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Effect of Moisture Content on the Physicomechanical Properties of Mucuna Pruriens and Veracruz Verities

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Abstract This study determined some physical and mechanical properties of Mucuna Pruriens and Veracruz seeds grown in Nigeria under differentmoisture contents range of 6.04 to 15.82% (db). The physical properties were determined using a Mettler Toledo weighing machine, moisture analyzer, multi-purpose oven dryer and a Vernier caliper, while the mechanical properties were determined using an Instron Universal Testing Machine. The results of the physical properties showed that the major diameter, minor diameter, intermediate diameter and the porosity, ranged from 1.4 to 1.86 (cm); 0.76 to 0.82 (cm); 1.09 to 1.29 (cm); and 0.22 to 0.41 respectively across both varieties. The variation in moisture and physical parameters were found to be linear. Therefore, moisture content of the sample solely affects the physical properties of the Mucuna Pruriens and Veracruz. This result is similar to what was reported by [2, 4, 6, 9]. The results of the mechanical properties of the Mucuna Pruriens and Veracruz were found to be moisture content dependent (6.04 to 15.82%) (db). The relationship that exist between moisture content and the mechanical properties was statistically significant at ($p<0.05$) level**.** The relationship between moisture content and both the physical and the mechanical properties was statistically significant at ($p<0.05$) level. It was also found that it is more economical to load both sample in vertical loading position at 15.82 % moisture content to reduce energy demand when necessary to crack or compress the seed.

Keywords Physical properties, mechanical properties, Mucuna Pruriens, Veracruz, moisture content, Loading Positions

Introduction

Mucuna (Pruriens and Veracruz)

Agbara as is commonly called by the Igbos in Eastern part of Nigeria is an annual climbing legume that belongs to the fabaceae family, sub family of papillionaceas. It 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 [6]. 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 [7]. 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 [6], 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. The chemical responsible for the itching is a protein in mucuna and serotonin. The seeds are shiny black or brown, ovoid and 12mm long[14].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 proteinsdue 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 [13]. Previous research and findings made it possible for commercial exploitation of these pulses both for nutrition and therapeutic purposes. There are limited literature on the effluence of moisture content on the physical and mechanical properties two varieties of Mucuna Pruriens. The data generated from the physical and mechanical of two varieties of Mucuna Pruriens and Veracruz will aid in the design and fabrication of machines for harvesting and post-harvest handling and processes. It is therefore, necessary to understand the behavior of these two varieties of Mucuna Slaonei products when it is subjected compressive test and its physical observation as a function of moisture content, which this work sets as its main objective. 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 effect of moisture content on the physical and mechanical properties of two varieties (Pruriens and Veracruz) of velvet bean using Universal Testing Machine with Blue-Hill software at three different moisture content and two different loading positions.

Materials and Methods

Sample Collection

The two varieties of Mucuna Pruriens samples (Pruriens and Veracruz) used for this research work were collected at a suitablr moisture content from a local farm in Urban in Udenu Local Government Area of Enugu State, Nigeria on 27th November 2015, at geographical coordinates are 6^0 59'0'' North 7^0 27'0'' East.

(a)

(b)

Figure 1: Mucuna seeds varieties (a = Pruriens and b = Veracruz)

Sample Preparation

The Mucuna Pruriens seeds samples were cleaned and graded by hand picking to separate the good from the damaged ones. The separated seed samples were preserved at the initial moisture condition by storing them in air tight polythene bags. Moisture content of the Mucuna Pruriens seeds was determined using the oven method described by [1, 3]. Samples were dried in an oven set at 105°C for 6three moisture levels were used to investigate the effect of moisture content on the physical and mechanical properties. Seed samples of desired moisture levels were prepared by conditioning the samples using the method of [1, 3]. This involved soaking of each samples in clean water for a period of one to four hours. Soaking was then followed by spreading the samples out in a thin layer to dry in natural air for about eight hours. After this, the samples were sealed in polyethylene bags and stored in that condition for a further 24 h. This enabled stable and uniform moisture content of the samples to be achieved. Then the samples were taken to the laboratory where the physical and mechanical properties were carried out. The apparatus used include; veneer caliper, for measuring the axial dimensions; Mettler -Toledo Electric digital weighing balance with model number XP204 and 0.001 sensitive, for weighing the samples at intervals; Multi-Purpose Oven Dryer, drying the sample; and Instron Universal Testing Machine, for force-deformation characteristics.

