

# Effect of Moisture Content on the Physicomechanical Properties of *Mucuna Sloanei*

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**Abstract:** This study determined some physical and mechanical properties of Big and Small sized varieties of Horse-Eye Bean (*mucuna sloanei*) seeds grown in Nigeria under different moisture contents range of 10.5 to 16.87% (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 sphericity, ranged from 25.61 to 32.52 (mm); 17.84 to 20.66 (mm); 24.24 to 30.18 (mm); and 0.82 to 0.89 respectively across both varieties. Also results for the mechanical properties obtained ranged from 444.08 to 902.10 N for maximum load; 1.96 to 8.12 mm for compressive extension at maximum load; 0.62 to 1.96 N/MM<sup>2</sup> for compressive strength; and 1.65 to 4.14 KJ for deformation energy at horizontal loading position. At vertical loading position, results obtained ranged from 870.43 to 1825.42 N for maximum load; 22.5 to 11.79 mm for compressive extension at maximum load; 0.85 to 2.26 N/MM<sup>2</sup> for compressive strength; and 1.97 to 12.85 KJ for deformation energy. 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 to be more economical to load the Big Sized Horse Eye Bean (Ukpo Nnukwu) in horizontal loading position at 10.5% moisture content and Small Size Horse Eye Bean (Ukpo Ntakiri) in horizontal loading position at 16.87% moisture content to reduce energy demand when necessary to crack or compress.

**Keywords:** Physical properties, mechanical properties, Horse-Eye Bean, moisture content and Loading Positions.

## 1. Introduction

The effect of moisture content on the physical and mechanical properties of agricultural material is essential in the design and adjustment of machines used during harvest, cleaning, separation, handling and storage. This information on the physical and mechanical properties of agricultural products is a yardstick in the processing of agricultural products into different food products. Many researchers (Eze et al. 2017; Oluka *et al.* 2012; Aviara *et al.* 2012; Bart-Plange *et al.* 2012; Sarpong *et al.* 2016) reported on the physical and mechanical properties of different biomaterial materials under different conditions. Their results showed that under different treatments, the biomaterial displays different behavior (Mohsenin, 1986). In agricultural products, physical and mechanical damages that occur during harvesting and handling of agricultural products such as physical bruises of the products and internal forces which causes mechanical damages like variation in temperature and moisture content during harvesting and transportation encourages the activities of microorganisms which after cause deterioration of agricultural products. Therefore, there is need to understand these damages and bring everlasting solution to it.

Horse Eye Bean (*mucuna sloanei*) (ukpo) is one of the over numerous species of shrubs and climbing vines that is generally accepted due to its important benefits to humans and their environment. It is a legume mainly found in the tropical and sub-tropical part of the world, but mainly in Nigeria. In Nigeria, it is called 'ukpo' by the Igbos, 'karasuu' by the Hausas, 'yerepe' by the Yorubas, and 'ibabat' by the Efiks, (Eze and Eze, 2017). It is mainly used as a food thickener in Nigeria, (Nkpa, 2004). It contains phosphorus, but very little in the supply of iron and calcium (Okaka *et al.*, 2006). Horse Eye Bean (*mucuna sloanei*), according to previous researches carried out on its

nutritional content, it is known to contain 20-25% of crude protein, 43.5-49.0% carbohydrate, 25.0-27.4% of crude fiber, 5.05-7.0% fat, and 6.46-14.0% of moisture content (Akpata and Muachi 2001). It contains LDOPA (a chemical that is made and used as part of the normal biology of humans and some animals and plants) a neuro transmitter that is used to treat Parkinson disease (Nwosu *et al.*, 2011). Due to its gelatization properties and gummy texture, *mucuna sloanei* is used as soup recipes in eating garri, pounded yam and fufu (Nwosu, 2011). Its commercial, nutritive, medicinal and pharmaceutical values can never be over emphasized. In order to explore all these benefits of this agricultural product (Horse Eye Bean), there is need to process it into different food formulations and food products. Processing of Horse Eye Bean involves cracking it with a hard object in order to extract the seed kernel. The seed kernel will then be parboiled, dried, grounded into fine powder and packaged in fanciful bags for marketing or use for food recipes mainly for soup thickening. The existing method of carrying out this above processing procedures are task demanding, labour intensive, time consuming and very wasteful. Therefore, it is very necessary to properly understand the some of the physical and mechanical properties of this Horse Eye Bean that are relevant in the designing and fabrication of its postharvest processing machines and equipment. Thus, the objective of this study is to determine the effect of moisture content on the physical and mechanical properties of Horse Eye Bean seed relevant to its processing, storage and handling.

