Evaluation of the Mechanical Properties of *Vitex doniana*

***Ogunjobi, K.M.* [1], *Adetogun, A.C.* [1] *and Omole, A. O.* [2]**
[*1] *Department of Forestry and Wildlife Management, Federal University of Agriculture, Abeokuta, Nigeria.*
[2] *Department of Forest Resources Management, University of Ibadan, Ibadan, Nigeria.*
ogunjobikm@funaab.edu.ng.

Abstract
Mechanical properties of *Vitex doniana* were evaluated in this study. Four (4) trees purposefully marked out at 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). Wood properties evaluated were Impact Bending (IMB), Modulus of Rupture (MOR), Modulus of Elasticity (MOE) and Maximum Compressive Strength Parallel to Grain (MCS//). The mean IMB was 0.69m. A close IMB values were recorded for samples between 10% and 90% MH which could be termed as the zone of constancy. The MOR ranged from 80.2 N/mm^2 at 70% MH to 90.40N/ mm^2 at butt and the mean value was 85.4 N/mm^2. The mean MOE was 6380N/mm^2. Inconsistent pattern of variation in MOE was observed in the axial direction. Mean MCS// was 40.8N/mm^2 and it varied inconsistently along the axial positions of the tree. MCS// decreased from butt to 10% MH and then increased before decreasing steadily with values ranging from 33.8N/mm^2 at 90% MH to 49.417N/mm^2 at the butt. *Vitex doniana* exhibited values which could be found useful in both light and heavy constructions.

Keywords: *Vitex doniana*, mechanical properties, radial variation, axial variation.

Introduction
There is an increasing gap between the demand and the supply of wood and wood products in Nigeria. According to RMRDC (2010) the total volume of useable wood in the reserved forest areas was 239, 775,500m^3 . These reported useable volume was a sharp decline in the reported volume of 473, 509, 205.943m^3 by Akindele *et al* in 2001 . With a result as this over a period of ten years, it follows that the extreme wood shortages are expected and mechanisms to curtail it should be evolved. Part of the strategies of meeting the wood shortages is the introduction of some under-utilised indigenous woods into the timber market as substitutes to those traditional economic hardwoods that are dwindling in population. *Vitex doniana* is one of the species that its wood has been greatly underutilised. Arising from the complexity of wood, its utilisation, particularly for construction purposes calls for a clear understanding of its mechanical properties.

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 external 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. Desch and Dinwoodie (1996) 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 the content of the wood. The mechanical properties of a wood are the cumulative effect of inherent attributes. The parameters that are often used in determining the strength properties of wood include Impact Bending (IMB), Modulus of Rupture (MOR), Modulus of Elasticity (MOE) and Maximum Compressive Strength Parallel to Grain (MCS//).

There has been pressure on the strong and durable species with known properties such as *Millicia excelsa*, *Khaya spp*, *Afzelia africana*, *Nauclea diderichii*, *Triplochiton scleroxylon*, *Terminalia spp* and *Cordia millenii* (Onilude and Ogunsanwo, 2002) in order to meet the increasing demand. Adekunle *et al* , 2002 reported that the rate at which the forest is being depleted due to population growth, indiscriminate logging for constructional and other purposes and farming is alarming. In order to mitigate the pressure on the aforementioned species, other species are currently being introduced into the market as sawn timber as demand for wood and its products for building and construction purposes are increasing (Oluwadare and Somorin , 2007). They also serve as a potential substitute to the endangered wood species. According to Barany *et al*, 2003, wood species that are underutilized as timber are other species which does not belong to the traditional species commonly harvested such as *Milicia excelsa*, *Entandophragma species*, *Triplochiton scleroxylon*, *Afzelia africana*, *Nesogordonia papaverifera*, *Terminalia ivorensis* , *Lovoa tichloides* etc .

The generic name " Vitex" , is an old Latin name for the genus. *Vitex doniana* (Verbanaceae) is the most abundant and widespread of the genus occurring in Savannah regions. The genus *Vitex* consists of over 270 species, predominantly trees and shrubs, and is restricted to tropical and sub tropical regions, although a few species are also found in the temperate zones (Padamalatha *et al*., 2009). Among them is *V. doniana* also called black plum. Detail of its botany is given by Agbede and Ibitoye, (2007). *V. doniana* is widely spread in tropical West Africa and extending eastward to Uganda, Kenya and Tanzania and is also grown throughout the world as ornamental and as sources of wood and unusual chemical, some of which have medicinal properties (Kapooria and Aime, 2005). *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 (Keay, 1964).

