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Relationship between Mechanical Properties of Vitex *doniana*, a Lesser Known Species and Implications for Utilization

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Abstract: *Relationship between the mechanical properties of Vitex doniana, a lesser known wood species was investigated towards determining its potentials for utilization. Four trees obtained from the free area of Olokemeji Forest Reserve, Ogun State, Nigeria were sampled at butt (50cm above the ground) and at 10%, 30%, 50%, 70% and 90% of merchantable height (MH) The samples were also partitioned into corewood, middlewood and outerwood. Impact Bending (IMB), Modulus of Rupture (MOR), Modulus of Elasticity (MOE) and Maximum Compressive Strength Parallel to Grain (MCS//) were determined. Relationship between the mechanical properties was determined using regression equation. Results showed that Mean IMB, MOR, MOE and MCSS// were 0.69m, 85.4 N/mm^2 , 6380N/mm^2 and 40.8N/mm^2 respectively. The best relationship existed between IMB and MCS// (R^2 = 0.75) followed by between MOR and MOE (R^2 =0.71) while the least relationship (R^2 = 0.43) existed between MOR and MCS//.*

Keywords: *Axial variation, Mechanical properties, relationship, radial variation, Vitex doniana.*

I. Introduction

The generic name "Vitex", is an old Latin name for the genus. *Vitex doniana* is the most abundant and widespread of the genus occurring in Savannah regions. *Vitex doniana* (Verbanaceae) commonly known as black plum or "ori-nla" is wide spread in the south western Nigeria as a perennial tree. It is a deciduous forest tree of coastal woodland, riverine and lowland forests and deciduous woodland, extending as high as upland grassland. It is a medium sized deciduous tree which is about 8-18m high. It has a heavy rounded crown and a clear bole up to 5m. The bark is rough, pale brown or greyish white, rather smooth with narrow fissures. The bases of old trees have oblong scales.

The mechanical properties of a wood are the behaviour of the wood under an applied force. It refers to the ability of the material to resist eternal loads or forces tending to cause change in its size and alteration in its shape. These changes in size or shape are known as deformation or strain. [1] identified three kinds of primary stresses acting on a body. The force may be acting in compression if it shortens a dimension or reduces the volume of the body in which case it is called compressive stress. The behaviour of wood under an applied force on the other hand depends on the kind of forces applied, cellular alignment and content of wood. The mechanical properties of a wood are the cumulative effect of inherent attributes. The parameters that are often used in determining the mechanical properties of wood include Impact Bending (IMB), Modulus of Rupture (MOR), Modulus of Elasticity (MOE),Maximum Compressive Strength Parallel to Grain (MCS//).

Impact bending which is also known as maximum hammer drop shows the ability of wood samples to resist suddenly applied load. It is one of the three criteria used in the laboratory for measuring toughness [1]. The amount of shock resistance of a solid body depends on the ability to absorb energy and dissipate it before deformation [2]. MOR is the ultimate bending strength of a material which describes the load required to cause a wood beam to fail and can be thought of as the ultimate resistance or strength that can be expected. MOR is a parameter for measuring bending strength of wood. It measures the equivalent of stress in the extreme fibres of the specimen at the point of failure. [3] described MOR as the magnitude of load required to cause failure in bending stresses. Modulus of elasticity is the ability of a material to regain its original shape and size after being stressed [3 and 1]. The ability of a wood member to bend freely and regain normal shape is called flexibility and the ability to resist bending is called stiffness.

The modulus of elasticity which is a measure of the relationship between stress and strain within the limit of proportionality provides a convenient measure of stiffness or flexibility of a timber. The greater the MOE the stiffer the timber and conversely, the lower the modulus of elasticity MOE, the more flexible is the wood member.MCS // is the ability of a piece of material to withstand loads in compression parallel to the grain up to the point of failure [3]. The maximum compressive strength plays an important role in utilization of wood as a building and construction material.

The importance of relationship between the mechanical properties to utilization of a species cannot be overemphasized. Therefore, in order to determine the potentials of *Vitex doniana* for utilization, this study investigated the relationship among the properties.

II. Methodology

Forty five (45) trees of *Vitex doniana* which had no reaction tendencies, which bole were devoid of crookedness (clear and straight bole) with absence of excessive knots were purposefully marked at the free area of Olokemeji Forest Area in Odeda Local Government Area, Ogun State, Nigeria. Four (4) trees were randomly selected from the forty five (45) trees purposefully marked out and a speigel relascope was used to determine the following: Total height (TH), Merchantable height (MH), Diameter at breast height (DBH), and Crown depth (CD).

