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RESEARCH ARTICLE

MECHANICAL STRENGTH PROPERTIES OF *MANGIFERA INDICA* IN AXIAL DIRECTION AT DIFFERENT MOISTURE REGIMES.

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Abstract

This study assessed the Modulus of Rupture (MOR), Modulus of elasticity (MOE) and Impact strength (IM) of *Mangifera indica* woods in axial direction. The dimensions of wood samples were determined in accordance to British Standard (BS) 373(1957) and samples were subjected to the oven dry method for moisture content(MC) determination at Green state (90%) and Dry basis (12% MC). The result showed that there was significant difference ($P<0.05$) between MOR in the green and dry bases and along axial heights. The axial variations on wet basis shows that, MOR was highest at the base with 42.30Nmm^2 followed by the middle with 42.16 Nmm^2 and least at the top with 19.64 Nmm^2 while at 12% MC, MOR was highest at the middle with 48.59 Nmm^2 followed by the top with 43.18 Nmm^2 and lowest at the bottom with 43.14 Nmm^2. There was significant difference ($P<0.05$) between the Modulus of Elasticity (MOE) in the wet and dry bases. Conversely, at their axial heights there was no significant difference ($P>0.05$) between stands.MOE at the wet bases along axial heights was highest at the middle (10272.3Nmm^2) followed by base (8202.06 Nmm^2) and least at the top (5137.71Nmm^2) whereon the dry basis, MOE was highest at the base (52112.80 Nmm^2) followed by middle (14070.38 Nmm^2) and least at the top (9386.40 Nmm^2). There was no significant difference ($P>0.05$) of the Impact Strength (IM) in their different moisture regimes (wet and dry bases).IM strength at the wet and dry bases was highest at the middle (1.86; 2.16 Nmm^2) followed by the base (1.85; 2.51Nmm^2) and least at the top (1.48; 1.52Nmm^2). A comparison with other species indicates that *Mangifera indica* serve other utilitarian purpose apart from its fruit benefits.

Introduction:-

Mangifera indica Linn (Mango) is a hard wood species that belongs to the Anacardiaceae family and genus *Mangifera.* .It is an evergreen tree that attains a height of 15-30m and when cultivated can attain a height of 3-10m (More, 2004; Bally, 2006). It develops a girth of over 4m with a dense and umbrella shaped crown (Keay e*t al*, 1964; Bally, 2006). The specie is a native of Asia-specifically India where it has spread to other parts of the world. The existence of Mango in Nigeria dates back to the 20th century through the travels of merchant missionaries and colonist which has resulted to an indigenous species in the cropping systems (Aiyelaagbe, 2002; Niyishir, 2004).

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Wood as a substance of great complexities more than other engineering materials (Aguda, *et al*, 2012) which calls for a degree of scientific, engineering and technological understanding. Thus, wood is a heterogeneous conglomeration of large number of cells which are hollow, spindle shaped and parallel to each other exhibiting hydroscopic and anisotropic tendencies. Suffice to say, wood has varying modes of behavior in relation to their moisture content and elastic properties which in turn affect their strength properties.

Modulus of rupture is a measure of the specimens' strength before rupture (Meier, 2008). It reflects the maximum load carrying capacity of a member in bending and is proportional to a maximum borne by the specimen (Green, *et al*, 1999).The Modulus of elasticity is a measure of resistance to bending (Kwaku *et al*, 2014) while the impact strength is the ability of the wood to resist suddenly applied load (Nwisuator and Emerhi, 2014). Thus, mechanical properties emphasises the ability of members to resist applied and/or external force.
The fruit tree *Mangifera indica* has been known before now for its food purpose and medical value to man. This study is however imperative to unravel its strength property, MOR to bring it to fore to serve for other utilitarian purposes.

Materials and Method:-

Study Area:-
The woods were obtained from Rivers State University of Science and Technology, Nkpolu-Oroworukwo, Port Harcourt, River state Nigeria. Mature standing trees of *Mangifera indica* were randomly selected and felled.