## 2. Materials and Method

### 2.1 Source of Sample

The Horse Eye Bean samples used for this research work were collected from a local farm at a stable storage moisture.



Figure 1: Big Sized Horse Eye Bean (Ukpo Nnukwu)



Figure 2: Small Sized Horse Eye Bean (Ukpo Ntakiri)

## 2.2 Sample Preparation

The seeds were properly cleaned and sorted to select viable seeds. After that, the sample was wrapped with polythene bag and covered in plastic containers to avoid change in moisture contents. Then the sample 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.

## 2.3 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 (Mohsenin, 1986).

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

$$GMD = (\sqrt[3]{axbxc}) \quad (2)$$

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

According to Mohsenin, 1986, Harmonic Mean, Square mean, and Equivalent Mean Diameters were calculated using;

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

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

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

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

**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 (Eze and Eze, 2017);

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

**Surface Area (mm<sup>2</sup>)**: This was calculated using an equation as reported by (Eze and Eze, 2017).

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

Where; A = surface of the seeds (mm<sup>2</sup>); d = minor diameter (mm);  $\lambda = 3.142$ mm.

**Unit Volume (mm<sup>3</sup>)**: The unit volume of the seeds was calculated from major, minor and intermediate (thickness) diameter obtained as reported by (Eze and Eze, 2017);

$$\text{Unit volume (mm}^3\text{)} = \frac{\lambda (bxc)^{1/3}}{6} \quad (8)$$

Where; V = Volume of the seeds (mm<sup>3</sup>); a = major diameter (mm); b = minor diameter (mm), c = Intermediate diameter (mm).

**Bulk Density (g/cm<sup>3</sup>)**: 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 (Eze and Oluka, 2017);

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

Where; eb = bulk density (g/mm<sup>3</sup>); w = weight of the seed (g); V = volume of the seeds (mm<sup>3</sup>).

**Specific Gravity**: This is the ratio of the density of a solid or liquid to the density of water (Eze and Oluka, 2017). It can also be expressed as the ratio of the density of a gas to the density of wet air at STP. Thus;

$$\text{Specific gravity} = \frac{\text{density of the substance}}{\text{weight of equal amount of water}} \quad (10)$$

**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 (Mohsenin, 1987);

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

Where; MC = moisture content (%);  $W_w$  = weight of wet sample (g);  $W_D$  = weight of dry sample (g).

### 2.4 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):** 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  $\delta c$ , (Eze and Eze, 2017). Thus;

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

Where;  $\delta c$  = compressive strength (N/mm<sup>2</sup>);  $fc$  = maximum load at fracture (N);

$A$  = cross sectional area of the sample (mm<sup>2</sup>).

**Stiffness (N/mm<sup>2</sup>):** Stiffness is rigidity of a material and the extent at which it resists deformation in response to applied force. The stiffness,  $S_t$  of a material is measure of the resistance offered by an elastic material to deformation. It is the ratio of the stress to strain ( $\delta/\epsilon$ ), (Eze and Eze, 2017);

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

Where  $S_t$  = stiffness (N/mm<sup>2</sup>);  $F$  = force on the material;  $\delta$  = deformation on the material.

**Toughness (J/M<sup>3</sup>):** This is 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 (Eze and Eze, 2017);

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

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

$$Deformation Energy = R_f \times D.r \quad (15)$$

Where;  $R_f$  = Rupture Force;

$D.r$  = Deformation at Rupture.