2.1 Selection of Specimen

Bolts of 50cm long were marked and cross- cut at six different positions along the merchantable length of each of the trees. These were (50cm above the ground) at the base and at 10%, 30%, 50%, 70% and 90% of merchantable height . The radial strips were partitioned into three zones based on the relative distance from the pith. Ring numbers 1-10 were categorized as corewood, 11-20 as middlewood and 21 – 30 as outerwood zone. The number of rings decreased vertically with corresponding increase in the width of rings which ensured effective partitioning of the wood into corewwood, middlewood and outerwood as carried out by [4].

2.2 Conversion to Test Specimen

The 10 × 40cm radial strips were converted to test specimens of standard size of 20mm × 20mm × 300mm in accordance with British Standard BS 373 using a circular saw at the workshop of the Forestry Research Institute of Nigeria, FRIN, Ibadan. The specimens were kept in a dessicator prior to testing for mechanical properties so as to prevent possible dimensional changes as a result of loss of moisture from wood.

2.3 Tests for Mechanical Properties

All test samples were converted to standard sizes of 20mm × 20mm × 300mm and 20mm × 20mm × 60mm in the workshop of the Forestry Research Institute of Nigeria using Tensometer machine according to [5]. Representatives of axial and radial directions were taken.

2.4 Determination of Modulus of Rupture

The static bending tests were carried out using Hounsfield Tensometer in accordance with British Standard Method BS 373. Seventy- two standard test specimens of 20mm×20mm ×300mm were used to test Modulus of Rupture (MOR) of the wood of *Vitex doniana*. The test samples were prepared in such a way that growth rings were parallel to one edge. Each test specimen was loaded at 0.1 mm/ sec, with the growth rings parallel to the direction of loading, (that is specimens were loaded on the radial face). The bending strength of wood usually expressed as MOR is the equivalent fibre stress in the extreme fibres of the specimen at the point of failure and was calculated using the formula as shown in equation 1:

$$MOR = \frac{3PL}{2bd^2} \left(\frac{N}{mm^2}\right) \qquad (1)$$

Where P = load in Newton (N)
L = span in (mm)
b = width in (mm)
d = depth in (mm)

2.5 Determination of Modulus of Elasticity

The Modulus of Elasticity (MOE) of the test specimens were calculated from the values obtained at the point of failure recorded during tests for Modulus of Rupture. During the MOR, a load - deflection graph was simultaneously plotted on the testing machine to provide for the calculations of delta Δ an addition to the parameters that were earlier defined in MOR. The delta was calculated using the Pythagoras rule $c^2 = a^2 + b^2$ on the deflection curve as the distance from the start of experiment to a perpendicular line drawn from the proportional limit to the absica of the graph drawn during modulus of rupture test. The MOE was then calculated using the formula as shown in equation 2 below:

$$MOE = \frac{PL^3}{4\Delta bd^3}\left(\frac{N}{mm^2}\right) \qquad (2)$$

Where P = load in Newton (N)
L = span in (mm)
b = width in (mm)
d = depth in (mm)
Δ = the deflection at beam centre at proportional limit.

2.6 Determination of Maximum Compression Strength

The maximum compressive strength parallel to grain was determined from the failed samples used for static bending tests. The sample size used was 20mm ×20mm×60mm in accordance to the provisions of BS 373. The test specimens were tested in radial compression with Housfield Tensometer. The test specimens were put on the compression cage to prevent buckling and loaded at machine speed of 0.001mm/sec until compression failure occurred. The corresponding reading of the mercury level was taken and recorded. This was divided by the cross sectional area of the test specimen to obtain value for maximum compressive strength parallel to grain (MCS//)

Maximum Compressive strength was calculated using equation 3:

$$MCS = \frac{P}{bd}\left(\frac{N}{mm^2}\right) \qquad (3)$$

Where P = load (N)
b = width in (mm)
d = depth in (mm)

2.7 Impact Bending Test

Test specimens of 20mm ×20mm×300mm were prepared in accordance to British standard BS 373 using the Hatt-Turner Impact Testing Machine at the Forestry Research Institute of Nigeria, Ibadan. In this test, a hammer of standard weight (1.5kg) dropped from increasing height of 50.8mm on to the centre of the test specimen which was supported over a span of 240mm until the specimen failed. The height at which failure occurred was recorded in meters as the height of maximum hammer drop . Seventy - two test specimens were subjected to repeated hammer blow. Test Specimens were placed in such a way that growth rings were parallel to the direction of hammer drop so as to ensure uniformity of standard as position of test specimen with respect to the direction of the growth rings affects the ultimate strength of wood [6].