There have been great attempts to commercialise many of the underutilized wood species as this seems to be the only potent weapon against the scarcity and escalating cost of the already known species. However, there is dearth of relevant information that could enhance maximum utilization of the species. The generation of basic information on *Vitex doniana* is considered to be an excellent opportunity towards promoting more timber utilization activities.

Materials and Methods

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

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 positions were (50cm above the ground) at the base and at 10%, 30%, 50%, 70% and 90% of merchantable height . The bolts were labelled 'UP' and 'LP' representing the upper and lower portions of the test materials. The labelled portions were maintained throughout the wood conversion process. Fungal infection was prevented by spraying 5% solution of Sodium pentachlorophenate on the fresh surfaces of the processed bolts. Along the four directional planes of the surface of the bolts, strips were created and 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 core, middle and outer as done by Shupe *et al*, (1995).

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, Ibadan, Nigeria. 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. The converted test specimens were coded as North, South, West and East along the four cardinal planes of the surface of the bolts. Each plane was divided into two halves and denoted as ('a') and ('b') representing each half of the central plank. Forty (40) test samples were obtained from each of the six discs, giving a total of 960 test samples.

Tests for Mechanical Properties

All test samples were converted to standard sizes of 20mm × 20mm × 300mm and 20mm × 20mm × 60mm using Tensometer machine according to the British Standard BS 373 (1989). Representatives of axial and radial directions were taken.

Determination of Modulus of Rupture

The static bending tests were carried out using Hounsfield Tensometer. Seventy- two standard test specimens of 20mm×20mm ×300mm were used to test for the MOR. 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.

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

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

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 MOR. 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 MOR test. The MOE was then calculated using the formula in equation 2 :

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

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

Determination of Maximum Compression Strength

The maximum compressive strength parallel to grain (MCS//) 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 (MCS//)

Maximum Compressive strength was calculated with equation 3 :

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

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

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 (Dinwoodie, 1989).

Data Analysis

Data generated from the study were then subjected to statistical processing using a combination of descriptive and inferential statistics. (analysis of variance).

Results

The 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 sampling heights had significant effects on the IMB as shown in the results of the analysis of variance at 5% level of significance (Table 2). According to Panshin and dezeeuw (1980), about 70% of the variation in the IMB of wood is as a result of height. 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. MOR decreased steadily from butt to 30% MH and then increased. The inconsistency in MOR was

Table 1: The Mechanical Properties of *Vitex doniana*

Wood Property	Tree	**Mean ± S.E.**	**Radial Position**	**Mean ± S.E.**	Sampling Height %	**Mean ± S.E.**
Impact Bending	A	0.701 ± 0.006^a.	Core wood	0.582 ± 0.005^a	10	0. 720± 0.007^a
	B	0.677 ± 0.006^b	Middle wood	0.679±0.005^b	30	0.702 ± 0.007^a
	C	0.671 ± 0.006^b	Outer wood	0.820± 0.005	50	0.650 ± 0.007^b
	D	0.726± 0.006^c			70	0.610 ± 0.007c
					90	0.580 ± 0.007^d
					Butt	0.900 ± 0.007^e
Modulus of Rupture	A	84.200 ± 0.242^a	Core wood	74.587 ± 0.209^a	10	88.300 ± 0.296^a
	B	83.094 ± 0.242^b	Middle wood	85.533 ± 0.209^b	30	80.400 ± 0.296^b
	C	83.606 ± 0.242^{ab}	Outer wood	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 Elasticity	A	6673.183 ± 1.354^a	Core wood	74.587 ± 0.209^a	10	8047.700 ± 1.659^a
	B	6667.428 ± 1.354^b	Middle wood	85.533 ± 0.209^b	30	6520.967 ± 1.659^b
	C	6671.022 ± 1.354^{ab}	Outer wood	92.633 ± 0.209^c	50	6522.000 ± 1.659^b
	D	6677.656 ± 1.354^c			70	5680.367 ± 1.659^c
					90	83.842± 0.296^d
					Butt	90.400 ± 0.296^e
Maximum Compression Stress	A	41.839 ± 0.239^a	Core wood	36.733 ± 0.207^a	10	42.733 ± 0.292^a
	B	41.083 ± 0.239^b	Middle wood	42.867 ± 0.207^b	30	42.900 ± 0.292^a
	C	41.139 ± 0.239^{ab}	Outer wood	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

