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DETERMINATION OFPHYSICOMECHANICAL PROPERTIES OF VELVET BEAN (*Mucuna Pruriens*) FROM SOUTH EASTERN NIGERIA

P. C. Eze[1,*], C. N. Eze[2] and R.S. Agu[3]

[1,2] DEPT. OF AGRIC AND BIORESOURCE ENG. ENUGU STATE UNIV. OF SCIENCE AND TECH., ENUGU STATE NIGERIA.
[3] DEPARTMENT OF AGRICULTURAL TECHNOLOGY, ENUGU STATE POLYTECHNIC, IWOLLO, ENUGU STATE NIGERIA.
E-mail addresses: [1] *paul.eze@esut.edu.ng,* [2] *nkechi.eze@esut.edu.ng,* [3] *aguromanus@gmail.com*

ABSTRACT

Selected physical and mechanical properties of velvet bean (Mucuna pruriens) were studied at two moisture content levels of 13% and 20% (d_b). Compression strength characteristics were conducted under quasi-static compressive force at longitudinal and latitudinal (lateral) loading positions and the rupture forces, compressive strength, modulus of deformability, toughness, stiffness and force at bio-yield point determined as the mechanical properties at varying loading positions. Results indicated that volume (7.398 - 9.416 mm^3), surface area (73.289 - 111.782 mm^2), geometric mean diameter (9.18 - 11.68mm), and weight (0.872 - 1.055 g) of the velvet bean seed increased linearly with increase in moisture content. Also, the bulk density, specific gravity (0.118 - 0.112 g/mm^3), sphericity (0.737 - 0.704) and aspect ratio (0.776 - 0.719) decreased linearly with increase in moisture content. These indicate that Velvet beans have wide size ranges and no single sample of the grains can effectively represent the other. In the case of the force-deformation characteristics, result indicates that the force and corresponding deformation to rupture of velvet bean seeds were found to vary from 525N, 5mm in longitudinal loading position to 800N, 7mm in lateral loading position at 13% moisture content and 131.25N, 3mm in longitudinal loading to 237.5N, 4.75mm in lateral loading at 20% (w_b) moisture content. The bio-yield force, compressive strength, stiffness and toughness of the velvet bean seeds varied from 375 N, 14.412 N/mm^2, 105 N/mm and 354.836 J/mm^{3}respectively in longitudinal loading position to 475 N, 21, 961 N/mm^2, 114. 286 N/mm^2 and 756.961 N/mm^{2}respectively in lateral loading position at 13% moisture content and 112.5N, 3.53N/mm^2, 43.75 N/mm and 41.817 J/mm^{3}respectively in longitudinal loading and 175 N, 6.388 N/mm^2, 50 N/mm and 119.809 J/mm^{3}respectively in lateral loading at 20% (w_b) moisture content. Generally, the compressive strength of the velvet bean seeds is higher at lateral loading position than at the longitudinal loading position.

Key Words: *Physical Properties, Mechanical Properties, Velvet Bean, Moisture content, Loading Positions.*

1. INTRODUCTION

Mucuna pruriens is a tropical legume, commonly known as velvet bean or cowitch or cowhage. It is one of the most popular medicinal plants in Africa and Asia, and is constituent of more than 200 indigenous drug formulations. It is found in the plains of India [1, 27, 29]. The demand for mucuna in India as well as in international drug markets increased many fold only after the discovery of the presence of L-3, 4-Dihydroxyl Phenyl Alamine (L-DOPA), an anti-Parkinson's (PD) disease drug in the mucuna seeds [9]. The genus mucuna belongs to the family leguminosae and consists of 100 species of climbing vines and shrubs. The name of the genus is derived from the word mucuna [32], and found in the woodlands of tropical areas especially in tropical Africa, India, and the Caribbean. Velvet bean (*mucuna pruriens*) is a twining annual crop that can reach 15m in length. The plant is almost completely covered with fuzzy hair when young, but almost free of hairs when older. The leaves are trifoliate, alternate, or spiralled, gray-silky beneath; petioles are long and silky, 6.3 to 11.3cm. Leaflets are membranous, terminal leaflets are smaller, lateral very unequal sized. Flowers are dark purple, white or lavender in colour, pea-like but larger with distinctive curved petals and occur in drooping racemes as shown in fig. 1.