Preparation of Sample:-
Tree samples were collected from the Top, Middle, and Base of merchantable height (Mitchell and Dane, 1997). The species were immediately covered with a black nylon bag to prevent moisture loss. Specimens from the different positions were trimmed to 20x20x300mm in accordance to British Standard(BS) 373(1957) for Modulus of Rupture, Modulus of elasticity and Impact Strength. Test samples were taken to the Forestry Research Institute of Nigeria (FRIN), Ibadan for assessment. The wood specimens were oven dried at 105^0C and conditioned to have a stabilised moisture content of 12% for comparism with the moist wood at 90% MC.

Determination of Modulus of Rupture (MOR):-
The Modulus of rupture (MOR) was determined using specimen size of 20x20x300mm in accordance to BS 373(1957) from the three positions (Mitchell and Dane, 1997). The load was applied at the rate of 0.1m/sec using a Housfield Tensometer at the Forestry Product Development and Utilization Department of FRIN. The maximum load was noted. Values were substituted into the MOR formula;

$$MOR = \frac{3PL}{2bd^2} \text{ (N/mm}^2\text{)}$$

Where;

MOR= Modulus of Rupture
P=Breaking Load at the Moment of Failure
L=Distance between Knife Edge which the sample is supported (mm)
b=Average Specimen (Wood) Breath (mm)
d=Average Specimen (wood) Depth (mm)

Determination of the Modulus of Elasticity (MOE):-
The Modulus of Elasticity was determined from the values obtained at the point of failure (Breaking load) recorded during test of MOR

$$MOE = \frac{PL^3}{\Delta Bd^3} \text{ (N/mm}^2\text{)}$$

Where;
P=Breaking Load/ Maximum Load at Failure (N)
L=Distance between Knife edge/Span (mm)
B=Sample Depth/Thickness (mm)
Δ =Deflection at bean centre at proportional load.

Determination of Impact Strength Parallel to Grain:-

The Impact strength test was done using the Hatt-Tuner impact tester in accordance to BS373 (1957) with a standard test samples of 20x20x300mm supported over a span of 240mm on a support radius of 15mm with spring restricted yokes fitted to arrest rebounce. The test samples were subjected to a repeated blow from a weight of 1.5kg at increasing height initially from 50.8mm, and then every 25.4mm until complete failure occurred. The height at which failure occurred was recorded in meter as the height of maximum hammer drop (Ogunsanwo and Omole, 2010).

Experimental Design and Data Analysis:-

Completely Randomized Design with three treatments replicated thrice and a descriptive statistics and a one-way analysis of variance (ANOVA) were used to analyze the data

Results:-

The Modulus of Rupture (MOR) results indicated that there was significant difference ($P<0.05$) between the green samples and at 12% Moisture Content (dry basis), along axial heights and among the woods (Appendix 1). In the green state Tree 2 had the higher load carrying capacity (LCC) or (MOR) of 38.21 Nmm^2 (29.17- 46.94 Nmm^2), followed by Tree 1 with 36.77Nmm^2 (13.79- 49.64 Nmm^2) and least with Tree 3 as 29.12Nmm^2 (15.96- 38.76 Nmm^2) (Table 1). However, on dry basis there was an upturn of values with Tree 1 having the highest average MOR of 58.01 Nmm^2(40.87-55.16 Nmm^2) followed by Tree 2 with 44.50Nmm^2(42.20- 46.46 Nmm^2) and Tree 3 with least 43.95Nmm^2(42.10- 46.43 Nmm^2) . The axial variations at their wet bases showed that, MOR was highest at the base with 42.30Nmm^2 followed by the middle with 42.16 Nmm^2 and least at the top with 19.64 Nmm^2 (Table 1) while on the dry basis, MOR was highest at the middle with 48.59 Nmm^2 followed by the top with 43.18 Nmm^2 and lowest at the bottom with 43.14 Nmm^2. (Table 1).