Determination of Physical Properties

Some of the physical properties such as shapes, sizes, surface area, volume, sphericity, bulk density, specific gravity and moisture content that are relevant to the design of a particular agricultural products processing machine were determined using standard methods. Then, Arithmetic Mean Diameter, Harmonic Mean, Square Mean, Equivalent Mean and Geometric Mean Diameter were determined using the following equations reported by [9, 10].

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

$$GMD = (axbxc)1 \quad (2)$$

Where; a = major diameter; b = minor diameter; c = intermediate diameter; AMD = Arithmetic Mean Diameter (cm); GMD = Geometric Mean Diameter (cm).

According to [9], Harmonic Mean, Square mean, and Equivalent Mean Diameters were calculated using;

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

$$SMD = \sqrt{axb} + (bxc) + (cxa) \quad (4)$$

$$EQMD = \frac{SMD+GMD+AMD}{3} \quad (5)$$

Where; a = major diameter (cm); b = minor diameter (cm); c = thickness (cm);
HMD = harmonic mean diameter (cm); SMD = square mean diameter (cm);
EQMD = equivalent mean diameter (cm).

SPHERICITY, S (%): This is the measure of how spherical (round) Mucuna sloanei seed is. Sphericity or shape factor is the degree to which an object resembles a sphere. It is defined as the ratio of the volume of triaxial ellipse solid to the volume of sphere. It was determined using an equation as reported by [6];

$$\text{Sphericity } (S)\% = \frac{GMD}{a} \quad (6)$$

SURFACE AREA (cm^2); this was calculated using an equation as reported by [6].

$$A = \frac{\lambda d^2}{4} \quad (7)$$

Where; A = surface of the seeds (mm^2);
d = minor diameter (cm); λ = 3.142mm.

Porosity: The porosity $\mathcal{E}$ in % indicates the amount of pores in the bulk materials [5], presents a formula for its calculation as

$$\mathcal{E} = 100\left(1 - \frac{\ell_b}{\ell_s}\right) \quad (8)$$

$$where\ \varepsilon = porosity\ (\%)$$
$$\ell_b = bulk\ density\ (g/cm^3)$$
$$\ell_s = solid\ density\ (g/cm^3)$$

BULK DENSITY (g/cm^3): The bulk density is the ratio of the mass sample of the seeds to its total volume. It was obtained using equation as reported by [6];

$$\textbf{Bulk density (eb):} \ = \frac{w}{v} \quad (9)$$

Where; eb = bulk density (g/cm^3);
w = weight of the seed (g); V = volume of the seeds (cm^3).

Aspect Ratio

The aspect ratio (Ra) is used in classification of grain or seed shape and it was calculated using equation

$$Ra = \frac{b}{a} \quad (10)$$

Ra = aspect ratio; a = major diameter (cm); b = minor diameter (cm)

MOISTURE CONTENT (MC) %: This is the quality of water contains in the sample. The experiment was carried out under the influence of three (3) different moisture contents 10.5 %, 13 .2 %, and 16% under wet base. The oven dry method of moisture content determination using a multi-purpose drying oven (OKH – HX – IA) drying oven was used to determine the moisture content (MC) of the samples. The weight of the wet sample and the weight of the dry sample were determined and moisture content is calculated using the equation as expressed by [10];

$$\boldsymbol{MC} = \frac{W_w - W_D}{W_D} \; X\ 100\% \quad (11)$$

Where; MC = moisture content (%);

W_w = weight of wet sample (g); W_D = weight of dry sample (g).