Fig. 2 (i) shows the fruits which are curved longitudinal pods which usually contain 4 to 6 seeds, about 10cm long [1] and are densely covered with persistent pale-brown or grey trichomes that cause irritating blisters or itching if they come in contact with human skin. According to [1], the chemical responsible for the itching is a protein in mucuna and serotonin. The seeds {fig.2 (ii)} are shiny black or brown, ovoid and 12mm long [1, 27, 33].

* **Corresponding author, tel: +234 – 803 – 264 – 2302**

Figure 1: Picture of velvet bean (mucuna preriens) tree at flowering stage

Mucuna pruriens are consumed and promoted by small holder farmers in Africa, South America and South Asia, as a green manure or a cover crop because this plant possess valuable medicinal properties and has been studied for various activities such as itching, anti-oxidant, anti-diabetic, anti-neoplastic, anti-epileptic, anti-microbial, aphrodisiac and anthelmintic activity. It has also been shown to be neuro-protective and as a fertility agent (in men), has analgesic and anti-inflammatory activities. Velvet bean seed is rich in protein (23 - 35%), has nutritional qualities comparable to that of other pulses and considered viable source of dietary proteins [13] due to its high protein concentration in addition to its digestibility.

Legume proteins are used as ingredients primarily to increase nutritional quality and to provide a variety of functional properties, including desirable structure, texture, flavour and colour characteristics in formulated food products. Many varieties and accessions of mucuna have great demand in food and pharmaceutical industries. Nutritional importance of mucuna seeds as a source of protein supplement in food and feed has been well documented [28]. Mucuna seeds are used to provide symptomatic relief in Parkinson's disease (PD) [22]. These seeds are prescribed in the form of powder to treat leucorrhoea, spermatorrhoea, and in cases requiring aphrodisiac action. A variety of preparations made from mucuna seeds are used for the management of several free radical-mediated diseases like ageing, rheumatoid, arthritis, diabetes, male infertility and nervous disorders. Mucuna seeds have also been shown to be rich in antioxidant properties [30]. Although, mucuna seeds have versatile food and pharmaceutical values, methods of processing and storing in tropical conditions render the seeds susceptible to microbial contamination including toxygenic moulds incurring substantial losses, which makes this work viable. Fungal and mycotoxin contamination is the main concern to minimize the economic losses and reduce the potential risks to human and livestock health [31]. Recently, the loss in the world's food supply has been estimated to be about 25% due to microbial contamination, improper handling and storage. To date, no detailed reports are available on the extent of microbial and toxin contamination of mucuna seeds. Mucuna pruriens root according to [4] are bitter, thermogenic, anthelmintic, diuretic, emollient, stimulant, purgative, febrifuge and toxic. It is considered useful to relieve constipation, nephropathy, dysmenorrhoea, amenorrhea, elephantiasis, dropsy, ulcer and delirium [34]. Leaves are popular potherbs; used as a fodder crops and are useful in ulcers, inflammation, cephalagia, and general debility. An ointment prepared with mucuna hairs act as a local stimulant and mild vesicant [27]. The plant and its extracts are used in tribal communities as a toxin antagonist for various snakebites. The seeds are found to have antidepressant properties in case of depressive neurosis when consumed [25] and formulations of the seed powder have shown promise in the management and treatment of Parkinson's disease [5].

Figure 2 (i) Un-dehulled Velvet Bean Pods, (ii) Velvet Bean Seeds

Recently, enormous research effort has been carried out and documented with reference to nutritional/anti-nutritional factors and different processing aids to minimize/eliminate ANF'S to a greater extent. Furthermore, major research works were undertaken to reduce or completely eliminate or deactivate certain anti-nutritional factors by traditional and technological methods [7]. At the outset, research findings paved the way for commercial exploitation of these pulses both for nutrition and therapeutic purposes. However, only limited information is available with regard to physical properties of *Mucuna Pruriens* [8, 26]. In order to design and develop machine(s)/equipment(s) for handling, conveying, grading, drying and packaging, it is necessary to determine their physical and mechanical properties as a function of moisture content, which this work sets as its main objective. Bulk density, true density, and porosity can be useful in sizing grain hoppers and storage facilities and in turn, they can affect the rate of heat and mass transfer of moisture during aeration and drying processes. In addition, this work is essential in the processing of velvet bean (*mucuna pruriens*) and in the prevention of mechanical damages during handling, processing and storage of the bean seed. Equally, knowledge of these properties will serve as a guide to designers of the processing, storage and general handling equipment. Therefore, the objective of this research is to determine the physical and mechanical properties of velvet bean (mucuna pruriens)