III. Data Analysis

3.1 Duncan Analysis

Duncan analysis was used to compare the means so as to determine the variability between the individual tress.

3.2 Simple Linear Regression Analysis

In order to determine the extent of response of a variable Y to a change in variable X, simple linear regression analysis was employed in this study as shown in equation 4:

$$Y_1 = b_0 + b_iX_i + E_1 \qquad (4)$$

The coefficient of determination "R^2" was used to verify the suitability of the regression equations for each observation. This index measures the proportion of the variation in the dependent variable (Y) which is explained by variation in the independent variable (X).

IV. Results And Discussion

The four trees that were sampled had varying characteristics despite the fact that they were all from the same location. The variation in the characteristics of the individual trees under study is in consonance with earlier studies by [7] and [8] that parameters of trees vary from site to site and within trees. Mean IMB was 0.69m. It ranged from 0.58 at 90% MH to 0.90m at butt. Radially, IMB increased linearly from the corewood (0.582m) through the middlewood (0.679m) while the highest value (0.820m) was recorded at the outerwood. A near uniform IMB was recorded between 10% and 90% MH which could be termed as the zone of constancy. The result corroborates the observation of [8] on Douglas fir, [9] on *Pseudotsuga menziensii* and [10] on *Mastixiodendronn parachyclados.* The pattern of radial variation agrees with the findings of [11],[12] and [13] on *Triplochiton scelroxylon*, *Gmelina arborea* and *Ficus mucoso* respectively. According to [3], about 70% of the variation in the IMB of wood is as a result of height. This pattern of variation in the axial plane is traceable to the effects of high concentration of growth promoting substances in the apical meristem of young trees [3]. The results of the analysis of variance of radial variation in IMB showed that significant differences existed between wood types and this was due to the effect of age.

The mean MOR was 85.4 N/mm^2 which ranged from 80.2 N/mm^2 at 70% MH to 90.40N/ mm^2 at butt. An irregular pattern of variation of MOR was recorded in the axial plane. The MOR decreased steadily from butt to 30% MH and then increased. The inconsistency in MOR was recorded towards the crown region. Although, it was reported by [14] that MOR decreases with height, the result of this study agrees with the observation of [15]. The inconsistency in the pattern of variation of MOR along the wood of *Vitex doniana* may be due to the presence of encased knots towards the crown region of the wood. It could also be attributed to the fact that the material nature of wood makes it susceptible to changing influences, the Radial variation showed that it increased from the corewood to the outerwood as recorded in impact bending. This pattern of variation agrees with the findings of [11], [12],[13] on *Triplochiton scleroxylon*, *Ficus mucoso*, *Gmelina arborea* respectively. Variations existed between individual trees.

The mean MOE was 6380N/mm^2. Axial variation in MOE of *Vitex doniana* showed inconsistency pattern of variation. MOE increased from butt to 10% MH and then reduced gradually before increasing at the 90% MH. Interaction between the tree and sampling height on one hand and the tree and radial position on the other hand, had no significant effects. Result showed a high level of unpredictability in the crown region of *Vitex doniana.* This is against the back drop of the fact that the crown formation is uniform. According to [16], the crown region is critical for lumber because wood obtained from this zone is knotty. This is attributed to the effects of photosynthesis in the crown region being under the influence of intense activities. The radial pattern showed a steady increase from corewood to outerwood which supports the findings of [13] on *Ficus mucoso,* [12] on *Gmelina arborea,* and [11] on *Triplochiton scleroxylon*

Table 1: Summary of the Mean ± Standard Error values of selected mechanical properties

