Some engineering properties of Palmyra palm tree (borassus aethiopum) germinating shoot

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Abstract: This study was carried out to determine some engineering properties of germinating shoot of Palmyra Palm tree (Borassus aethiopum) relevant to the design of an agricultural harvesting machine. Seed volume, sphericity, weight, surface area, aspect ratio and compressive strength were determined at three different moisture contents of 41.72%, 26.11% and 18.39% (wb) respectively. Standard methods and instruments were used to conduct the experiments. The results of the physical properties revealed that the major, intermediate and minor diameters, surface area and weight increased with the increase in moisture content. The maximum mean values of the major, intermediate and minor diameters were 280.00 mm, 33.00 mm and 25.90 mm respectively while the minimum mean values were 209.67 mm, 16.67 mm and 15.21 mm at the three moisture contents respectively. The mean coefficient of variation for the major, intermediate and minor diameters were 10.57%, 32.84% and 10.59% respectively. The statistical analysis carried out on the physical properties shows that the F value (38.77) is greater than the F-critical value and also the P-value 1.74×1032is less than the significance level (α= 0.05) which means there is a significant difference between the physical properties of germinating shoot within the range of moisture contents. The mechanical properties of the Palmyra palm germinating shoot revealed a mean force at break as 1247.10 N, 650.00 N and 707.10 N for longitudinal, natural and transverse loading positions respectively. The stress at break has mean values of 1247.10 N/mm^2, 650.00N/mm^2 and 707.10 N/mm^2 for longitudinal natural and transverse loading positions respectively. The energy at break has mean values of 2.16Nm, 2.42 Nm and 1.80Nm, for longitudinal natural and transverse loading positions respectively. The mean values of the energy at yield for longitudinal, natural and transverse loading positions were 1.56 Nm, 1.03 Nm and 1.44 Nm respectively. The stress at yield has mean values of 1158.50 N/mm^2, 627.67 N/mm^2 and 734.25 N/mm^2 for longitudinal, natural and transverse loading positions respectively. While the mean values for the Young's modulus at longitudinal, natural and transverse loading positions were 15326.00 N/mm^2, 5768.80 N/mm^2, and 5010.90 N/mm^2 respectively.

Keywords: germinating shoot of Palmyra Palm, Muruchi, libido, engineering properties

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1 Introduction

Palmyra palm tree (*Borassus aethiopum*) is a dioecious palm tree of African origin, which belongs to Palmae or Arecaceae family (Chaurasiya et al., 2014; Ali et al., 2010). Botanists believed that it originated in Africa (ICRAF, 1992) and its dispersal is motivated by elephants. Palmyra palm tree grows in most of the West African states (FAO, 1988). In Nigeria, it is mostly found in Northern part of the country (Iorliam et al., 2012). The various ethnic groups in Nigeria identify this plant by different names. The Hausa call it *Giginya*, Yoruba call it *Agbonoludu*, Igbos calls it *Ubiri*, Fulanis call it *Dubbe*, Nupe call it *Egbachi* and Babur–Bura calls it *Mna* (Akinniyi et al., 2000; Aminu, 2014; Ayarkwa, 1997; Kasper, 1995).

The male and female inflorescences are tapped to produce a sweet sap. The palms are able to retain fresh water via storage in the main stem (Krauss et al., 2015). When the fruits are cut, three jelly seed sockets with pale-white translucent flesh are found inside similar to that of the lychee but with a milder flavor and they are

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edible. The flesh has a sweet taste and jelly part of the fruit is covered with a thin, yellowish-brown skin and the fruits are harvested by hand (Bayton et al., 2006). Palmyra palm is described as unique and stately. Also the roots, shoots and fruits are utilized for medicinal purposes. The root powder mixed with sheep butter is used to treat sore throat and bronchitis. Palm wine from Palmyra palm is considered an aphrodisiac and stimulant (FAO, 1988). Economically, the fibres extracted from the base of the leaf stalk have valuable qualities of resistance to chemical, termites and water. The young leaves before unfolding can be split into strips and woven into thin mats, baskets and other household materials. The leaf midribs are used to make brooms, fish traps and nets, the leaf stalk endings can be soaked in water to provide fibres that are used as sponges or filters. The trunk is hard moderately heavy and brown with black fibres, the strong trunks are very resistant to decay and to insect especially termites. They are also used for construction of bridges, shower cabins and dugout canoes mostly in rural areas of African countries (Akinniyi et al., 2000). Palmyra palms sap and juice are rich in sugars (10%-17%, w/v) (Chooklin et al., 2011; Sahni et al., 2014). The Palmyra tree is highly respected in Tamil culture in India; it is called "karpaha" or celestial tree because all its parts without exception are of importance to the culture (Sandhya et al., 2010). The Palmyra palm shell extract has been proven to be an effective low cost and eco-friendly inhibitor (Vijayalakshmi et al., 2010). The process of adsorption showed that Palmyra palm nut is very effective in the uptake of copper II from aqueous solution (Nwabanne and Igbokwe, 2011).