Table 1:- Modulus of Rupture in Axial direction on Wet and Dry (@ 12 %MC) Bases

Tree Number	Top	Middle	Base	Average
WET				
Tree 1	13.79	46.89	49.64	36.77
Tree 2	29.17	46.94	38.52	38.21
Tree3	15.96	32.65	38.76	29.12
Average	19.64	42.16	42.30	34.70
DRY				
Tree 1	41.37	55.16	40.87	58.01
Tree 2	44.85	44.20	46.46	44.50
Tree3	43.32	46.43	42.10	43.95
Average	43.18	48.59	43.14	43.95

Appendix 2 indicates significant difference ($P<0.05$) between the Modulus of Elasticity (MOE) of the different woods in the wet and dry basis. Conversely, at their axial heights and interaction there was no significant difference ($P>0.05$) between stands. Thus, the mean MOE values at the wet state and their respective axial range values are higher at Tree 2 with 9083.06Nmm^2 (7148.73-10141.64 Nmm^2) followed by Tree 1 having 7788.78Nmm^2 (3910.28-12533.65 Nmm^2) and Tree 3 with the least as 6740.21Nmm^2 (4354.11-7542.11Nmm^2). However, at 12% Moisture content (Dry state) there was no much change in relation to their moisture regime and axial heights. Tree 1 has the highest MOE with 13760.25 Nmm^2 (10905.86-17578.86 Nmm^2) followed by Tree 2, 12571.65 Nmm^2 (9104.72-16136.78 Nmm^2) and least with Tree 3 with 10849.73 Nmm^2 (8148.73-12241.64 Nmm^2) (Table 2).

Table 2: Modulus of elasticity in Axial direction on Wet and Dry (@ 12 %MC) Bases

Tree Number	Top	Middle	Base	Average
WET				
Tree 1	3910.28	12533.65	6922.43	7788.78
Tree 2	7148.73	9958.82	10141.64	9083.06
Tree3	4354.11	8324.43	7542.11	6740.21
Average	5137.71	10272.3	8202.06	7870.68
DRY				
Tree 1	10905.75	17578.86	127960.04	13760.25
Tree 2	9104.72	12473.47	16136.78	12571.65
Tree3	8148.73	12158.82	12241.64	10849.73
Average	9386.40	14070.38	52112.80	12393.88

The results in Appendix 3 shows that there was no significant difference (P>0.05) of the Impact Strength in their different moisture regimes (wet and dry basis), axial heights and interactions between woods. The mean Impact strength(IM) in the green state shows that Tree 2 had the highest IM of 2.15 Nmm^2 (1.80-2.37 Nmm^2) followed by Tree 1, 1.55 Nmm^2(0.85-2.15 Nmm^2) and Tree 3 with the least IM of 1.49 Nmm^2(1.23-1.65 Nmm^2). Whereas at 12% MC, Tree 1 had the highest IM of 2.21 Nmm^2 (1.30-3.10 Nmm^2) followed by Tree 2 having 2.09 Nmm^2 (1.95-2.14 Nmm^2) (Fig.1).