Wood Property	Tree	Mean ± S.E.	Radial Position	Mean ± S.E.	Sampling Height	Mean ± S.E.
Impact Bending	A	0.701 ± 0.006^{a}	Corewood	0.582 ± 0.005^{a}	10%	0.720 ± 0.007^{a}
	B	0.677 ± 0.006^{b}	Middlewood	0.679 ± 0.005^{b}	30%	0.702 ± 0.007^{a}
	C	0.671 ± 0.006^{b}	Outerwood	0.820 ± 0.005^{c}	50%	0.650 ± 0.007^{b}
	D	0.726 ± 0.006^{c}			70%	0.610 ± .007c
					90%	0.580 ± 0.007^{d}
					Butt	0.900 ± 0.007^{e}
Modulus of Rupture	A	84.200 ± 0.242^{a}	Corewood	74.587 ± 0.209^{a}	10%	88.300 ±0.296^{a}
	B	83.094 ± 0.242^{b}	Middlewood	85.533 ± 0.209^{b}	30%	80.400 ± 0.296^{b}
	C	83.606 ± 0.242^{ab}	Outerwood	92.633 ± 0.209^{c}	50%	82.367 ± 0.296^{c}
	D	86.106 ± 0.242^{c}			70%	80.200 ± 0.296^{b}
					90%	83.842± 0.296^{d}
					Butt	90.400 ± 0.296^{e}
Modulus of Elasticity	A	6673.183 ± 1.354^{a}	Corewood	5464.283 ± 1.173^{a}	10%	8047.700 ± 1.659^{a}
	B	6667.428 ± 1.354^{b}	Middlewood	6943.983 ± 1.173^{b}	30%	6520.967 ± 1.659^{b}
	C	6671.022 ± 1.354^{ab}	Outerwood	7608.700 ± 1.173^{c}	50%	6522.000 ± 1.659^{b}
	D	6677.656 ± 1.354^{c}			70%	5680.367 ± 1.659^{c}

Table 1 continues

Wood Property	Tree	Mean ± S.E.	Radial Position	Mean ± S.E.	Sampling Height	Mean ± S.E.
					90%	5815.200 ± 1.659^{d}
					Butt	7447.700 ± 1.659^{e}
Maximum Compression Strength	A	41.839 ± 0.239^{a}	Corewood	36.733 ± 0.207^{a}	10%	42.733 ± 0.292^{a}
	B	41.083 ± 0.239^{b}	Middlewood	42.867 ± 0.207^{b}	30%	42.900 ± 0.292^{a}
	C	41.139 ± 0.239^{ab}	Outerwood	44.775 ± 0.207^{c}	50%	41.000 ± 0.292^{b}
	D	41.772 ± 0.239^{ab}			70%	38.400 ± 0.292^{c}
					90%	34.300 ± 0.292^{d}
					Butt	49.417 ± 0.292^{e}

Mean value of maximum compressive strength was 40.8N/mm$^{2.}$ It varied inconsistently along the wood of *Vitex doniana* . The MCS// decreased from butt to 10% MH and then increased before decreasing steadily. Its value ranged from 33.8N/mm^{2} at 90% MH to 49.417N/mm^{2} at butt. The inconsistency may be due to the masking effects along the bole of *Vitex doniana*. The fact that the MCS// was lowest at the 90% MH gave an indication that the crown region suffered more from felling stress. Radially, the MCS// increased from the corewood (35.6Nmm2) to the outerwood (45.5Nmm^{2}) while 41.3Nmm^{2} was recorded at the middlewood. This result is in conformity with the report of [17] and [12].

The study showed that all the strength properties exhibited varying relationship with one another (Table 3). The best relationship existed between IMB and MCS ($R^2 = 0.75$). This agrees with the report of [11] that IMB and MCS had the best relationship ($R^2 = 0.83$). The higher value of relationship may be due to the fact that his Obeche trees were of plantation origin which was subject to maintenance and silvicultural practices. The least relationship was between MOR and MCS (R^2 = 0. 43) contrary to between IMB and MOE reported by [11]. [16] reported a high relationship between MOE and MOR in plantation grown *Tectona grandis*. The inconsistencies may be as a result of interplay between the inherent anatomical properties of the three species apart from the expected differences in the naturally grown and plantation grown species.

Table 3 : Relationship between pairs of mechanical properties of *Vitex doniana*

Pair of Properties	b_0	b_i	R	R^2	Std. Error
IMB vs MOR	-0.490	0.014	0.787	0.619	0.10238
IMB vs MOE	0.100	8.81×10^{-5}	0.771	0.595	0.10559
IMB vs MCS //	-0.223	0.022	0.867	0.751	0.08280
MOR vs MOE	48.343	0.005	0.845	0.714	5.00372
MOR vs MCS //	46.155	0.957	0.658	0.433	7.04581
MOE vs MCS //	386.134	156.991	0.696	0.484	1043.90913

$$Y_i = b_0 + b_iX_i + \mu \quad (i = 1, 2, 3)$$

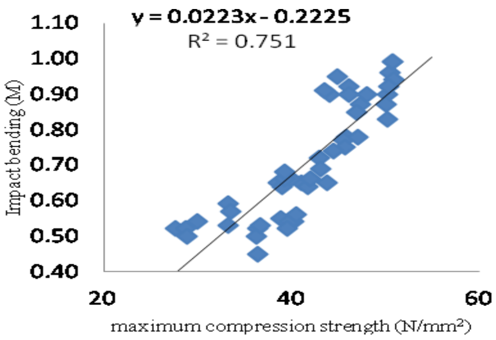

Fig. 1: Relationship between impact bending and maximum compression strength in *Vitex doniana*

