Determination of Selected Engineering Properties of Cowpea (*Vigna unguiculata*) Related to Design of Processing Machines

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ABSTRACT

In this study, some selected engineering properties of two improved varieties of cowpea (Sampea 7 and Tvx 3236) grown in Nigeria were determined. The properties of Sampea 7 are: Length (9.48 ± 1.46 mm), width (6.75 ± 0.66 mm), thickness (5.35 ± 0.73 mm), roundness (2.38 ± 0.28), sphericity (3.64 ± 0.46), mass (48.0 ± 10.0 g), volume (1.04 ± 0.26 mm^3), density (1.00 ± 0.28 kg/m^3), surface area (10.74 ± 1.78 cm^2), angle of internal friction (11.05 ± 2.07°), angle of repose (20.50± 2.38º) and moisture content (7.01 ± 0.05% db). The compressive strength, tensile strength, abrasive strength, shear strength and torsion strength of Sampea 7 are 66.25 ±16.12 N, 65.53 ±15.51 N, 64.55 ±14.55 N, 65.20 ±15.50 N and 65.00 ±16.10 N, respectively while its hardness is 7.98 ± 0.03 kg. The properties of Tvx 3236 are: Length (7.76 ± 0.56 mm), width (5.25 ± 0.14 mm), thickness (4.11 ± 0.42 mm), roundness (1.42 ± 0.14), sphericity (5.12 ± 1.00), mass (32.0 ± 8.0 g), volume (0.70 ± 0.10 mm^3), density (0.48 ± 0.20 kg/m^3), surface area (8.80 ± 1.02 cm^2), angle of internal friction (9.23 ± 1.58°), angle of repose (21.05± 1.26º) and moisture content (6.7± 0.22%db). The compressive strength, tensile strength, abrasive strength, shear strength and torsion strength for Tvx 3236 are 93.65 ±13.62 N, 93.55 ±13.71 N, 92.56 ±13.70 N, 93.50 ±13.60 N and 92.75 ±13.65 N, respectively while its hardness is 11.96 ± 3.57 kg. Statistical tests on the properties showed that dimensions, compressive strength, tensile strength, hardness, abrasive strength, shear strength and torsion strength of the two cowpea varieties are highly significant at 5% level; roundness, sphericity, volume, surface area and angle of internal friction are significant at 5% level; while mass, density, angle of repose and moisture content are not significant at 5% level.

Keywords: Cowpea, Biomaterials, Engineering properties, Mechanical properties, Physical properties

INTRODUCTION

Modern agriculture has brought about the handling and processing of plant and animal materials by various means ranging from mechanical, thermal, electrical, optical, to even sonic techniques. The ever increasing importance of agricultural products together with the complexity of modern technology for their production, processing and storage need a better knowledge of their engineering properties so that machines, processes and handling operations can be designed for maximum efficiency and the highest quality of the final end products (Mohsenin, 1970). For instance, the application of physical properties such as shape which is an important parameter for stress distribution in materials under load is important in developing sizing and grading machines and for analytical prediction of its drying behaviour (Esref and Halil, 2007).

It is important to have an accurate estimate of shape, size, volume, density, surface area and other physical and mechanical properties that may be considered as engineering parameters for that product, when biomaterials are studied either in bulk or individually. Also, mechanical damage to seeds which occurs in harvesting, threshing, and handling can seriously affect viability and germination power, growth vigour, insect and fungi attack and also the quality of the final products (Mohsenin, 1970). Knowledge of mechanical properties (properties that have to do with the behaviour of agricultural products under applied forces) such as stress, strain, hardness and compressive strength is vital to engineers handling agricultural products. The determination of mechanical properties of agricultural products under static or dynamic loading is aimed at textural measurement of unprocessed and processed food materials; the reduction of mechanical damage to agricultural produce during postharvest handling, processing, and storage; and the determination of design parameters for harvesting and postharvest systems. Therefore, a rational approach to the design of agricultural machinery, equipment and facilities will involve the knowledge of the engineering properties of the products.

The objective of this study is to determine some selected engineering (physical and mechanical) properties of two improved varieties of cowpea grown in Nigeria, to establish a convenient reference data for their mechanization and processing. The knowledge of the engineering properties is useful for both engineers and food scientists; plant and animal breeders and it is also important in data collection in the design of machines, structures, processes and controls; and in determining the efficiency of a machine or an operation.

MATERIALS AND METHODS

Selection of Materials

Two improved varieties (Sampea 7 and TVx3236) of cowpea (*Vigna unguiculata*) were used in this study. They were sourced from Yarcasua village in Saminaka, Kaduna State of Nigeria. Sixty kernels of each sample were used for the study. The samples were numbered to avoid the repeat of measurements with the same seed.