Table 2: Results of the analysis of variance for mechanical properties

Sources of Variation	df	Impact Bending	Modulus of Rupture	Modulus of Elasticity	Maximum Compression Strength
Tree	3	19.548**	29.656**	9.963**	2.847 NS
Radial Position	2	598.628**	1886.729**	875746.970**	413.646**
Sampling Height	5	272.446**	203.553**	309388.186**	299.538**
Tree * Radial Position	6	0.415 NS	1.718 NS	0.440 NS	0.853 NS
Tree * Sampling Height	15	1.003 NS	1.845 NS	0.438 NS	0.560 NS
Radial Position * Sampling Height	10	18.435**	61.736**	48136.614**	19.159**
Tree * Radial Position * Sampling Height	30	9.623**	3.43*	2.15N	18.694**
Error	210				
Total	281				

* = Significant at 5% level, ** =Significant at 1% level, NS = Not Significant at 5% level

recorded towards the crown region. Radial variation showed that it increased from the corewood to the outerwood as recorded for IMB.

The mean MOE was 6380N/mm^2. Axial variation in MOE showed inconsistency pattern of variation. It 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 at 5%. Result showed a high level of unpredictability in the crown region of *Vitex doniana.* The radial pattern showed a steady increase from corewood to outerwood.

The mean value of maximum compressive strength was 40.8N/mm$^{2.}$. It varied inconsistently along the wood. 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. Radially, the MCS// increased from the core wood (35.6Nmm^2) to the outerwood (45.5Nmm^2) while 41.3Nmm^2 was recorded at the middle wood.

Discussion

The four trees that were sampled had varying characteristics despite the fact that they were all from the same location. This could be adduced to inherent factors within the tree . The variation in the characteristics of the individual trees under study is in consonance with earlier studies by Shukla *et al* (1988) and Sauter (1995) that parameters of trees vary from site to site and within trees. The pattern of variation in IMB in the axial plane is traceable to the effects of high concentration of growth promoting substances in the apical meristem of young trees (Panshin and dezeeuw, 1980). 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 Sauter, (1995) on Douglas fir, Lausberg *et al* (1995) on *Pseudotsuga menziensii* and Haygreen *et al* (1982) on *Mastixiodendronn parachyclados.* The pattern of variation in MOR agrees with the findings of Ogunsanwo (2000), Adedipe (2004) and Adejoba (2008) on *Triplochiton scelroxylon*, *Gmelina arborea* and *Ficus mucoso* respectively. The inconsistency in the pattern of variation of MOR along the wood 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 pattern of variation exhibited by the MOE exhibited indicated a high level of unpredictability in the crown region of V. doniana. This is against the back drop of the fact that the crown formation is uniform. According to Sanwo (1983), 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 inconsistency in MCS// 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. The result of radial variation in MCS// is in conformity with the report of Cruz *et al* (1967) and Adedipe (2004).

Conclusion

The investigation of the mechanical properties of *Vitex doniana* is crucial to its maximum utilization. Despite the fact that the species were from an unmanaged environment, 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 (Lavers,1969, Forest Product,1976, Adedipe 2004, Ogunsanwo, 2000 and Adejoba, 2008). The wood has high IMB which makes it attractive for utilization in manufacturing of sporting equipments such as hockey sticks. The zone of constancy implies that a reasonable portion of it will be relevant to its 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. The butt could be used in the production of rail sleepers while other remnants could be used in the production of particle board and other items with low requirements in terms of strength. Maximum utilization of the wood is advocated so that wood that has taken several years to form is not subjected to waste in terms of underutilization.

References

Adedipe, O.E. (2004) : Machining and Mechanical Properties of Plantation Grown *Gmelina arborea* wood. Thesis submitted for the Award of Master of Agricultural Technology, Department of Forestry and Wood Technology, Federal University of Technology, Akure. 81p.

Adejoba, O.R (2008) : Lesser-Used Wood Species in Akure and their relevance to Sustainable Forest Management. Journal of Nigeria Environmental Society. Vol.4 No2 pp 181-186.

Adekunle,V.A., Akande, S.O. and Fuwape J.A. (2002) : Impacts of overexploitation on biodiversity yield and Sustainable Use of Tropical Rainforest Ecosystem.A case Study of Omo Forest Reserve, South West, Nigeria.Proc. of the 28th Annual Conf. Of Forestry Association of Nigeria 252-263.

Agbede, J.O. and Ibitoye, A.A. (2007). Chemical Composition of Black plum (*Vitex doniana*); an underutilized fruit. *J.Food Agric*. *Env.* 5(2**):** 95- 96.