2. MATERIALS AND METHOD

2.1 Sample Collection and Preparation

The velvet bean (*Mucuna Pruriens*) seeds used in this work were collected from a farm in Akwuke in Enugu South local government of Enugu State, Nigeria. The samples were dehulled and cleaned to remove dirts. After cleaning, the seeds were packed and taken to the Agricultural and Bioresource Engineering laboratory of Enugu State University of Science and Technology, Enugu where the physical properties were determined. Apparatus used included: a 0-12cm range micrometer screw gauge used to measure the major, minor and intermediate diameters of the seeds; and a mettler Toledo electronic weighing balance of model XP204, used for all weight measurements. The assessment was conducted at two different moisture contents (13% and 20% db) using 30 seeds which were randomly selected.

2.1.1 Determination of the Physical Properties of Beans (Mucuna Pruriens)

Physical properties, such as shape, size, volume, surface area, density, colour and appearance that are associated with design of a specific machine or analysis of the behaviour of the product in handling processes were determined, [18]. Some of these physical characteristics are inseparable in describing an object and were used to determine the size and sphericity of the bean using equations as reported by [10, 18]. The average diameters were calculated using arithmetic mean and geometric mean of the three axial dimensions as expressed in equations (1) and (2);

$$AMD = \frac{a+b+c}{3} \quad (1)$$

$$GMD = (abc)^{1/3} \quad (2)$$

Here, a, b and c respectively represents the major diameter, minor diameter and the thickness of the seeds while AMD and GMA represents the arithmetic mean and geometric mean diameters.

2.1.2 Sphericity

The geometric foundation of the concept of sphericity rests upon the isoperimetric property of a sphere. According to [18], sphericity, (S) can be determined using equation (3);

$$S = \frac{(abc)^{1/3}}{a} \quad (3)$$

2.1.3 Surface Area

The knowledge of the surface area and the diameter of agricultural products are essential for determination of terminal velocity, drag coefficient, and Reynolds number [18] which are observed in conveying solid materials by air or water. According to [11], the surface area,(A) of the beans of spherical shape can be evaluated from the expression in equation (4);

$$A = \frac{\pi D^2}{4} \quad (4)$$

In (4), A is surface area of bean of spherical shape in mm^2, D is the minor diameter of the sphere in mm and$\pi = \frac{22}{7}$.

2.1.4 Volume

The unit volume of the 30 individual seeds was determined from the values of major, minor and intermediate diameters (a, b, c) from the following relationship in equation (5).

$$V = \frac{abc}{6} \quad (5)$$

A metler toledo electronic weighing balance of model XP204 and 0.000lg sensitivity was used to determine the weight of the seeds. Measurements were replicated for 30 times and the total weight of the seeds was determined.

2.1.5 Bulk Density and Specific Gravity

Density and specific gravity of food, materials and agricultural products play an important role in many applications such as drying and sorting of hay [6]; design of silos and storage bins [24]; mechanical compression of ensilage [12]; separation from undesirable materials; maturity evaluation, etc, are some of the examples where bulk density has found application.

The bulk density could be determined from the expression given in equation (6);

$$\text{Bulk density} = \frac{W_s}{V_s} \quad (6)$$

Here, W_s is the weight of materials in grams and V_s is the volume of material in mm^3.

2.1.6 Aspect Ratio

A metler toledo electronic weighing balance of model XP204 and 0.000lg sensitivity was used to determine the weight of the seeds. Measurements were replicated for 30 times and the total weight of the seeds was determined. The aspect ratio (R_a) is used in classification of grain or seed shape and it was calculated using equation [33].