Determination of the Mechanical Properties

Compression tests were carried out on the sample at three different moisture levels under two different loading orientations namely; horizontal and vertical, using an INSTRON Universal Testing Machine (IUTM), of BlueHill 3 software, and Dell computer system of windows 8 software. The samples were compressed at the cross-head load of 5KN at speed of 5mins. As the compression began and progressed, a load deformation curve was plotted automatically in relation to the response of each sample under compression. Thirty randomly selected samples were tested at each loading orientation and at three different moisture contents. The load-deformations curves and its parameters were obtained. At the end of the compression test, maximum load, compressive extension, energy at maximum load and slope at maximum load were tabulated.

Compressive strength (N/mm^2): This measures the strength at which each sample under compressive test will crack. It was calculated as the ratio of applied force to the area of the sample, it is denoted as δc, [6], Thus;

$$\delta c = \frac{fc}{A}\left(\frac{N}{mm^2}\right) \quad (12)$$

Where; δc = compressive strength (N/mm^2);

$fc = maximum\ load\ at\ frature(N)$;

$A = cross\ sectional\ area\ of\ the\ sample$ (mm^2).

Stiffness (N/mm^2): Stiffness is rigidity of a material and the extent at which it resists deformation in response to applied force. The stiffness, $S_{t,}$ o f a material is measure of the resistance offered by an elastic material to deformation. It is the ratio of the stress to strain (δ/ε), [6];

$$S = \frac{F}{\delta} \quad (13)$$

Where S_t = stiffness (N/mm^2); F = force on the material; δ = deformation on the material.

Toughness (J/M^3): Thisis the amount of energy per unit volume that a material can absorb before rupturing occur. It is also defined as a material's resistance to fracture when stressed. It is approximated under the stress–strain curve. Mathematically, toughness can be stated as reported by [12],

$$Toughness = \frac{\text{Rupture Energy}}{\text{Volume of the material}} \quad (14)$$

Deformation Energy (N/MM): This is the total spent energy of a sample under compressive test at which deformation occur. It is given as;

$$Deformation\ Energy = Rf\ X\ D.r \quad (15)$$

Where;

$Rf = Rupture\ Force$;

$D.r\ Deformation\ at\ Rupture$.

Result and Discussion

Table 1: Physical Properties of Mucuna Pruriens and Veracruz Seed different moisture contents

Parameter	Moisture Content / Sample					
	6.04 (%)		10.37 (%)		15.82 (%)	
	Pruriens	Veracruz	Pruriens	Veracruz	Pruriens	Veracruz
Arithmetic Mean Diameter	0.09 (0.5)	0.08 (1.01)	0.09 (1.45)	1.12 (0.99)	1.19 (1.01)	1.21 (0.22)
Area (mm^2)	0.32 (0.01)	0.28 (1.13)	0.48 (0.09)	0.73 (0.95)	0.64 (0.99)	0.59 (0.98)
Equivalent Mean Diameter	0.79 (0.04)	0.78 (0.01)	0.95 (1.02)	0.93 (0.02)	1.06 (0.97)	1.04 (0.92)
Square Mean Diameter	0.91 (1.01)	0.87 (1.00)	1.07 (0.01)	1.09 (0.01)	1.19 (0.19)	1.17 (0.02)
Geometric Mean Diameter	0.89 (0.005)	0.85 (0.97)	1.07 (0.98)	1.06 (1.01)	1.19 (0.99)	1.2 (1.01)
Porosity	0.22 (0.02)	0.25 (1.8)	0.27 (0.02)	0.28 (1.9)	0.33 (0.9)	0.41 (0.1)
Weight (g)	0.49 (0.01)	0.43 (0.02)	0.72 (0.00)	0.68 (0.03)	1.35 (0.02)	1.45 (0.02)
Bulk Density (g/mm^3)	1.66 (0.09)	1.62 (0.01)	1.49 (0.99)	1.29 (0.02)	0.10 (0.01)	1.14 (0.01)
Major Diameter (cm)	1.4 (0.69)	1.42 (0.96)	1.7 (1.02)	1.68 (0.57)	1.83 (0.90)	1.86 (1.02)
Minor Diameter (cm)	0.78 (0.01)	0.76 (1.01)	0.79 (0.01)	0.80 (0.99)	0.80 (1.01)	0.82 (1.00)
Sphericity	0.81 (0.01)	0.80 (0.03)	0.76 (2.02)	0.86 (0.02)	0.68 (0.02)	0.69 (0.02)
Aspect Ratio	0.91 (0.10)	0.88 (0.03)	0.91 (0.01)	0.83 (0.01)	0.65 (0.01)	0.68 (0.01)
Intermediate Diameter (cm)	1.09 (0.03)	1.12 (0.97)	1.09 (1.99)	1.15 (1.01)	1.29 (0.01)	1.26 (0.02)
Harmonic Mean Diameter	2.61 (0.02)	2.63 (0.00)	2.91 (0.99)	2.90 (0.00)	3.4 (0.02)	3.42 (0.01)