However, the germinating shoot of the Palmyra palm called *Muruchi* in Hausa is well known in the Northern part of Nigeria and the people consume it either raw or cooked/boiled as food and used for medicinal purposes. It is popularly known to enhance libido in women, has aphrodisiac properties in men and serves as source of income to the farmers (Aminu, 2014). The seeds are sown on top of mounds and watered regularly within 45-60 days before germinating. The embryonic axis grows downward within a long apical tube into the soil and strikes roots. Growing upward from the roots is a bladeless first leaf within which accumulated food material translocate from the endosperm, thereby forming the starchy tuber. These shoots measure about 15 cm in length and 2.5 cm in width which are harvested before the plant begins to grow above the ground. The shoot weighs an average of 60 g and about half the weight is made up of usable starch. Assuming that a single tree bears 200-300 fruits per annum and that each fruit contains three seeds, the germinated seedlings could potentially yield 18-27 kg of starch. If they are dried after harvest, the shoots can be stored for several months (Davis and Johnson, 1987).

However, over the years, lack of engineering properties of the germinating shoot of Palmyra palm has hindered engineers in coming up with well mechanized system of harvesting, handling, processing, preservation and storage of the shoot. This has also discouraged the large scale farming of this particular Palmyra palm tree despite its economic importance. In view of the above, the determination of some engineering properties of the germinating shoot of Palmyra palm tree becomes necessary.

2 Materials and methods

2.1 Materials selection

The germinating shoots of Palmyra palm tree used in the experiment were obtained from a local market in Bida, Niger State, Nigeria. The Palmyra palm tree, fruits and the germinating shoots are shown in Figure1. The shoots were cleaned to remove foreign matters, dust, and dirt.

a. Palmyra palm tree b. Palmyra palm fruits c. Germinating shoot (Muruchi) of Palmyra palm tree

Figure 1 Palmyra palm tree– a; Palmyra palm fruits – b and Germinating shoot (Muruchi) of Palmyra palm tree - c

2.2 Determination of the engineering properties

Some engineering properties of germinating shoot of Palmyra palm (shape, size, volume, particle density, sphericity, weight, surface area, aspect ratio and compressive strength) at three different moisture contents of 41.72 %, 26.11% and 18.39 % (wb) were determined using the procedure described by American Society of Agricultural Engineers ASAE (2003); Henderson et al. (1997) and Mohsenin (1986).

2.3 Moisture content determination

The germinating shoot (*Muruchi*) of Palmyra palm samples were divided into three groups, A, B and C and the moisture content of each of the group were determined. The moisture content (M.C.) was determined by oven dry method at 104 ^{o}C for 24 hours using an oven with model number PBS11TSF as described by Henderson et al. (1997); AOAC, (2002); Dauda et al. (2014); and Dauda et al. (2015). The moisture content was computed using the expression given in Equation (1).

$$M.C.\ (wb) = \frac{M.C_i - M.C_f}{M.C_i} \quad (1)$$

Where:

M.C. (wb) = Moisture content wet basis, %;

$M.C_i$= Initial moisture content, %;

$M.C_f$ = Final moisture content, %.

2.4 Shape determination

The shape of Palmyra palm germinating shoot was determined using the standard chart method given by Mohsenin (1992).