$$\text{Ra} = \frac{b}{a} \quad (7)$$

2.1.7 Moisture Content

The oven-drying method of moisture content (M. C.) determination was used to determine the moisture content (wet base) of the seeds. The weight of dry samples (D_w) and the weight of wet samples (W_w) were determined and the moisture content evaluated from the expression given in equation (8);

$$\text{M.C} = \frac{W_w - D_w}{D_w} \quad (8)$$

2.2 Determination of Compressive Test

The compression tests were conducted in Civil Engineering materials Laboratory, University of Nigeria Nsukka (UNN). The tests were carried out using Mansanto Tensometer to determine the force-deformation characteristics of the Velvet bean (Mucuna Preriens) samples in longitudinal and lateral loading positions at two different moisture contents (13% and 20%w_b). The velvet bean samples were placed in two loading positions on the compression jaws, making sure that the centre of the tool was in alignment with the peak of the curvature of the velvet bean sample. Force was applied by turning the load arm of the testing machine at 2.5mm/min and the seed loaded to a point of maximum break (rupture point). This was accompanied by the corresponding drop on the force-deformation graph, which was plotted concurrently by the cursor and its attached needle which punctured the graph sheet at frequent intervals, thereby recording the force and the corresponding deformation. The resultant graph produced by joining the successive puncture shows force-deformation curve, indicating bio-yield points, and rupture force points which were measured at different loading positions and moisture contents. Three replications of the test were taken for velvet bean seed. The test room temperature was maintained at 29^{0}C. After the experiments, the rupture force, deformation, modulus of deformability, toughness and stiffness of the test samples were determined. Figure 3shows the block diagram of orientations of velvet bean (Mucuna Pruriens) under compressive loading.

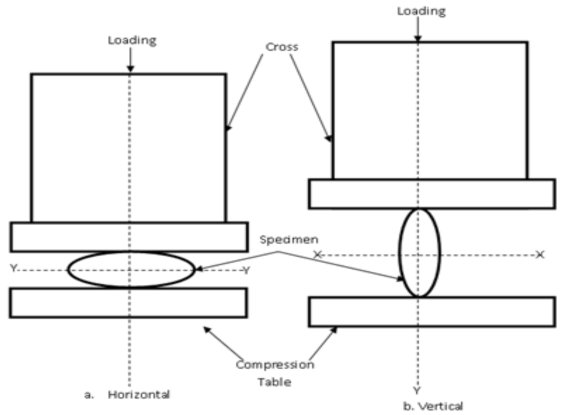

Figure 3: Block Diagram of Orientations of Velvet Bean under Compressive Loading

2.2.1 Toughness

Toughness is the amount of work or energy required to bring about rupture in a material. It was determined by computation of the area under the force deformation curve before rupture expressed as obtained in equation (9) [18].

$$\text{Toughness} = \frac{Rupture\ Energy}{Volume\ of Material} \quad (9)$$

2.2.2 Stiffness

Stiffness was computed using equation (10), as reported by [16].

$$\text{Stiffness} = \frac{Force\ at\ rupture}{Deformation\ at\ rupture} \quad (10)$$

2.2.3 Deformation Energy

Deformation energy was computed using equation (11);

Deformation energy = Rupture force x Deformation at rupture (11).

2.2.4 Compressive Strength

The maximum compressive stress (which a material is capable of sustaining) is the normal stress due to forces directed towards the plane on which it acts and was calculated from the maximum load during a compression test and the original cross sectional area of the specimen. The compressive strength is calculated using equation (12);

$$rc = \frac{F_c}{A} \quad (12)$$

In (12), r_c is the compressive strength in N/mm^2, F_c is the maximum load at fracture in N and A is the cross sectional area of specimen in mm^2.

2.2.5 Bio-yield Point

In some agricultural products, the presence of this bio-yield point is an indication of initial cell rupture in the cellular structure of the material [2]. The bio-yield point may occur at any point beyond the point of inflection (Linear Limit) where the curve deviates from the initial straight line portion.

2.2.6 Rupture Point

The rupture point is a point on the force deformation curve at which the axial loaded specimen ruptures under a load [18]. In biological materials, rupture may cause punctures of shell or skin cracking or fracture planes. This point is detected by a continuous decrease of the load in the force deformation curve.

3. RESULTS AND DISCUSSION

Table 1 shows the mean physical properties of 30 samples of velvet bean. The dimensions increased with an increase in moisture content. This shows that there is an increase in the dimensions which contributed to expansion as a result of moisture intake within the velvet bean.