Preparation of Materials

All foreign materials such as dust, stones, chaff, immature and broken seeds as well as bad seeds were removed by winnowing and picking. Sample selection was randomized all through the tests.

Determination of Physical Properties

Size, Surface area, Roundness and Sphericity

To determine the size of the grains, 3 groups of samples consisting of twenty seeds of cowpea were randomly taken and their linear dimensions – length (L), width (W) and thickness (T) measured using a digital callipers Model Mecanic Type 6911 (VWR Scientific, Switzerland).

Projected areas of the grains were measured using a digital camera (Samsung S 760, 7.2 MP). Roundness was determined by drawing circles to circumscribe the traced boundaries of the sample and by relating the largest and smallest circumscribed circles. Using equation (1) (Curray, 1991), roundness was obtained.

$$Roundness = \frac{\sum r}{NR} \quad (1)$$

r = radius of curvature; R = radius of the maximum inscribed circle; N = total number of corners summed.

Sphericity was estimated from equation (2) (Mohsenin, 1970).

$$Sphericity = \frac{d_e}{d_i} \quad (2)$$

d_e = diameter of a sphere of the same volume as the object, d_i = diameter of the circumscribing sphere or usually the longer diameter of the object.

Weight, Volume and Density

Weight of the seeds was obtained with an electric weighing balance (Adventurer OHAUS, Meller, Switzerland: Type PM 2000; Serial No: H52764; sensitivity ± 0.001g). Volume was calculated using the measured dimensions and grain density determined from the relationship between mass, density and volume using equation (3).

$$Density, \rho = \frac{Mass, m}{Volume, v} \quad (3)$$

Angle of internal friction and Angle of repose

Angle of internal friction on plywood surface was determined by the tilting surface method (Mingjin *et al*., 2003) and the angle of repose by the geometrical approach described by (Chukwu and Akande, 2007). Equation (4) (Mohsenin, 1970; Chukwu and Akande, 2007) was used to calculate the angle of repose.

$$\theta_r = \tan^{-1}\frac{2(H_c - H_p)}{D_p} \quad (4)$$

θ_r = Angle of repose, H_c = height of cone, H_p = height of platform, D_p = diameter of platform.

Moisture content

Moisture content was determined as recommended by Association of Official Analytical Chemists (AOAC) (1995). This involves measuring the weight of sample before and after oven drying at temperature 72˚ C for 9 hours for the first moisture content and 132˚C for 18 hours for the second moisture content. The moisture content was then estimated on dry basis using equation (5).

$$M_c = \frac{W_w - W_d}{W_d} x100 \quad (5)$$

M_c = moisture content (dry basis); W_w = Weight of materials before oven drying; W_d = Weight of material after oven drying.

Determination of Mechanical Properties

Mechanical properties of cowpea were evaluated using 60 seeds and appropriate instruments.

Compressive strength

A recording compression force gauge (UKK compression force gauge produced by Imada, Northbrook, USA; Model: UK-10 kg and accuracy ± 0.3%) was used to obtain the compressive strength of the seeds. The slots were screwed to compress the seeds placed between them. The counter reading was taken immediately the first cracking sound was heard.

Tensile strength

A recording tension force gauge (UKT tension force gauge produced by Imada, Northbrook, USA; Model: UK-10 kg and accuracy ± 0.3%) was used to obtain the tensile strength of the samples. A sample was placed between the two ends of the measuring instrument and the reading was immediately taken as displayed by the digital force gauge.

Hardness

Universal hardness tester (INNOVATEST, Model CV-700 by CVInstruments, Europe BV) was used to obtain the hardness of the 20 seeds. The upper part of instrument slot was screwed downward to press the sample. The first sound made by the sample when tightly pressed indicates its hardness. The counter reading was taken where the sample was not making a total contact with the tester. The hardness value divided by contact area gives the contact hardness number.

Abrasive strength

The abrasive strength was obtained with the hardness tester. The upper, middle and lower parts of the instrument were used at different times for 20-seed samples each. The slots were screwed to a different end on each experiment. The first sound made by the sample at each time of the experiment indicates the abrasive strength effect.

Shear strength

A recording, single column model instron universal materials testing machine (produced by Instron Incorporated, USA, Model No: 3344 and accuracy ± 0.2%) was used to obtain the shear strength of the samples. The slots were screwed to compress the sample placed between them. The reading was taken immediately the first cracking sound was heard.