### 3. Result and Discussion

**Table 1:** Physical Properties of Big and Small Sized Horse Eye Bean Seed (Ukpo Nnukwu and Ntakiri) at different moisture contents

Parameters	Moisture Content / Sample					
	10.5 (%)		13.2 (%)		16.87 (%)	
	Big Size	Small Size	Big Size	Small Size	Big Size	Small Size
Major Diameter (mm)	28.32 (0.69)	26.50 (0.96)	29.92 (0.02)	25.61 (0.57)	32.52 (0.90)	29.23 (1.02)
Minor Diameter (mm)	19.98 (0.01)	17.88 (1.01)	20.66 (0.01)	17.84 (0.99)	20.09 (1.01)	19.38 (1.00)
Intermediate Diameter (mm)	27.66 (0.03)	24.34 (0.97)	29.09 (0.99)	24.24 (1.01)	30.18 (0.01)	27.54 (0.02)
Size (mm)	25.01 (0.02)	21.32 (1.8)	26.20 (0.02)	23.34 (1.9)	27.11 (0.9)	24.83 (0.1)
Sphericity	0.88 (0.01)	0.89 (0.03)	0.87 (2.02)	0.86 (0.02)	0.83 (0.02)	0.82 (0.02)
Weight (g)	7.63 (0.01)	6.42 (0.02)	8.62 (0.00)	6.4 (0.03)	9.10 (0.02)	7.12 (0.02)
Volume (mm <sup>3</sup> )	20.17 (0.06)	19.63 (1.01)	21.12 (0.00)	19.61 (0.02)	21.62 (0.76)	21.17 (0.99)
Bulk Density (g/mm <sup>3</sup> )	21.17 (0.99)	0.38 (0.01)	0.41 (0.99)	0.39 (0.02)	0.42 (0.01)	0.43 (0.01)
Specific Gravity	0.38 (0.02)	0.39 (0.03)	0.41 (0.00)	0.36 (0.01)	0.41 (0.01)	0.43 (0.03)
Area (mm <sup>2</sup> )	598.36 (0.9)	463.50 (1.13)	664.76 (0.99)	462.86 (0.95)	720.20 (0.99)	624.27 (0.98)
Aspect Ratio	0.97 (0.0)	0.86 (0.03)	0.97 (0.01)	0.83 (0.01)	0.72 (0.01)	0.83 (0.01)
Arithmetic Mean Diameter	25.30 (1.02)	22.61 (1.01)	26.56 (3.00)	22.61 (0.99)	27.59 (1.01)	24.72 (0.02)
Geometric Mean Diameter	24.97 (0.98)	21.07 (0.97)	26.18 (0.98)	21.01 (1.01)	27.11 (0.99)	24.22 (0.01)
Square Mean Diameter	43.56 (1.01)	39.98 (1.00)	45.71 (0.01)	39.97 (0.01)	47.42 (0.99)	42.82 (0.02)
Equivalent Mean Diameter	31.28 (0.98)	28.42 (0.01)	32.81 (0.02)	28.41 (0.02)	34.06 (0.97)	31.10 (0.92)
Harmonic Mean Diameter	0.12 (0.02)	0.12 (0.00)	0.11 (0.99)	0.12 (0.00)	0.12 (0.02)	0.10 (0.00)

**Table 2:** Mechanical Properties of Big and Small Sized Horse Eye Bean Seed (Ukpo Nnukwu and Ntakiri) at different moisture contents and loading orientations

Moisture Content (%)	Variety	Loading Position	Maximum Load (N)	Compressive Extension at Maximum (mm)	Energy at Maximum load (J)	Toughness (J/M <sup>2</sup> )	Stiffness (N/MM)	Compressive Strength (N/MM <sup>2</sup> )	Deformation Energy (KJ)
10.5	Big Size (Nnukwu)	Horizontal	841.55	1.96	0.48	0.02	429.36	1.41	1.65
		Vertical	876.22	2.25	0.58	0.03	389.43	1.46	1.97
	Small Size (Ntakiri)	Horizontal	796.94	2.54	0.85	0.13	358.98	1.96	2.32
		Vertical	911.82	3.16	0.78	0.16	253.80	1.72	2.50
13.2	Big Size (Nnukwu)	Horizontal	806.79	4.75	1.79	0.08	169.84	1.21	3.83
		Vertical	1612.42	7.97	5.93	0.28	202.31	2.4	12.85



