	I_A	50.960	74.770	38.320	31.860	74.180	31.860	74.770	54.018	19.899
Deflection at Break (mm)	M_A	0.533	0.716	0.830	0.767	0.960	0.533	0.960	0.761	0.157
	I_A	0.419	1.205	0.466	0.630	0.970	0.419	1.205	0.738	0.339

CONCLUSION

Some physical, aerodynamic and mechanical properties of rice and cowpea in respect to threshing equipment were determined. Based on the results, the following conclusions were made.

i. When designing the screen of a thresher, the average minimum diameter to use for rice and cowpea should be 3.66 mm and 6.44 mm respectively.
ii. Base on the respective terminal velocities of both the rice and cowpea grains, the maximum air speed that is required from the blower should be 6.50 m/s and 13.90 m/s respectively.
iii. The rupture energy resulting from the spikes on the grains must not exceed 0.009 Nm and 0.02 Nm for rice and cowpea grains respectively.
iv. When designing for the hopper, galvanize steel and mild steel are recommended.

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