As presented in Table 1, the sphericity, *S,* of the velvet bean (*Mucuna Pruriens*) decreased with an increase in moisture content. At 13% moisture content, the sphericity increased to 0.737 but decreased to 0.704 at 20% moisture content. This indicates that relative proportion changes occurred in the dimensions of the velvet bean (*Mucuna Pruriens*) seeds. The finding is similar to that of [3] who reported that the sphericity increased with decrease in the seed size with the small sized seeds having the highest sphericity.

The volume of the velvet bean seeds increased from 7.398mm^3 to 9.416mm^3 with an increase in moisture content. This increase in volume may be attributed to expansion in size dimensions which was as a result of increase of the velvet bean that resulted to the displacement of more liquid [18].

Table 1 also showed that the bulk density and specific gravity of the velvet bean varied from 0.118g/mm^3 at 13%moisture content to 0.112g/mm^3 at 20% moisture content. This result indicates a decrease in bulk density and specific gravity with an increase in moisture content. This implies that there was an increase in weight of the sample owing to the moisture in the velvet bean which was lower than the volumetric expansion of the bulk agro-material, as reported by [20] for sorghum seeds. Similarly, the surface area of the velvet bean (*Mucuna Pruriens*) increased with an increase in moisture content. The surface area increased from 73.289mm^2 at 13% moisture content to 111.782mm^2 at 20% moisture content. This result indicates that the increase in the values may be attributed to their dependence on the size dimensions of the velvet bean which are similar to the report of [23] for cowpeas. Table 1 shows that the weight of the seeds increased from 0.872g to 1.055g as moisture content increased from 13% to 20%. Also, Table 1 showed that the aspect ratio increased with decrease in moisture content. The aspect ratio increased at 13% moisture content (0.776) but decreased at 20% moisture content (0.719).

Table 2 and figures 4 to 7 represent the mechanical properties of velvet bean (*Mucuna Pruriens*) at two different moisture contents (13% and 20%w_b) and at two loading positions (longitudinal and lateral positions).

Table 1: The mean physical properties of velvet bean (Mucuna pruriens) at different moisture contents

Moisture Content (%)	Major Diameter (mm)	Minor Diameter (mm)	Intermediate Diameter (mm)	Geometric Mean (mm)	Sphericity	Weight (g)	Volume (g/mm^3)	Bulk Density (g/mm^3)	Specific Gravity	Area (mm^2)	Aspect Ratio
13	12.45 (0.59)	9.66 (0.57)	6.43 (0.35)	9.18 (0.49)	0.737 (0.83)	0.872 (0.03)	7.398 (0.40)	0.118 (0.08)	0.118 (0.08)	73.289 (0.26)	0.776 (0.97)
20	6.60 (1.06)	11.93 (0.66)	8.05 (0.53)	11.68 (0.72)	0.704 (0.68)	1.055 (0.17)	9.416 (0.58)	0.112 (0.29)	0.112 (0.29)	111.782 (0.26)	0.719 (0.62)

Each value is the mean of 30 test samples. Values in parenthesis are the standard deviation

Table 2: Mechanical properties of velvet bean at two different moisture contents and at two loading positions

Moisture Content (%)	Loading Position	Rupture Force (N)	Bioyield Force (N)	Deformation & Rupture (mm)	Compressive Strength (Nmm^3)	Modulus of deformability (Nmm^3)	Stiffness (Nmm)	Toughnes s (J/mm^2)	Deformation Energy (J)
13	Longitudinal	525.00	375.00	5.00	14.412	19.600	105.00	354.836	2625.00
	Lateral	800.00	475.00	7.00	21.961	16.642	114.286	756.961	5600.00
20	Longitudinal	131.25	112.50	3.00	3.530	15.390	43.750	41.817	393.75
	Lateral	237.50	175.00	4.75	6.388	4.410	50.00	119.809	1128.13

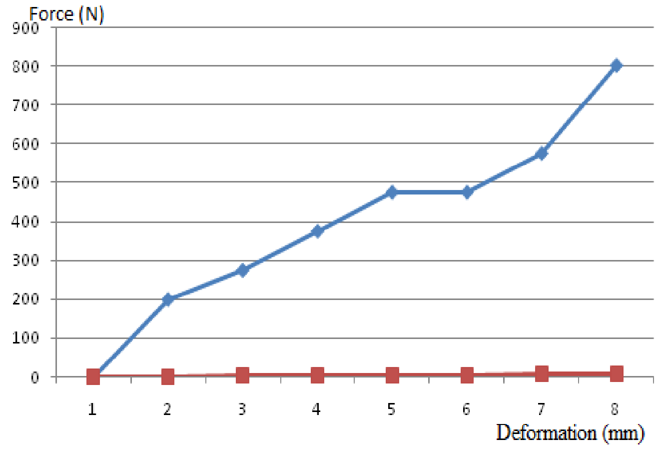

Figure 4: Force-deformation curve of horizontal loading position at 13% moisture content