Torsion strength

A torsion balance (PASCD scientific, USA, Model AP-8215) was used to obtain the torsion strength of the samples. The slots were glued to the torsion balance to twist the sample placed on it and the reading was taken instantly the first cracking sound was heard.

Statistical Analysis

The tools used in computation and comparison of data are mean, standard deviation and coefficient of variation using SPSS 11.5 for Windows. A t-test was used to determine significance differences between means of the two improved varieties of cowpea studied.

RESULTS AND DICUSSION

The engineering properties of the two varieties of cowpea studied are presented in Table 1. The mean length, width and thickness for Sampea 7 were found to be 9.48 mm, 6.75 mm, and 5.35 mm, respectively. For Tvx 3236, the mean length, width and thickness are 7.76 mm, 5.25 mm, and 4.11 mm, respectively. The importance of these dimensions in determining sieve apertures and other parameters in machine design were discussed by (Mohsenin, 1986; Omobuwajo et al., 1999; Heidarbeigi *et al*., 2009). The size and shape are, for instance, important in the electrostatic separation of agricultural products from undesirable materials and in the development of sizing and grading machinery.

The mean roundness and sphericity of Sampea 7 are 2.38 and 3.64, respectively and respectivley1.42 and 5.12 for Tvx 3236. Roundness and sphericity are properties that relate to shape and are needed for an analytical prediction of the drying behaviours of agricultural grains (Esref and Halil, 2007).

The mean mass, volume, density and surface area of Sampea are 48 g, 1.04 mm^3, 1.00 kg/m^3 and 10.74 cm^2, respectively while the values for Tvx 3236 are 32 g, 0.70 mm^3, 0.48 kg/m^3 and 8.80 cm^2 in that order. Mass, volume and density of food materials and agricultural products play an important role in the design of silos and storage bins (Waziri and Mittal, 1997); determining the purity of seeds (Jaeger, 1997); stability of feed pellet and wafers (Gustustafson and Kjelgard, 2000); mechanical compressing of ensilages (Ige, 1997) and maturity evaluation (Fashina, 1996).

Table 1: Engineering Properties of Cowpea (Sampea 7 and Tvx 3236)

Parameter	Sampea 7		Tvx 3236		Table
	Mean ± SD	CoV[a]	Mean ± SD	CoV	t-values
Length (mm)	9.48 ± 1.46**	3.01	7.76 ± 0.56**	3.38	1.30
Width (mm)	6.75 ± 0.66**	2.19	5.25 ± 0.14**	2.43	1.30
Thickness (mm)	5.35 ± 0.73**	1.03	4.11 ± 0.42**	1.53	1.30
Roundness	2.38 ± 0.28*	4.48	1.42 ± 0.14*	5.04	1.70
Sphericity	3.64 ± 0.46*	5.98	5.12 ± 1.00*	16.34	1.70
Mass (g)	48.0 ± 10.0^{ns}	0.43	32.0 ± 8.0^{ns}	1.35	0.17
Volume (mm^3)	1.04 ± 0.26*	5.58	0.70 ± 0.10*	16.34	1.70
Density (kg/m^3)	1.00 ± 0.28^{ns}	2.66	0.48 ± 0.20^{ns}	6.78	1.70
Surface area(cm^2)	10.74 ± 1.78*	0.24	8.80 ± 1.02*	1.94	1.70
Angle of friction (º)	11.05 ± 2.07*	1.01	9.23 ± 1.58*	2.34	1.73
Angle of repose (º)	20.50± 2.38^{ns}	1.70	21.05± 1.26^{ns}	1.94	1.73
Moisture content (%db)	7.01 ± 0.05^{ns}	0.51	6.7 ± 0.22^{ns}	0.82	0.17
Compresive strength (N)	66.25 ± 16.12**	0.94	93.65 ±13.62**	1.54	1.73
Tensile strength (N)	65.53 ± 15.51**	0.93	93.55 ±13.71**	1.52	1.73
Hardness (kg)	7.98 ± 0.03**	0.01	11.96 ± 3.57**	9.76	1.73
Abrasive strength (N)	64.55 ± 14.55**	0.84	92.56 ±13.70**	1.51	1.73
Shear strength (N)	65.20 ± 15.50**	0.93	93.50 ±13.60**	1.53	1.73
Torsion strength (N)	65.00 ± 16.10**	0.90	92.75 ±13.65**	1.50	1.73

a = coefficient of variation; ** highly significant at 5% level; * significant at 5% level; ns = not significant at 5% level.