Table 2: Mechanical Properties of Mucuna Pruriens and Veracruz Seed at different moisture contents and loading orientations

Moisture Content (%)	Variety	Loading Position	Maximum Load (N)	Compressive Extension at Maximum (cm)	Energy at Max. load (J)	Toughness (J/M^2)	Stiffness (N/MM)	Compressive Strength (N/MM^2)	Deformation Energy (KJ)
	Pruriens	Horizontal	958.2	1.18	0.28	176.46	812.06	26.15	1.30
		Vertical	86.45	0.75	0.10	15.93	115.27	2.36	0.64
6.04	Veracruz	Horizontal	895.01	1.14	0.26	164.83	821.11	24.42	1.311
		Vertical	95.28	0.94	0.12	17.55	101.36	2.66	0.64
	Pruriens	Horizontal	1957.57	2.95	2.30	284.12	663.58	35.03	5.77
		Vertical	540.50	1.77	0.29	78.45	305.37	9.67	0.956
10.37	Veracruz	Horizontal	1930.4	2.44	2.26	280.18	791.15	34.54	5.77
		Vertical	562.42	1.97	0.82	81.63	285.49	10.05	0.956
	Pruriens	Horizontal	1108.66	1.76	0.29	123.32	629.92	13.31	1.95
		Vertical	72.60	4.04	0.08	80.76	17.97	0.87	0.293
15.82	Veracruz	Horizontal	1098.74	1.57	0.85	122.22	699.83	13.19	1.95
		Vertical	87.26	4.25	0.31	87.71	20.58	1.05	0.293

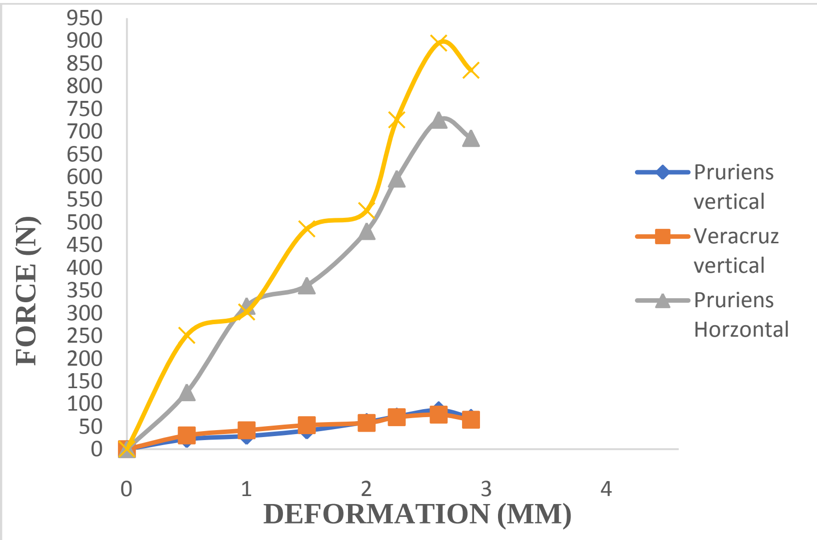

Figure 2: Effect of Moisture content and Loading Positions on the Force-deformation characteristics of Pruriens and Veracruz Mucuna at 6.04% (db)