2.5 Determination of Palmyra palm germinating shoot size

Thirty pieces of Palmyra palm germinating shoot were selected randomly and grouped into A, B, and C, which were numbered A1 to A10, B1 to B10, and C1 to C10. Axial dimension in terms of major diameter (D1), intermediate diameter (D2), and minor diameter (D3) were measured using a vernier caliper reading to 0.01 mm precision. The values of the axial dimensions were used for calculating the arithmetic mean diameter (AMD), the geometric mean diameter (GMD), square mean diameter (SMD), equivalent diameter (EQD), the sphericity (SC) and aspect ratio (AR) of the materials under investigation using Equation (2) to Equation (7) as given by Mohsenin, (1986); (1992); Eke et al. (2007); Ghadge and Prasad (2012).

$$AMD = A = \frac{1}{3}[D1 + D2 + D3] \quad (2)$$

$$GMD = B = [D1XD2XD3]^{1/3} \quad (3)$$

$$SMD = C = \frac{\sqrt{D1D2 + D2D3 + D3D1}}{3} \quad (4)$$

$$EQD = \frac{A + B + C}{3} \quad (5)$$

$$SC = \frac{GMD}{D1} \text{ x } 100 \quad (6)$$

$$AR = \frac{D2}{D1} \text{ x } 100 \quad (7)$$

2.6 Measurement of volume

The volume of individual specimen was measured using the toluene displacement method (Moshenin, 1992).

Each weighed Palmyra palm germinating shoot was tied with a string lowered into the measuring cylinder with toluene and volume of toluene displaced in a measuring cylinder was taken as the volume of the Palmyra palm germinating shoot.

2.7 Surface area determination

The surface area of Palmyra palm germinating shoot was determined by analogy with a sphere of the same geometric mean diameter, using the following Equation (8) given by Khazaei (2012) and Altuntas et al. (2005).

$$SA = \pi(GMD)^2 \quad (8)$$

Where:

SA = surface area, mm^2;

GMD = geometric mean diameter, mm.

2.8 Mechanical properties determination

The machine used in determining the mechanical properties of the Palmyra palm germinating shoot was the Universal Testometric AX machine with model No. M 500-25KN, 011 1NR, manufactured by Testometric Company limited. This machine is software driven; manual operations are involved only when loading and unloading the product. The platens for compression testing were fixed in the opposite position. The stationary plate was at the bottom, while the movable plate was attached to the arm that applied the pressure. The pressure was applied at the upper arm at a speed of 25 mm/min by pressing down on the Palmyra palm germinating shoot which was placed on the bottom plate. The display screen on the load cell of the machine measured the variations in pressure applied on the product and the dimension of the product till it failed. All the details were saved in the computer system that has been interfaced with the machine and downloaded.

2.9 Statistical analysis

The computation of the mean standard deviation and coefficient of variation as well as the skewness for the physical properties were analysed using Microsoft Excel 2007 at 95% confidence level. The data obtained was also subjected to one way ANOVA using SPSS 20.0 statistical package.

3 Results and discussion

3.1 Physical properties

The results obtained from the measurement of the physical properties conducted on the selected samples are presented in Table 1. The major diameter, intermediate diameter, and minor diameter, measured surface area and weight increased with the increase in moisture content with high coefficients of variation (significant at $p < 0.05$). The mean maximum values of the major, intermediate and minor diameters are 280.00 mm, 33.00 mm and 25.90 mm respectively while the mean minimum values were 209.67 mm, 16.67 mm and 15.21 mm respectively. The mean coefficient of variation of the major, intermediate and minor diameters were 10.57%, 32.84% and 10.59% respectively. It was observed that the axial dimensions of the shoot determined varied with variations in the moisture contents. The mean values of the weight of the germinating shoot at the three different moisture contents of 41.72%, 26.11% and 18.39% (w.b.) were 81.28 g, 49.44 g and 39.31 g respectively. While the mean volumes were 87.66 cm^3, 37.00 cm^3 and 31.33 cm^3 repectively. Table 1 also presents the mean, standard deviation and the coefficient of variation of the germinating shoot measured at the three different moisture contents. The geometric mean, square mean and equivalent diameters at 41.72% moisture content ranges from 10.48 to 71.02 mm, 43.11 mm to 81.01and 93.57 mm to 117.04 mm respectively while the sphericity and surface area also ranges from 1.04 to 1.14 and 344.87 mm^2 to 15849.39 mm^2 respectively. At the 26.11% moisture content, the geometric mean diameter, square mean diameter and equivalent diameter ranges from 4.56 mm to 46.92 mm, 10.07 to 60.82 mm and 73.79 mm to 108.35 mm respectively while the sphericity, aspect ratio and surface area also ranges from 0.021% to 0.21%, 0.83% to 1.88%, 1.27 cm^2 to 1.42 cm^2 and 65.24 to 6917.63 mm^2. At 18.39% moisture content, the geometric mean diameter, square mean diameter and equivalent diameter ranges from 43.30 mm to 53.38 mm, 53.27 mm to 66.79 mm and 80.17 mm to 103.64 mm respectively. While the sphericity, aspect ratio and surface area have values ranging from 0.18% to 0.22%, 1.11% to 1.35% and 5890.06 mm^2 to 8951.46 mm^2 respectively.