	Small Size (Ntakiri)	Horizontal	902.10	4.59	1.53	0.22	196.53	1.66	4.14
		Vertical	1825.42	4.39	0.58	0.21	120.35	0.85	2.31
16.87	Big Size (Nnukwu)	Horizontal	444.08	8.12	1.53	0.07	54.68	0.62	3.61
		Vertical	870.43	11.79	4.45	0.20	73.85	1.21	9.72
	Small Size (Ntakiri)	Horizontal	528.35	4.39	0.58	0.21	120.35	0.85	2.31
		Vertical	1422.46	5.27	2.42	0.25	269.91	2.26	7.49

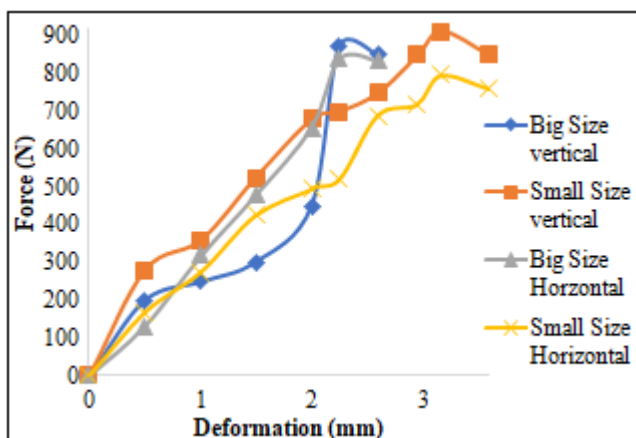


Figure 3: Effect of Moisture content and Loading Positions on the Force-deformation characteristics of Big and Small Sized Horse Eye Bean at 10.5% (db)

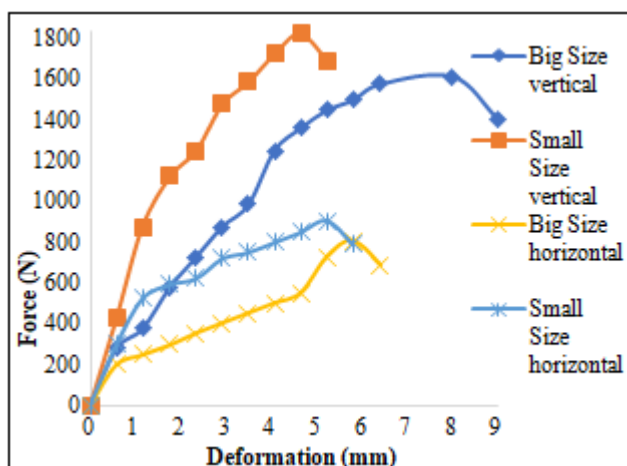


Figure 4: Effect of moisture content and Loading Positions on the force-deformation characteristics of Big and Small Sized Horse Eye Bean at 13.2% (db)

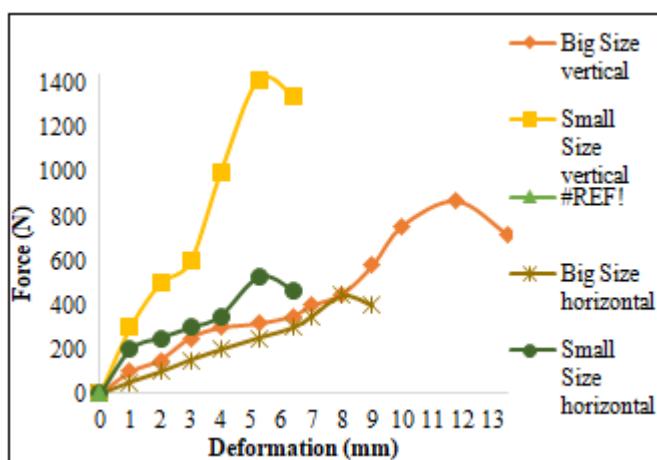


Figure 5: Effect of Moisture content and Loading Positions on the force-deformation characteristics of Big and Small Sized Horse Eye Bean a 16.87% (db)