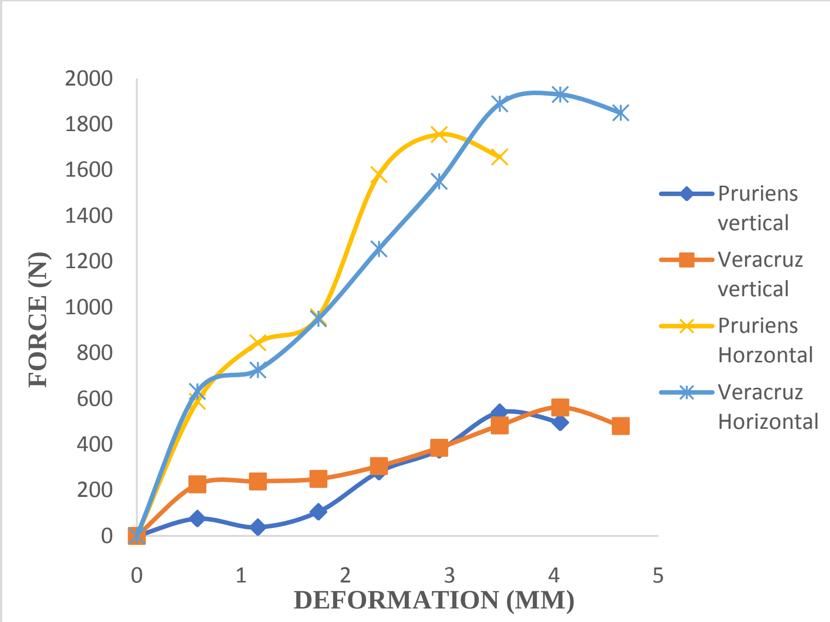

Figure 3: Effect of Moisture content and Loading Positions on the Force-deformation characteristics of Pruriens and Veracruz Mucuna at 10.37 % (db)

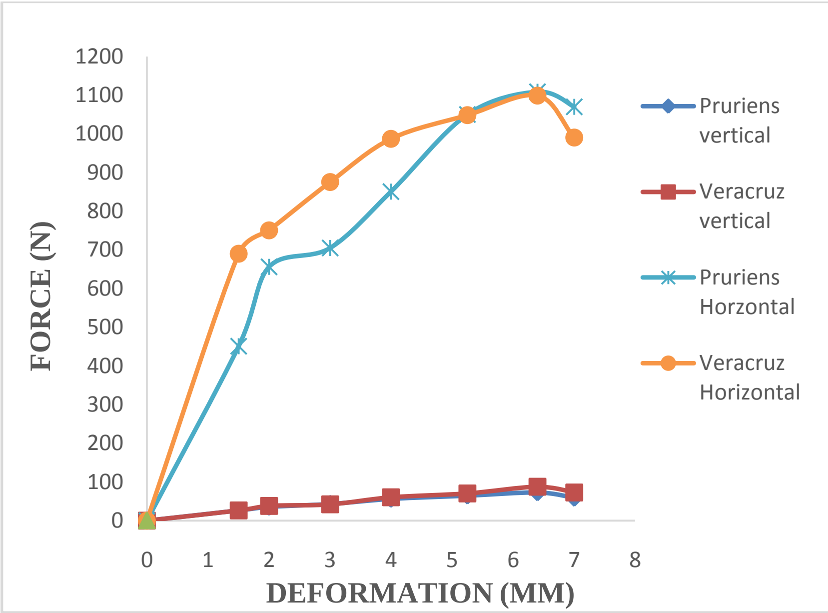

Figure 4: Effect of Moisture content and Loading Positions on the Force-deformation characteristics of Pruriens and Veracruz Mucuna at 15.82% (db)