Table 1 Axial dimensions of germinating shoot of Palmyra palm (*borassusaethiopum*)

S/No.	***Measured parameters***														
	41.72% m.c (w.b)					**26.11%m.c (w.b)**					**18.39% m.c (w.b)**				
	Max.	**Min.**	**Avg.**	**SD**	**CV, %**	**Max.**	**Min.**	**Avg.**	**SD**	**CV, %**	**Max.**	**Min.**	**Avg.**	**SD**	**CV, %**
Major ϕ mm	300.00	220.50	261.60	28.10	10.74	270.00	209.00	248.09	27.65	11.14	270.00	200.00	238.9	23.61	**9.88**
Interme-diate ϕ, mm	40.21	20.81	27.40	10.59	38.67	28.00	0.90	17.64	7.38	41.83	30.08	20.21	22.39	4.03	**18.01**
Minor ϕ, mm	40.11	20.71	24.56	6.68	27.18	17.07	0.48	12.97	4.35	3.85	20.51	20.11	20.25	0.14	**0.72**
Seed weight, g	81.25	81.28	81.28	0.00	0.00	49.44	49.44	49.44	0.00	0.00	39.34	39.33	39.31	0.00	**0.00**
Seed Volume, cm^3	91.00	85.00	87.66	3.05	3.48	40.00	35.00	37.00	2.64	7.15	37.00	28.00	31.33	4.93	**15.74**

The frequency distributions of the physical characteristics of the germinating shoot are presented in Table 2. Positive skewness indicates a distribution with an asymmetric tail extending towards more value. Negative skewness indicates the distribution with an asymmetric tail extending towards more negative value. Zero value indicates symmetrical distribution.

Table 2 Frequency distribution of physical properties of germinating shoot of Palmyra palm (*borassus aethiopum*)

S/No.	Parameters	Skewness		
		Group A	Group B	Group C
1	Major diameter, mm	- 0.298	0.788	0.662
2	Intermediate diameter, mm	- 2.114	- 0.970	1,771
3	Minor diameter, mm	1.729	-2.667	0.798
4	GMD, mm	- 2.364	-2.721	0.877
5	SA, mm^2	-1.157	-1.979	0.983
6	AMD, mm	-0.166	0.091	- 0.726
7	SMD, mm	-1.804	-2.703	0.252
8	EQD, mm	-0.166	0.091	- 0.726
9	SC, %	-1.146	-2.095	- 0.033
10	AR, %	-1.819	-0.276	1.774

Note: GMD – geometric mean diameter; SA – surface area; AMD – arithmetic mean diameter; SMD – square mean diameter: EQD – equivalent diameter; SC – sphericity; AR - aspect ratio

The results of the statistical analysis on the physical properties of the germinating shoot are presented in Table 3, Table 4 and Table 5. The statistical analysis carried out on the physical properties at a moisture content range of 41.72% to 18.39% shows that the F value (38.77) is greater than the F-critical value and also the P- value 1.74×10^{32} is less than the significance level (α= 0.05) which means there is a wide statistically significant difference between the physical properties of germinating shoot within the range of moisture contents.