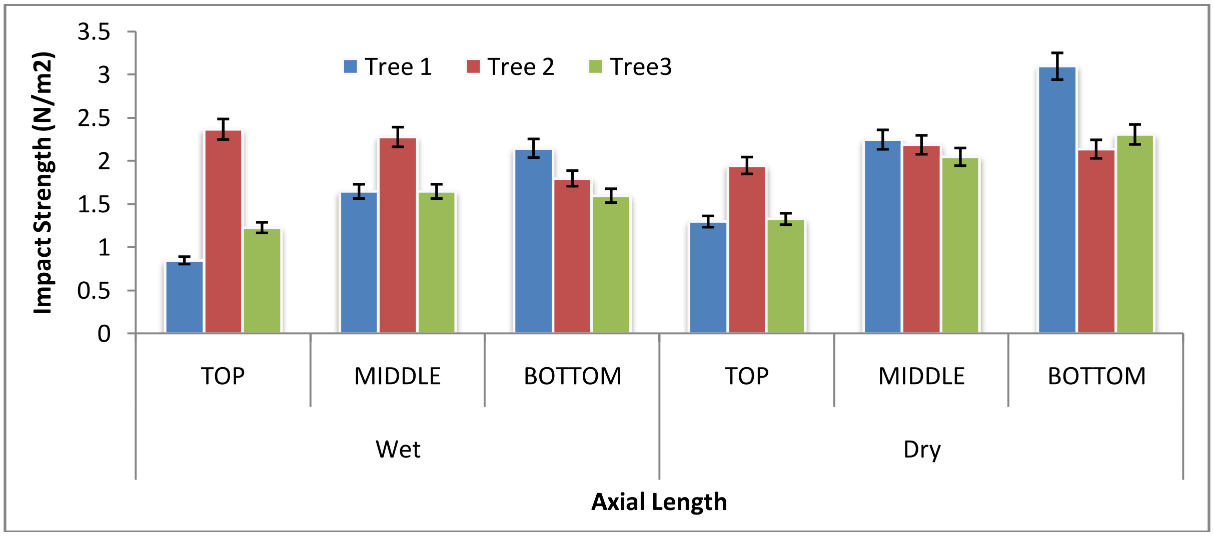

Figure 1:- Impact strength of trees along vertical length

Discussion:-

Modulus of rupture (MOR):-

The modulus of rupture reflects the maximum load carrying capacity of a member in bending and is proportional to the maximum moment borne by the specimen (Green, *et al* 1999).MOR is a very important criteria for determining wood strength (Kretschmann and Brendtsen,1992). The static bending strength values of the tree stands when green and at 12% MC had a difference in values at their various moisture regimes. This is evident to the fact that moisture played an important role in the strength properties of the wood (Armstrong, 1953) most especially with wood specimens subjected to bending, strength and stiffness increases with decrease in moisture content (Madsen,1972). Axially, the MOR increases from top to base with slight fluctuation in values and this variation trend agrees with the findings of Ogunsanwo (2000),Adedipe (2004) on axial variations of *Triplochiton scleroxylon, Fiscus mucoso* and *Gmelina aborea* and Fuwape and Fabiyi (2003)on *Nuclea diderrichii* but disagrees with the findings of Nwiisuator, *et al* (2014) on *Allanblackia floribunda*.. More so, these variations could occur as a result of effects of defects in the trees as opined by Aguda *et al* (2012) in that defects such as knots affects bending properties of trees and this in turn affects the affinity between MOR and sampling height. The reports also suggest that variability could be due to changing influences such as moisture, soil conditions, growing space etc (Green *et al*, 1999).

Modulus of elasticity:-

Modulus of elasticity is a measure of resistance to bending (Kwaku *et al*, 2014); this implies that deformations produced by low stress are completely recoverable after loads are removed (Green *et al*, 1999). In simplest term MOE measures the woods stiffness and is a good indicator of wood strength (Meier, 2008). The variations between the moisture regimes of the wood stands at their wet and dry basis is due to the fact that moisture lowers the stiffness (MOE) and strength of wood –it softens the wood cell walls, thus the cellulose micro fibrils are longer strongly bonded to each other making it easier to untangle and hence stretch the fibers (Yee, 2013 and University of Cambridge, 2004). This report also corroborates with the assertions of Cave, (1978), Green *et al*, (1999), Kretschmann and Green, (1996), Wang and Wang, (1999), Kojima and Yamamoto, (2004), that virtually all mechanical properties of wood decreases with increase in MC below the fiber saturation point. Temperature also played a salient role in relation to the MC of wood –as wood is cooled below normal temperature its mechanical properties (MOE) tends to increase. Conversely, when wood is heated its mechanical properties decreases. The magnitude of this change is dependent on the MC of the wood and when wood is heated on the duration of temperature exposure (Green and Evans, 2007). At the axial positions there was a decrease from the base to the top with little variations which were not significant supporting the findings of Nwiisuator, *et al* (2014) on *Allanblackia floribunda,* Aguda, *et al* (2012) on *Chrystophyllum albidum.* The result also revealed that the maturity of the wood played a role in the magnitude and partten of wood property variability (Panshin and Dezeeuw, 1980). Hence, this could have caused a difference in their values. On their interaction bases, the orientation of the microfibril angle (MFA) in the cell wall along the fibre axis is presumed to have played a primal role on the MOE and/stiffness of the wood. (Cave, 1968). Walker and Butterfield (1995) and Lichtenegger *et al* (1999) opined that woods with higher microfibril angle (MFA) has low MOE which supports the standards of (TEDB, 1994) on its classification on the modulus of elasticity of wood at 12% moisture content. Although with the TEDB (1994) standard the wood is classified as a heavy wood at the dry bases but not very heavy due to slight variation in values.