Discussion of Results

Physical Properties

From Table 1, it was observed that moisture content has galore effect on the physical properties of the Mucuna pruriens and Veracruz seed samples, as the increase in moisture content of Mucuna species also increase in the major diameter, minor diameter, thickness, weight, area, porosity, arithmetic mean diameter, geometric mean diameter, square mean diameter, harmonic mean diameter equivalent mean diameter for Mucuna Pruriens and the Mucuna Veracruz sample respectively. While aspect ratio, sphericity and bulk density decreased from 0.91 - 0.65, 0.81-0.68, 1.66 – 0.10 and 0.88 – 0.68, 0.80 – 0.69, 1.62 – 1.14 for both Mucuna Pruriens and Veracruz respectively as the moisture content of the both samples increased from 6.04 – 15.82 %. The results of the physical properties showed that the major diameter, minor diameter, intermediate diameter and the porosity, ranged from 1.4 to 1.86 (cm); 0.76 to 0.82(cm); 1.09 to 1.29 (cm); and 0.22 to 0.41 respectively across both varieties. The variation in moisture and physical parameters were found to be linear. Therefore, moisture content of the sample solely affects the physical properties of the Mucuna Pruriens and Veracruz. This result is similar to what was reported by [2, 4, 6, 8].

Mechanical Properties

Maximum Load (N): From the results in Table 2, it was observed that the maximum force required to crack the sample at horizontal loading position for Mucunapruriens and veracruz are 958.2 N, 1957.57N, 1108.66 N and 895.01 N, 1930.4 N, 1098.7 N respectively. Mucuna Pruriens and Veracruz had compressive force at vertical loading position as 86.45 N, 540.50 N, 72.60N and 95.28N, 562.42 N, 87.28N respectively for moisture content range of 6.04 – 15.82%. It was observed that, as the moisture content of both sample varied the maximum force required to crack the sample at both horizontal and vertical loading position. The trend of the variation in moisture content and cracking force of the sample were found to be parabolic. The values of compressive force show that, the sample horizontal loading position.

Compressive strength (N/mm^2): From the results in Table 2, compressive strength for horizontal loading position was recorded as 26.15N/mm^2, 35.03 N/mm^2, 13.31N/mm^{2}and 24.42 N/mm^2, 34.54 N/mm^2, 13.19N/mm^2 for Mucuna Pruriens and Veracruz respectively while at vertical loading position, it was recorded as 2.36N/mm^2, 9.67N/mm^2, 0.87N/mm^2 and 2.66N/mm^2, 10.05N/mm^2, 1.05N/mm^2 for Mucuna Pruriens and Veracruz respectively for moisture content range of 6.04 – 15.82%. It implies that the strength of Mucuna species were found to be higher at horizontal loading position than that of vertical loading position and this may be attributed to the smaller contact that occurred during loading of the sample at horizontal loading position. This position has higher resistance of the seed to be cracked.

Compressive extension (cm): From the results in Table 2, compressive extension recorded at horizontal loading position are 1.18mm, 2.95mm, 1.76mm and 1.14mm, 2.44mm, 1.57mm for Mucuna Pruriens and Veracruz respectively at moisture range of 10.5 – 16.87% while at vertical was 0.75mm, 1.77mm, 4.04mm and 0.94mm, 1.97mm, 4.25mm for Mucuna Pruriens and Veracruz species respectively at moisture range of 6.04 – 15.82 %. It was observed that as the moisture content increases the compressive extension shows progressive increase when the sample is in vertical position for both samples but at horizontal loading position the compressive extension with moisture content variation displays parabolic trend for both samples.

Energy at the maximum load required to crack the sample was presented on Table 2. For horizontal loading position, the energy was 0.28J, 2.30J, 0.29J and 0.26J, 2.26J, 0.85J for Mucuna Pruriens and Veracruz respectively at moisture range of 10.5 – 16.87 but in the vertical loading position it was 0.10J, 0.29J, 0.08J and 0.12J, 0.82J, 0.31J respectively for the moisture content range 0f 6.04 to 15. 82. The energy was found to be varied with increase in moisture content at horizontal and vertical loading position but the energy variation with moisture content was not linear but parabolic in nature. It implies that lesser energy is required to crack the sample at vertical loading position than horizontal loading position for both samples at across the moisture content tested.