Table 3 Results of statistical analysis on the physical properties of the germinating shoot of palmyra palm at 41.72% moisture content (w.b)

Groups	Count	Sum	Average	Variance	
Major diameter, mm	10	2615.5	261.55	790.14	
Intermediate diameter, mm	10	274.01	27.401	112.22	
Minor diameter, mm	10	245.6	24.56	44.581	
GMD, mm	10	527.53649	52.7536	253.03	
SA, mm^2	10	94595.452	9459.55	2E+07	
AMD, mm	10	1043.9916	104.399	65.958	
SMD, mm	10	679.19289	67.9193	98.452	
EQD, mm	10	1045.0367	104.504	66.09	
SC, %	10	2.053841	0.20538	0.0051	
AR, %	10	11.361022	1.1361	0.2094	
ANOVA					
Source of Variation	*SS*	*df*	*MS*	*F*	*F crit*
Between Groups	2.888E+11	11	2.6E+10	38.767	1.878388
Within Groups	7.314E+10	108	6.8E+08		
Total	3.619E+11	119			

Table 4 Results of statistical analysis on the physical properties of the germinating shoot of palmyra palm at 26.10 % moisture content (w.b)

Groups	Count	Sum	Average	Variance		
Major diameter, mm	11	2729	248.0909	764.8909		
Intermediate diameter, mm	11	194.14	17.64909	54.50475		
Minor diameter, mm	11	142.71	12.97364	18.92755		
GMD, mm	11	409.0043	37.18221	127.8709		
SA, mm^2	11	51800.24	4709.112	3080704		
AMD, mm	11	1020.928	92.81164	107.9417		
SMD, mm	11	545.4359	49.58508	187.5722		
EQD, mm	11	1021.95	92.90455	108.1579		
SC, %	11	1.649959	0.149996	0.002318		
AR, %	11	15.55819	1.41438	0.142863		
ANOVA						
Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between groups	3.84E+10	11	3.49E+09	59.43121	3.03E-43	1.86929
Within groups	7.05E+09	120	58779654			
Total	4.55E+10	131				

Table 5 Results of statistical analysis on the physical properties of the germinating shoot of palmyra palm at 18.39 % moisture content (w.b)

Groups	Count	Sum	Average	Variance		
Major diameter, mm	10	2389	238.9	557.8778		
Intermediate diameter, mm	10	223.97	22.397	16.27636		
Minor diameter, mm	10	202.57	20.257	0.021201		
GMD, mm	10	473.3229	47.33229	11.89604		
SA, mm^2	10	70728.07	7072.807	1108029		
AMD, mm	10	937.5748	93.75748	68.95391		
SMD, mm	10	594.7017	59.47017	20.39926		
EQD, mm	10	938.5133	93.85133	69.09203		
SC, %	10	1.990817	0.199082	0.000223		
AR, %	10	11.0544	1.10544	0.03897		
ANOVA						
Source of variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between groups	1.08E+11	11	9.79E+09	190.3475	2.35E-65	1.878388
Within groups	5.55E+09	108	51419263			
Total	1.13E+11	119				

It can also be seen in Table 3 at 41.72% moisture content, the average geometric mean diameter recorded was 52.75 mm, the average square mean diameter was 67.92 mm, the equivalent diameter was 104.50 mm and the arithmetic mean diameter was 104.40 mm, while the sphericity, surface area and the aspect ratio were 0.21%, 9459.55 mm^2 and 1.14% respectively.

From Table 4 at 26.10% moisture content, the average geometric mean diameter recorded was 37.18 mm, the average square mean diameter was 49.59 mm, the equivalent diameter was 92.90 mm and the arithmetic mean diameter was 92.81 mm. while the sphericity, surface area and the aspect ratio were 0.15%, 4709.11 mm^2 and 1.41% respectively.

Similarly it can be seen in Table 5 at 18.39% moisture content, the average geometric mean diameter recorded was 47.33 mm, the average square mean diameter was 59.47 mm, the equivalent diameter was 93.85 mm and the arithmetic mean diameter was 93.76 mm, while the sphericity, surface area and the aspect ratio were 0.20%, 7070.81 mm^2 and 1.11% respectively.

It was observed that the calculated parameters increased with increase in moisture content. These properties are dependent on the three axial dimensions, which were observed to increase with increase in moisture content.

3.2 Mechanical properties

The summary of results of the experiments conducted at three loading positions is presented in Table 6, Table 7 and Table 8. The average force at break was 1247.10 N, 650.00 N and 707.10 N for longitudinal, natural and transverse loading positions respectively. From the results, it can be deduced that the average force at break is lower in the natural loading position while it is relativelyhigher in transverse and longitudinal loading positions. This indicates less resistance was posed to compression in the natural position.