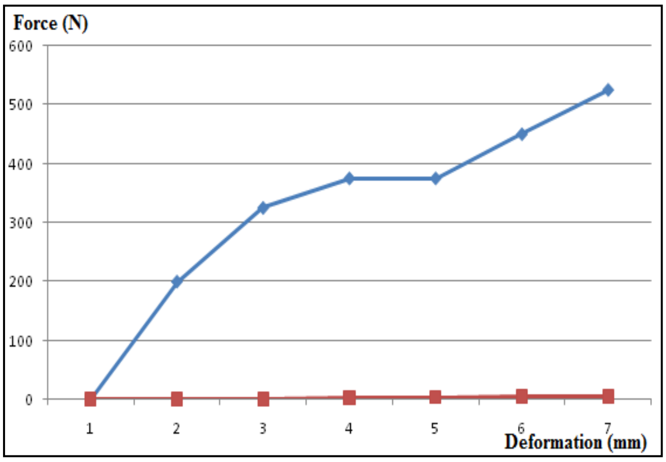

Figure 5: Force-deformation curve of vertical loading position at13% moisture content

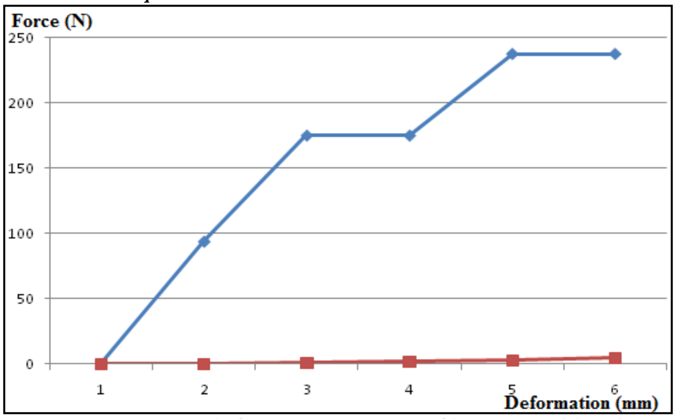

Figure 6: Force-deformation curve of horizontal loading position at20% moisture content

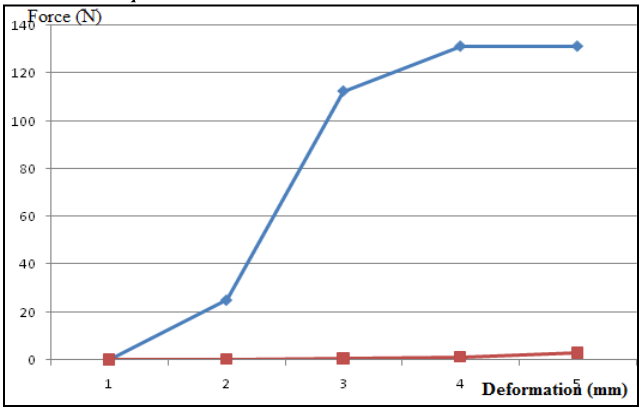

Figure 7: Force-deformation curve at vertical loading position at20% moisture content

The rupture force presented in Table 2 increased significantly at 13% moisture content in lateral loading position. In longitudinal loading position at 13% moisture content, the rupture force records 525N while in lateral loading position at same moisture content, the rupture force increased to 880N. At 20% moisture content, the rupture forces were 131.25N and 237.50N in longitudinal and lateral loading positions respectively.

The Bio-yield force in Table 2 indicate highest at 13% moisture content in lateral loading position and lowest at 20% moisture content in longitudinal loading position. The bio-yield force at 13% moisture content were 375N and 475N in longitudinal and lateral loading positions respectively while at 20% moisture content, the bio-yield force were 112.50N and 175.00N in Longitudinal and lateral loading positions respectively.