The surface area of an agricultural product is generally indicative of its pattern of behaviour in a flowing fluid such as air, as well as the ease of separating extraneous materials from the product during cleaning by pneumatic means (Omobuwajo, 1999). It is also important in heat and mass transfer processes such as drying and other thermal applications. The fact that the densities of the seeds are less than the density of water can be used to design separation or cleaning processes for the grains since lighter fractions will float. Bulk density and true density can be useful in sizing grain hoppers and storage facilities; they can affect the rate of heat and mass transfer of moisture during aeration and drying processes. Grain densities have been of interest in breakage susceptibility and hardness studies (Heidarbeigi *et al*., 2009).

The mean angle of internal friction and angle of repose of Sampea are respectively 11.05° and 20.50° and for Tvx 3236 are 9.23° and 21.05°, respectively. The angle of internal friction indicates the angle at which chutes must be positioned in order to achieve consistent flow of material through it (Olajide and Igbeka, 2003). The angle of repose determines the maximum angle of a pile of grain in the horizontal plane, and is important in the filling of a flat storage facility when grain is not piled at a uniform bed depth but is peaked (Mohsenin, 1986). The static coefficient of friction is used to determine the angle at which chutes must be positioned in order to achieve consistent flow of materials through the chute. Also the design of grain hoppers for processing machinery requires data on bulk density and angle of repose.

The mean moisture contents (dry basis) of Sampea 7 and Tvx 3236 are 7.01% and 6.70%, respectively. The moisture content of a produce simply indicates the amount of water present in that agricultural produce and this is of great importance to food scientists and processing engineers as it assists them to determine certain adaptation and resistance to processing stages such as drying, bagging, storage, cooking and even consumption.

The mean compressive strength, tensile strength, hardness, abrasive strength, shear strength and torsion strength of Sampea 7 are 66.25 N, 65.53 N, 7.98 kg, 64.55 N, 65.20 N and 65.00 N, respectively and for Tvx 3236 they are respectively 93.65 N, 93.55 N, 11,96 kg, 92.56 N, 93.50 N and 92.75 N. These properties are those that have to do with the behaviour of agricultural products under applied forces.

A vast knowledge of mechanical properties such as hardness and compression tests is vital to engineers handling agricultural products. According to Anazodo (1983), knowledge of mechanical properties of agricultural products (such as compressive and tensile strength) under static or dynamic loading is aimed at textural measurement of unprocessed and processed food material; the reduction of mechanical damage to agricultural produce during handling, processing, and storage; and the determination of design parameters for harvest and post harvest systems. The probability of fracture of a particle under tension depends on the applied macroscopic stress and the size of the particle. A farm product machine designer needs knowledge of the tensile stress of cowpea for process design and handling. Hardness is defined as the ability of a material to resist indentation or abrasion. This property is required for the design of agricultural processing to minimise breakage and wastage (Ryder, 1996).

Abrasive strength is very crucial in the processing of agricultural produce, because it has to do with the ability of engineers and food technologist to remove or protect the very tight coated membrane on grains such as cowpea seeds. In food processing, for example, the membrane will have to be removed or protected depending on the nature of the grain processing involved. For instance, planting operations will require the engineers and agriculturists to ensure that the membranes are well protected as they are vital in germination and growth.

Shear strength in reference to grains is a term used to describe the maximum strength of grains at which point significant plastic deformation or yielding occurs due to an applied shear stress. The real effect of shear strength on grain depends on the rate at which the shearing occurs. Shear strength is very important in the design of equipment for processing of agricultural produce by engineers, agriculturists and food technologists, where the concept of the grain steady state shear strength is used. Factors that control shear strength include type of material to be processed, the state of the material (wet or dry) and the structure as at the time of processing.

Torsion strength involves a rotation in which one end of the rotating object is movable while the other is fixed or stationary. In design, the knowledge of torsion strength is vital. The effect on the farm produce of processing machines could be either beneficial or disastrous depending on the objective of the processing the product. Certain materials could perfectly fit into engineering designs while others could result in failures and negative results leading to wear, tear and plastic deformation.

Statistical tests on the engineering properties showed that dimensions, compressive strength, tensile strength, hardness, abrasive strength, shear strength and torsion strength of the two cowpea varieties are highly significant at 5% level; roundness, sphericity, volume, surface area and angle of internal friction are significant at 5% level; while mass, density, angle of repose and moisture content are not significant at 5% level.

CONCLUSION

Some engineering properties of two varieties of cowpea grown in Nigeria which may be useful in designing equipment for postharvest handling and processing operations were determined. Statistical test showed that there are significant differences between the engineering properties of the two crops studied. It was established that the determined engineering properties are vital for the design of postharvest handling and processing equipment for cowpea.

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