Table 6 Mechanical properties of Palmyra palm germinating shoot at longitudinal loading position

Test No.	Force at break, N	Stress at break, N/mm^2	Energy at break, N.m	Force at yield, N	Stress at yield, N/mm^2	Energy at yield, N.m	Young's modulus, N/mm^2
1	1235.4	1235.4	1.9878	-	-	-	13424
2	1230.7	1230.7	1.8088	1266.9	1266.9	1.7800	16573
3	1275.2	1275.2	2.6935	1050.1	1050.1	1.3389	15983
Min	1230.7	1230.7	1.8088	0.0	0.0	0.0000	13424
Max	1275.2	1275.2	2.6935	1266.9	1266.9	1.7800	16573
Mean	1247.1	1247.1	2.1634	1158.5	1158.5	1.5595	15326
Sd	24.4	24.4	0.4678	153.3	153.3	0.3119	1674

Table 7 Mechanical properties of Palmyra palm germinating shoot at natural loading position

Test No.	Force at break, N	Stress at break, N/mm^2	Energy at break, N.m	Force at yield, N	Stress at yield, N/mm^2	Energy at yield, N.m	Young's modulus, N/mm^2
1	551.80	551.80	3.1886	667.50	667.50	1.1010	5775.2
2	611.60	611.60	2.2932	620.70	620.70	1.2905	3040.7
3	786.60	786.60	1.7798	594.80	594.80	0.6908	8490.6
Min	551.80	551.80	1.7798	594.80	594.80	0.6908	3040.7
Max	786.60	786.60	3.1886	667.50	667.50	1.2905	8490.6
Mean	650.00	650.00	2.4205	627.67	627.67	1.0274	5768.8
Sd	122.02	122.02	0.7130	36.85	36.85	0.3065	2725.0

Table 8 Mechanical properties of Palmyra palm germinating shoot at transverse loading position

Test No.	Force at break, N	Stress at Break, N/mm^2	Energy at break, N.m	Force at Yield, N	Stress at Yield, N/mm^2	Energy at Yield, N.m	Young's Modulus, N/mm^2
1	811.90	811.90	1.4615	-	-	-	5205.6
2	668.30	668.30	2.1985	768.70	768.70	1.4658	5110.7
3	641.10	641.10	1.7545	699.80	699.80	1.4235	4716.4
Min	641.10	641.10	1.4615	0.00	0.00	0.0000	4716.4
Max	811.90	811.90	2.1985	768.70	768.70	1.4658	5205.6
Mean	707.10	707.10	1.8048	734.25	734.25	1.4446	5010.9
Sd	91.77	91.77	0.3711	48.72	48.72	0.0299	259.4

It can also be seen from the results presented in Table 6, Table 7 and Table 8, the stress at break mean values of 1247.10 N/mm^2, 650.00 N/mm^2 and 707.10 $N/mm^2$for Palmyra palm germinating shoot were obtained at longitudinal, natural and transverse loading positions respectively.

Similarly in Table 6, Table 7 and Table 8, it can be seen that the energy at break mean values of 2.16 Nm 2.42 Nm and 1.80 Nm, for longitudinal natural and transverse loading positions respectively. The mean higher value of energy requirement was recorded at the natural loading position than the longitudinal and transverse loading positions.

Stress at yield mean values of 1158.50 N/mm^2, 627.67 N/mm^2 and 734.25 N/mm^2 was recorded for longitudinal, natural and transverse loading positions respectively as can be seen in Table 6, Table 7 and Table 8. This reveals that the highest stress was recorded at the longitudinal loading position.

From Table 6 to Table 8, the mean values of the energy at yield for longitudinal, natural and transverse loading positions were 1.56 Nm, 1.03 Nm and 1.44 Nm respectively. This indicates a higher energy requirement at longitudinal loading position than the natural and transverse loading positions.

The mean young's modulus values for longitudinal, natural and transverse loading positions were 15326.00 N/mm^2, 5768.80 N/mm^2, and 5010.90 N/mm^2 respectively (Table 6, Table 7 and Table 8). This clearly shows higher young modulus at the longitudinal position than the natural and transverse loading positions.