## 4. Discussion of Results

### Physical Properties

From Table 1, it was observed that moisture content has profuse effect on the physical properties of the samples, as the increase in moisture content of the Horse-Eye Bean also increase in the major diameter, minor, thickness, size, weight, volume, bulk density, specific gravity, area, arithmetic mean diameter, geometric mean diameter, square mean diameter, equivalent mean diameter for Big Sized Horse-Eye Bean (Ukpo Nnukwu) and the Small Sized Horse-Eye Bean (Ukpo Ntakiri) respectively. The results of the physical properties showed that the major diameter, minor diameter, intermediate diameter and the sphericity, ranged from 25.61 to 32.52 (mm); 17.84 to 20.66 (mm); 24.24 to 30.18 (mm); and 0.82 to 0.89 respectively across both varieties. The variation in moisture and physical parameters were found to be linear while sphericity, aspect ratio and harmonic mean diameter decreases as the moisture content increases but the trend of the decrease in this nature were found to be linear decrease. Therefore, moisture content of the sample solely affects the physical properties of the Horse-Eye Bean. This result is similar to what was reported by Eze and Eze (2017) and Bart-Plange and A. Mohammed (2012).

### Mechanical Properties

**Compressive force (N):** From the results in Table 2, it was observed that the maximum force required to crack the sample at horizontal loading position for Big Sized Horse Eye Bean (Ukpo Nnukwu) and Small Sized Horse Eye Bean (Ukpo Ntakiri) are 841.55 N, 806.79N, 444.08 N and 796.94 N, 902.10 N, 528.53 N respectively. Big Sized Horse Eye Bean (Ukpo Nnukwu) and Small Sized Horse Eye Bean (Ukpo Ntakiri) had compressive force at vertical loading position as 876.22 N, 1612.42N, 870.43N and 911.82N, 1825.42N, 1422.46N respectively. It was observed that, as the moisture content increases the maximum force required to crack the sample decreased when the sample is loaded in horizontal position for both Big Sized Horse Eye Bean (Ukpo Nnukwu) and Small Sized Horse Eye Bean (Ukpo Ntakiri) while at vertical loading position, moisture content increase brings about parabolic increase trend on both samples. The values of compressive force show that, the sample requires lesser compressive force to get the sample cracked at horizontal loading position than on the vertical loading position.

**Compressive strength (N/mm<sup>2</sup>):** From the results in Table 2, compressive strength for horizontal loading position was recorded as 1.41N/mm<sup>2</sup>, 1.21N/mm<sup>2</sup>, 0.62N/mm<sup>2</sup> and 1.96N/mm<sup>2</sup>, 1.66N/mm<sup>2</sup>, 0.85N/mm<sup>2</sup> for Big Sized Horse Eye Bean (Ukpo Nnukwu) and Small Sized Horse Eye Bean (Ukpo Ntakiri) respectively while at vertical loading position, it was recorded as 1.46N/mm<sup>2</sup>, 2.4N/mm<sup>2</sup>,

1.21N/mm<sup>2</sup> and 1.72N/mm<sup>2</sup>, 3.36N/mm<sup>2</sup>, 2.26N/mm<sup>2</sup> for Big Sized Horse Eye Bean (Ukpo Nnukwu) and Small Sized Horse Eye Bean (Ukpo Ntakiri) respectively. It implies that the strength of Horse Eye Bean was higher at vertical loading position than that of horizontal loading position and this may be attributed to the smaller contact that occurred during loading of the sample at vertical position. This position has higher resistance of the nut to be cracked.

**Compressive extension (mm):** From the results in Table 2, compressive extension recorded at horizontal loading position are 1.96mm, 4.75mm, 8.12mm and 2.54mm, 4.59mm, 4.39mm for Big Sized Horse Eye Bean (Ukpo Nnukwu) and Small Sized Horse Eye Bean (Ukpo Ntakiri) respectively at moisture range of 10.5 – 16.87% while at vertical was 2.25mm, 7.97mm, 11.79mm and 3.16mm, 7.00mm, 5.27mm for Big Sized Horse Eye Bean (Ukpo Nnukwu) and Small Sized Horse Eye Bean (Ukpo Ntakiri) respectively at moisture range of 10.5 – 16.87 %. It was observed that as the moisture content increases the compressive extension shows progressive increase when the sample is in horizontal position for both samples but at vertical 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 0.48J, 1.791J, 1.53J and 0.85J, 1.53J, 0.58J for Big Sized Horse Eye Bean (Ukpo Nnukwu) and Small Sized Horse Eye Bean (Ukpo Ntakiri) respectively at moisture range of 10.5 – 16.87 but in the vertical loading position it was 0.58J, 5.93J, 4.45J and 0.78J, 5.87J, 2.42J respectively for the moisture content range tested. The energy was found to increase 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 horizontal loading position than vertical loading position for both samples at 16.87% moisture content.