Appendices

Appendix 1: ANOVA of MOR of sampled wood						
Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Sample (wet & dry)	454.3706	1	454.3706	11.71032	0.00506	4.747225
Columns (axial length)	638.5832	2	319.2916	8.228979	0.005622	3.885294
Interaction	427.722	2	213.861	5.511758	0.020047	3.885294
Within	465.6105	12	38.80088			
Total	1986.286	17				

Reject Ho since $F_{cal} > F_{crit}$: there is significant difference (P<0.05) between MOR of wet and dry sampled woods.
Reject Ho since $F_{cal} > F_{crit}$: there is significant difference (P<0.05) between MOR of along axial length of sampled woods.
Reject Ho since $F_{cal} > F_{crit}$: there is significant difference (P<0.05) between MOR of interaction amongst the sampled woods.

Appendix 2: ANOVA of MOE of sampled wood						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample (wet & Dry)	92066660	1	92066660	9.853067	0.008548	4.747225
Columns (Axial Length)	16103985	2	8051993	0.861732	0.446997	3.885294
Interaction	5008536	2	2504268	0.268009	0.76936	3.885294
Within	1.12E+08	12	9343960			
Total	2.25E+08	17				

Reject Ho since $F_{cal} > F_{crit}$: there is significant difference (P<0.05) between MOE of wet and dry sampled woods.
Accept Ho since $F_{cal} < F_{crit}$: there is no significant difference (P>0.05) between MOE of along axial length of sampled woods.
Accept Ho since $F_{cal} < F_{crit}$: there is no significant difference (P>0.05) between MOE of interaction amongst the sampled woods.

Appendix 3: ANOVA of IM of sampled woods						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample (wet & dry)	0.513422	1	0.513422	2.478039	0.141429	4.747225
Columns (axial length)	1.492633	2	0.746317	3.602108	0.059526	3.885294
Interaction	0.294078	2	0.147039	0.709685	0.511322	3.885294
Within	2.486267	12	0.207189			
Total	4.7864	17				

Accept Ho since $F_{cal} < F_{crit}$: there is no significant difference (P>0.05) between IM of wet and dry sampled wood.
Accept Ho since $F_{cal} < F_{crit}$: there is no significant difference (P>0.05) between IM of along the axial length of sampled wood.
Accept Ho since $F_{cal} < F_{crit}$: there is no significant difference (P>0.05) between interaction of IM of parameters of sampled woods.

Impact Strength:-

The impact strength result goes contrary to the assertions of Armstrong (1953), Mandsen (1972) and Guntekin and Aydin (2013) were by moisture plays a pivotal role in the strength properties of wood. This change could be as results of high extractive content inhibiting the flow of moisture in the cell walls of the wood. Strength generally increases consistently as wood is dried below the fiber saturation point (FSP) (Desch and Dinwoodie, 1996), except for impact strength and toughness (Wikipedia, 2016) which the results fulfilled. The mean impact strength ranges from 1.49-2.15Nmm^2 and 1.89-2.21Nmm^2 at the wet and dry basis respectively. This increase across the axial plan agrees with the findings of Ogunsanwo (2000), Aguda (2012), Adejoba (2008) and Adedipe (2004) in *Triplochiton scleroxylon, Fiscus mucuso and Gmelina arborea.*

Conclusion:-

From the study, *Mangifera indica* has shown an outstanding strength property when compared with other wood species. However, it is primal to state that moisture, site, location and individual characteristics influenced the variability between the stands. More so, with the strength values it can be deduced that the species is highly dense which is as a result of high density of the heartwood to sap wood .The species can be recommended for some engineering works like furniture making, aesthetics etc and other utilitarian purposes. However further research is also recommended for further strength properties.

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