It can be seen in Figure 2, Figure 3 and Figure 4, at 41.72% moisture content, the compressive load at breakage was 1.23 kN, 1.23 kN, 1.28 kN, 1.32 kN, and 1.35 kN with deformation of 4.33 mm, 4.08 mm, 5.04 mm, 9.02 mm, and 9.07 mm. While at 26.11% moisture content, the compressive load at breakage was 0.55 kN, 0.661 kN, 0.78 kN, 0.40 kN and 0.81 kN with deformation of 7.91 mm, 7.59, 4.70, 9.17 mm and 9.07 mm respectively. Also for the 18.39% moisture content, the compressive load at break were 0.81 kN, 0.67 kN, 0.64 kN, 1.79 kN and 0.95 kN with deformation of 5.65 mm, 6.81 mm, 6.11 mm, 16.99 mm and 6.25 mm respectively. The variation in the values of the compressive load and deformation of the germinating shoot during the test describes the trend of the slope as is shown in the Figure 2, Figure 3 and Figure 4. It was also observed that the trend of the slope depends on the moisture content. It is worthy to note that the probability of fracture of the germinating shoot under tension or compression depends on the applied macroscopic stress and the size of the shoot.

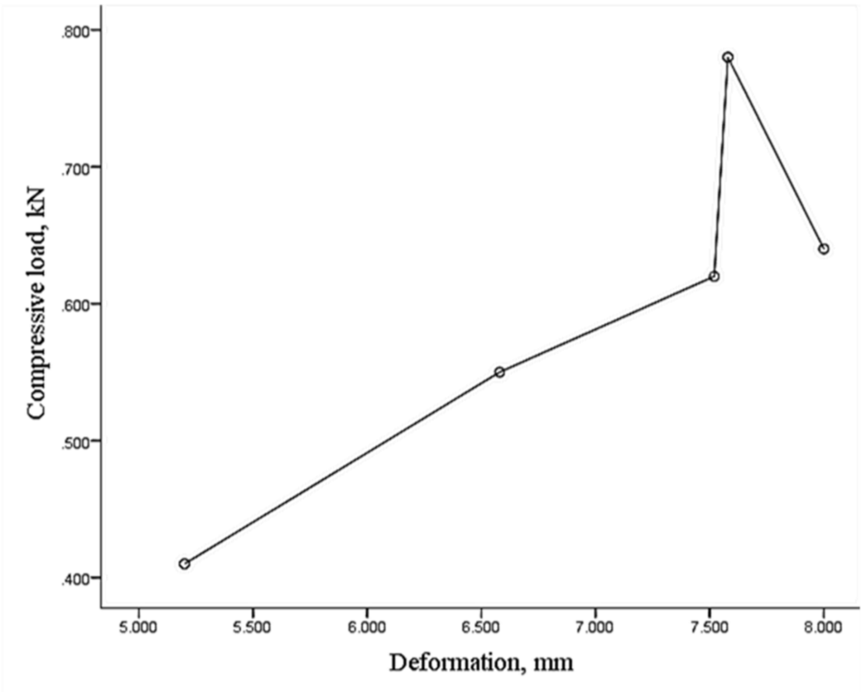

Figure 2 Compressive load against deformation at 41.74% moisture content

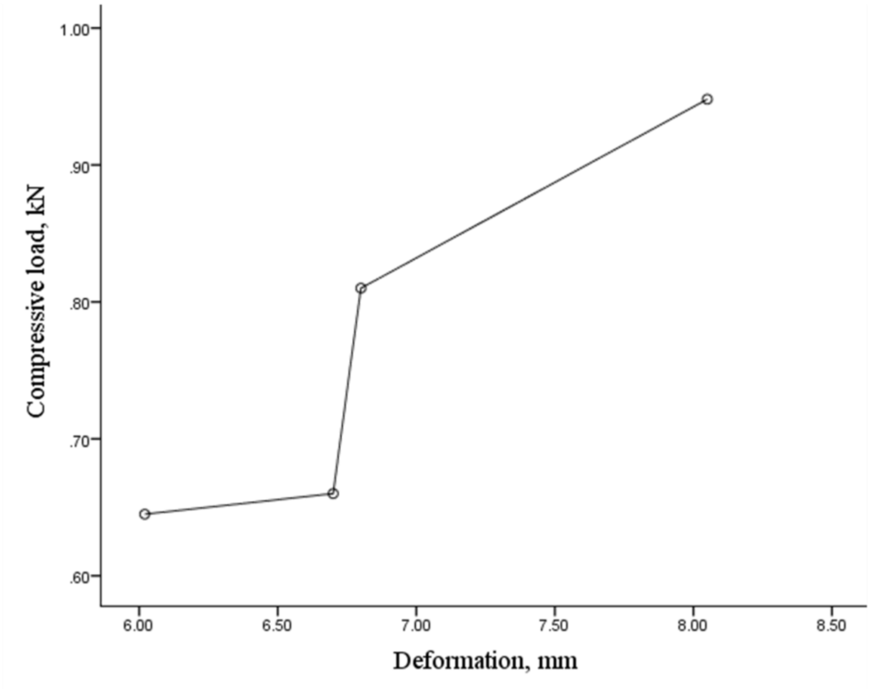

Figure 3 Compressive load against deformation at 26.11% moisture content

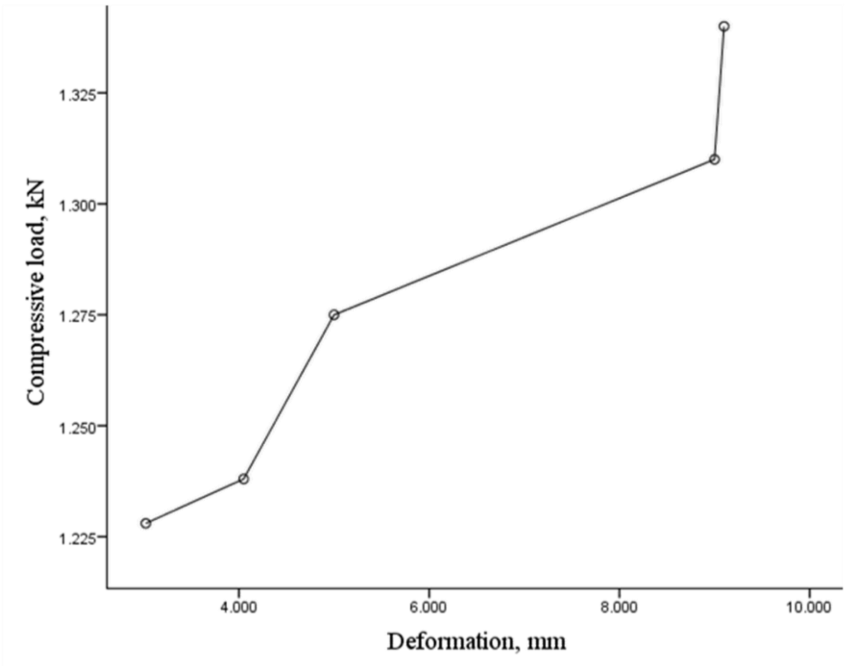

Figure 4 Compressive load against deformation at 18.39% moisture content

4 Conclusions