Toughness (J/M^2): The toughness of the sample as shown in the Table 2 were 176.46 J/M^2, 284.12 J/M^2, 123.32 J/M^2 and 164.83 J/M^2, 280.18 J/M^2, 122.22 at the horizontal loading position for Mucuna Pruriens and Veracruz respectively at 6.04 – 15.82 % moisture range and 15.93 J/M^2, 78.45 J/M^2, 80.76 J/M^2 and 17.55 J/M^2, 81.63 J/M^2, 87.71 J/M^2 for Mucuna Pruriens and Veracruz in the vertical loading position respectively at moisture range of 6.04 – 15.82%. It was observed that, as the moisture content increases the toughness of the material also increases at vertical loading position while the variation of moisture content with toughness at horizontal loading position displayed a parabolic trend. The toughness of the sample was found to be higher at horizontal loading position. It was observed that the Mucuna Pruriens is tougher in terms of cracking at horizontal position than vertical loading position

Stiffness (N/mm): The stiffness of the sample at different loading position was presented in the Table 2 at horizontal loading position was recorded as 812.06N/mm, 663.58 N/mm,629.92N/mm and 821.11 N/mm, N/mm, 791.15 N/mm for Mucuna Pruriens and Veracruz respectively at 6.04 -15.82% moisture content while at vertical loading ,stiffness were found to be 115.27 N/mm, 305.37 N/mm, 17.97 N/mm and 101.36 N/mm, 285.49N/mm, 20.58 N/mm for Mucuna Pruriens and Veracruz respectively at 6.04 -15.82% moisture content range. This is similar to what was reported by Eze et al., (2017) on same sample and what [8].

Deformation Energy (J) was presented in Table 2 at 6.04 – 15.82 moisture content range. The results obtained at horizontal loading position was 1.30KJ, 5.77KJ, 1.96 KJ and 1.311KJ, 5.77KJ, 1.95KJ for Mucuna Pruriens and Veracruz respectively at 6.04 -15.82% moisture content respectively while at vertical loading position 0.64KJ, 0.956 KJ, 0.29KJ and 0.64KJ, 0.956KJ, 0.29 KJ for Mucuna Pruriens and Veracruz respectively at 6.04-15.82% moisture content respectively. It was observed that the increase in moisture content of the sample varied the total energy that will cause rupture on the sample. It was noticed that the deformation energy of Mucuna Pruriens on both loading positions was higher than Veracruz its positions. It implies that, Mucuna Pruriens is stronger at each of the loading positions. But for both sample, deformation energy was found to be higher at every horizontal loading position.

The ANOVA for mechanical properties was done based on two loading positions (horizontal and vertical). The results showed that for both the Mucuna Pruriens and Veracruz the observed differences in the mechanical properties were not statistically significant at both loading positions, hence the null hypothesis is accepted. Their F-values were all found to be lower than their F-critical values However, with respect to moisture content, the reverse was observed hence the null hypothesis is rejected. Their F-values for within moisture content were found to be higher than F-critical values.

Conclusions

It was concluded that the data generated from physical properties of Mucuna Pruriens cannot be used in designing of food processing, handling and storage systems for Veracruz as physical properties of both species tested varied linearly with moisture content. Most were found to increase with increase in moisture content apart from aspect ratio, sphericity and bulk density that decreased across the moisture content. The results of the mechanical properties of the Mucuna Pruriens and Veracruz were found to be moisture content dependent (6.04 to 15.82%) (db). The relationship that exist between moisture content and the mechanical properties was statistically significant at ($p<0.05$) level**.** It is also economical to load both sample in vertical loading position at 15.82 % moisture content to reduce energy demand when necessary to crack or compress the seed.

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