Akindele, S.O., Dyck. J., Akindunmi, F.F, Papka, P.M, and Olaleye O.A. (2001) : Estimate of Nigeria's Timber Resources. In L Ppoola, J.E Abu and P.I. Oni ed. Proceedings of the 27th Annual Conference of the Forestry Association of Nigeria, Abuja FCT. Pp 1-11

Barany M., Hammett, A., L. Hammett and Araman P (2003) : Lesser – Used Wood Species of Bolivia and their relevance to Sustainable Forest Management. *Forest Products Journal*. 53/7(8)6p.

British Standard Institution (1989) : BS 373 Methods of Testing Clear Small Specimen of Timber.British Standard Institution, London. 20pp

Cruz, R. (1967) : Effect of Height and Pitch Orientation on Wood Strength in Panshin and dezeeuw (1980) , Textbook of Wood Technology 704pp

Desch, H.E.; revised by Dinwoodie, J.M. 1996. Timber, structure, properties, conversion, and use. 7th ed. London: MacMillan Press, Ltd.

Emila-Adela,S.;Fotin,A. and Cismaru,I.(2008). Evaluation of surface quality after profiled milling of Alder and Birch wood. Proligno Journal of Wood Engineering, Vol. 4, No.2 Pp. 57-68.

Forest Products Laboratory. (1999). *Wood Handbook: Wood as an Engineering Material.* USDA General Technical Report FPL-GTR-113. U.S. Department of Agriculture Forest Service, Madison, WI.

Haygreen, J.G. and J.L. Bowyer (1982) : Forest Product and Wood Science : An Introduction. Pub. IOWA State University Press 495pp.

Kapooria, R.G. and Aime, M.C. (2005). Report of Oliver Scitula on *Vitex doniana* in
Zambia. *Afr. J. Sci. Technol.* 3(2)**:** 57 - 60.

Lausberg, M.J.F., D.J. Cown, D.J. McConchie and J.H. Skipwith (1995) : Variation in some wood properties of Pseudotsuga menziensii provenances grown in New Zealand. New Zealand Journal of Forestry Science 25 (2) 147- 163

Lavers, G.M (1969) : The strength properties of timbres. Forest Product Research Bulletin, NO 62pp.

Ogunsanwo, O.Y. (2000) : Characterisation of wood properties of plantation Grown Obeche (Triplochiton scleroxylon K. Schum) in Omo Forest Reserve, Ogun State,Nigeria. Ph.D. Thesis. Dept. Of Forest Resources Management, University of Ibadan. 272pp.

Oluwadare, A. O and Somorin O. A (2007) : Preliminary Report on Utilization Potential of Gliricidia sepium (Jacq) Steud for timber. Research Journal of Forestry. 1: 80-85

Onilude MA & Ogunsanwo OY. (2002) : Mechanical properties of plantation grown obeche (*Triplochiton scleroxylon*) and their relationship with wood specific gravity. *Journal of Tropical Forest Products* 8: 160–167. Owonubi JJ. 1999. Forestry and update on forest production.

Padamalatha, K., Jayaram, K., Rajau, N.L., Prasad, M.N.V. and Arora, R. (2009): Ethnopharmacology and Biotechnological Significance of *Vitex, Global Sci. Books* 3 (1**):** 6 - 14.

Panshin, A.J. and C. De Zeeuw 1980. Textbook of Wood Technology Vol. 1 Fourth Edition Mc Graw- Hill Book Company 704 pp.

Purushotham, A and M.C. Tewari 1961. A preliminary note on the preparation of copper and zinc preservatives from cashew nut shell liquid. *J.Timb.Dryers preservsers Assoc. India.* **7** (3): 8-10.

RMRDC (2010) : Report on the Multidisciplinary Task Force on Wood and Wood Products Sector RMRDC. Unpublished.

Sanwo, S.K. (1983) : Variations in the wood characteristics of plantation grown teak *Tectona grandis* in Nigeria. Ph.D. Thesis, University of Wales (1983). 287pp.

Sauter, U.H. (1995) : Variation of Technological Wood Properties of Douglas fir as an expression of different growth condition. XX IUFRO World Congress Proceeding, Tempere, Finland. 512pp.

Shukla, N.A., S.S. Rajput and L. Mohan (1988) : Some Studies on Variations of strength properties from pith to periphery in Eucalyptus hybrid. Journal of Indian Academy of Wood Science 19 (1) 39- 46.

Shupe, E.T.; Choong E.T and Yang, C.H. (1995): The effects of cultural treatments on the chemical composition of plantation grown loblolly pine plantations. Wood and fibre science 28 (2) 268- 275