Compressive strength in Table 2 indicates highest at 13% moisture content in lateral loading position (21.961N/mm^2) and lowest at 20% (w_b) moisture content in longitudinal loading position (3.530N/mm^2). This indicates that little force is required to cause rupture on the seed (velvet bean) as reported by Maduako, *et al.*, (2001) on bambara nuts.

The modulus of deformability was experienced more at 13% moisture content in longitudinal loading position. The modulus of deformability at 13% moisture content both in longitudinal and lateral loading positions were 19.60N/mm^2 and 16.642N/mm^2 respectively while at 20%(w_b) moisture content, the modulus of deformability were 1.539N/mm^2 and 4.410 N/mm^2 in longitudinal and lateral loading positions respectively.

The deformation energy of the seed increased at 13% moisture content in lateral loading position and decreased at 20% (w_b) moisture contents in longitudinal loading position. At 13% moisture content, the deformation energy for longitudinal and lateral loading positions were 2,625J and 5,600J respectively while at 20% moisture content, the deformation energy for longitudinal and Lateral loading positions were 393.75J and 1128.13J.

The toughness of the velvet bean seed indicates highest at 13% moisture content in lateral loading position and lowest at 20% (w_b) moisture content in longitudinal loading position. At 13% moisture content, the toughness of the seed increases from longitudinal loading position (354.826J/mm^3) to lateral loading position (756.961JN/mm^3) and decreases from lateral loading position (119.809Jmm^3) to longitudinal loading position (41.817N/mm^3) at 20%(w_b) moisture content.

The stiffness of the seed (velvet bean) significantly increase at 13% moisture content in lateral loading position and decreased at 20% moisture content in longitudinal loading position. At 13% moisture content, the stiffness of the seed were 105 J/mm^3 and 114.28 J/mm^3 in longitudinal and lateral loading positions respectively while at 20% moisture content, the stiffness were 43.75 J/mm^3 and 50 J/mm^{3}longitudinal and lateral loading positions respectively.

The velvet bean seed easily deformed at 20% (w_b) moisture content in longitudinal loading position but less deformed at 13% moisture content in lateral loading position. The deformation at rupture at 13% moisture content in longitudinal and lateral loading positions were 5.00mm and 7.00mm respectively while at 20%(w_b) content, the deformational at rupture both in longitudinal and lateral loading position were 3.00mm and 4.75mm respectively.

4. SUMMARY OF RESULTS

1. Considering the effects of moisture contents on the physical and mechanical properties, result shows that, at 20% (w_b) moisture content, the values obtained were higher in the physical properties than at 13% moisture content. However, in compressive test (mechanical properties), the obtained values at 13% moisture content were higher than the values at 20% (w_b) moisture content. Therefore, the deformation of the velvet bean (*Mucuna Pruriens*) was affected significantly with increase in moisture content.
2. The force at breaking occurred highest at 13% moisture content (475N) and rupture point occurred highest at 13% moisture content (800N). This indicates that any force beyond these points at this moisture content may cause damage to the velvet bean seed.
3. Lateral loading positions records higher values than longitudinal loading positions. Only in modulus of deformability do longitudinal loading position recorded higher than the lateral loading position.
4. In general, the effects on the size for rupture force, deformation and toughness indicates that the force required to initiate velvet bean rupture was greater at lateral loading positions than in longitudinal loading positions.

5. CONCLUSION

Physical and mechanical properties of velvet bean seed depended on its moisture content. The axial dimensions of velvet bean seeds increased with an increase in moisture content. This situation is due to water absorption by velvet bean seeds. Geometric mean diameter, volume, surface area and weight of the velvet bean (mucuna pruriens) also increased with increasing moisture content. Bulk density, specific gravity, sphericity and aspect ratio of the velvet bean seeds decreased with an increase in moisture content.

The toughness of the seed decreases as the moisture content increases from the initial value of 13% to 20% (w_b) where it becomes easy to break. To break the seed, moisture content at 20% (w_b) will be appropriate. The result also revealed that the value of the seeds compressive force at horizontal orientation was higher than that of vertical orientation. This information can be used in the design and development of processing and general handling of legume seeds and other post harvest processing machines. It is therefore, recommended that other properties of velvet bean (*mucuna Pruriens*) seed such as thermal and nutritional characteristics be determined and changes of these properties be examined as a function of moisture content.

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