**Toughness (J):** The toughness of the sample as shown in the Table 2 were 0.02J, 0.08J, 0.07J and 0.13J, 0.22J, 0.21J at the horizontal loading position for Big Sized Horse Eye Bean (Ukpo Nnukwu) and Small Sized Horse Eye Bean (Ukpo Ntakiri) respectively at 10.5 – 16.87 % moisture range and 0.03J, 0.28J, 0.20J and 0.16J, 0.34J, 0.25J for Big Sized Horse Eye Bean (Ukpo Nnukwu) and Small Sized Horse Eye Bean (Ukpo Ntakiri) in the vertical loading position respectively at moisture range of 10.5 – 16.87%. It was observed that, as the moisture content increases the toughness of the material also increases at both loading position and samples. The toughness of the sample was found to be higher at vertical loading position. It was observed that the Small Sized Horse Eye Bean (Ukpo Ntakiri) is tougher in terms of cracking than Big Sized Horse Eye Bean (Ukpo Nnukwu) as highest values of toughness was noticed on Small Sized Horse Eye Bean (Ukpo Ntakiri).

**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 429.36 N/mm, 169.84

N/mm, 54.68 N/mm and 358 N/mm, 196.53 N/mm, 120.35 N/mm for Big Sized Horse Eye Bean (Ukpo Nnukwu) and Small Sized Horse Eye Bean (Ukpo Ntakiri) respectively at 10.5 – 16.87% moisture content while at vertical loading ,stiffness were found to be 389.43N/mm, 202.31N/mm, 73.85N/mm and 253.80N/mm, 260.77N/mm, 269.91N/mm for Big Sized Horse Eye Bean (Ukpo Nnukwu) and Small Sized Horse Eye Bean (Ukpo Ntakiri) respectively at 10.5 – 16.87 % moisture range. This are similar to what was reported by Eze et al., (2017) on same sample and what Aviara et al., (2013) on *Brachystegia Eurycoma* seed.

**Deformation Energy (J)** was presented in Table 2 at 10.5 – 16.87 moisture content range. The results obtained at horizontal loading position was 1.65KJ, 3.83KJ, 3.61 KJ and 2.32KJ, 4.14KJ, 2.31KJ for Big Sized Horse Eye Bean (Ukpo Nnukwu) and Small Sized Horse Eye Bean (Ukpo Ntakiri) respectively while at vertical loading position 1.97KJ, 12.85 KJ, 9.72 KJ and 2.50KJ, 12.7 KJ, 7.49KJ for both Big Sized Horse Eye Bean (Ukpo Nnukwu) and Small Sized Horse Eye Bean (Ukpo Ntakiri) respectively. It was observed that the increase in moisture content of the sample increase the total energy that will cause rupture on the sample. It was noticed that the deformation energy of Small Sized Horse Eye Bean (Ukpo Ntakiri) on both loading positions was higher than Nnukwu Ukpo at its positions. It implies that, Small Sized Horse Eye Bean (Ukpo Ntakiri) is stronger at each of the loading positions. But for both sample, deformation energy was found to be higher at every vertical loading position.

The ANOVA for mechanical properties was done based on two loading positions (horizontal and vertical). The results showed that for both the Nnukwu and Ntakiri species 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 (2.08, 0.93, 1.56, 0.71 < 3.73). 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 (20.04, 17.49, 33.82, 25.03 > 2.76).

## 5. Conclusions

It was concluded that the data generated from physical properties of Big Sized Horse-Eye Bean (Ukpo Nnukwu) cannot be used in designing of food processing, handling and storage systems for Small Sized Horse-Eye Bean (Ukpo Ntakiri) 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 harmonic mean diameter that decreased across the moisture content.

The results of the mechanical properties of the Horse Eye Bean were found to be moisture content dependent (10.5 to 16.87%) (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 Big Sized Horse Eye Bean (Ukpo Nnukwu) in horizontal loading position at 10.5%

moisture content and Small Size Horse Eye Bean (Ukpo Ntakiri) in horizontal loading position at 16.87% moisture content to reduce energy demand when necessary to crack or compress the seed.

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