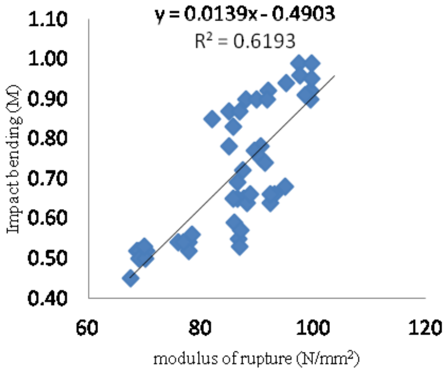

Fig. 2: Relationship between impact bending and modulus of rupture in *Vitex doniana*

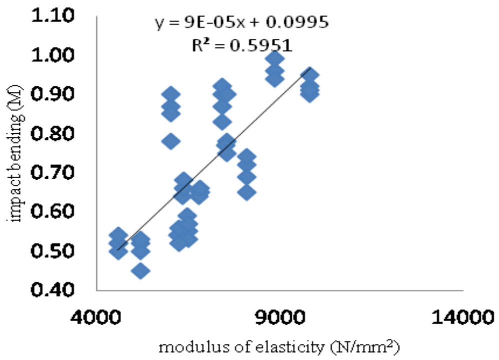

Fig. 3: Relationship between impact bending and modulus of elasticity in *Vitex doniana*

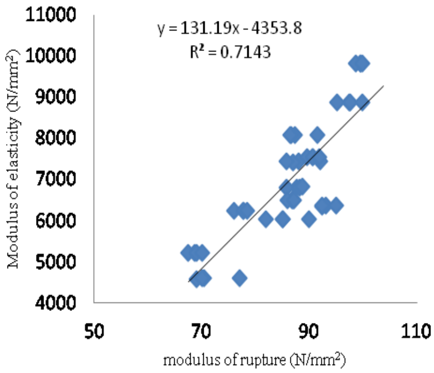

Fig. 4: Relationship between modulus of elasticity and modulus of rupture in *Vitex doniana*

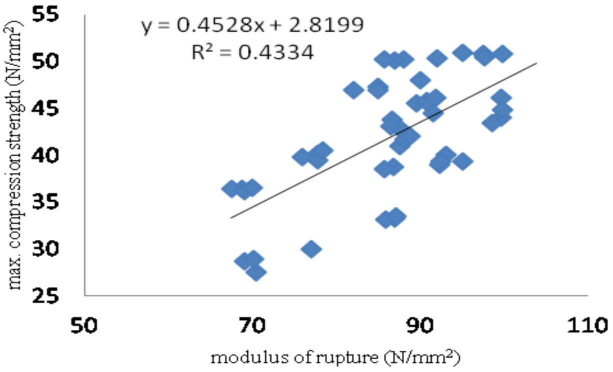

Fig. 5: Relationship between maximum compression strength and modulus of rupture in *Vitex doniana*

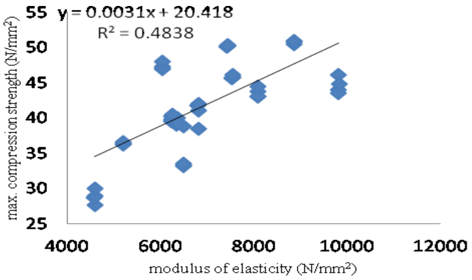

Fig. 6: Relationship between maximum compression strength and modulus of elasticity in *Vitex doniana*

V. Conclusion

Relevance of relationship between the mechanical properties cannot be overemphasized. Study of the mechanical properties showed that they exhibited values which could be found useful in both light and heavy constructions. The values recorded were in the range recorded for most economic species [18,19,20,12,11 and 13]. The wood has high IMB which makes it attractive for utilization in manufacturing of sporting equipments such as hockey sticks. The zone of constancy was between 10 and 90% MH which implies that a reasonable portion of it was relevant to utilization. Vitex could be tagged as utility wood. However, utilization for structural purposes should be limited to the zone of constancy while other portions could serve in areas with lower requirements. Strong relationship between IMB and MCS// and MOR and MOE is an indication of the utility attributes of the wood.

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