The engineering properties of the germinating shoot of Palmyra palm such as size, geometric mean diameter, arithmetic mean diameter, sphericity, volume, surface area and compressive strength were determined at moisture contents of 41.72%, 26.11% and 18.40% respectively. The major diameter, intermediate diameter, minor diameter, surface area, and weight increased with the increase in moisture content with high coefficients of variation (significant at $p < 0.05$). The statistical analysis carried out for physical properties at a moisture content range of 41.72% to 18.39% shows that the F value (38.77) is greater than the F-critical value and also the P- value 1.74×10^{32} is less than the significance level (α= 0.05) which means there is a wide statistically significant difference between the physical properties of germinating shoot at the different moisture contents.

The mechanical properties of the Palmyra palm germinating shoot revealed a mean force at break was 1247.10 N, 650.00 N and 707.10 N longitudinal, natural and transverse loading positions. Stress at break mean values of 1247.10 N/mm^2, 650.00 N/mm^2 and 707.10 N/mm^2 for longitudinal natural and transverse loading positions respectively. Energy at break mean values of 2.16 Nm 2.42 Nm and 1.80 Nm, for longitudinal natural and transverse loading positions respectively. Stress at yield mean values of 1158.50 N/mm^2, 627.67 N/mm^2 and 734.25 N/mm^2 was recorded for longitudinal, natural and transverse loading positions respectively. Mean values of the energy at yield for longitudinal, natural and transverse loading positions were 1.56 Nm, 1.03 Nm and 1.44 Nm respectively. The mean young's modulus values for longitudinal, natural and transverse loading positions were 15326.00 N/mm^2, 5768.80 N/mm^2, and 5010.90 N/mm^2 respectively.

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