Mechanical Properties of *Allanblackia Floribunda* Oliv at Axial and Radial Orientations

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Abstract
The study was carried out to evaluate the Impact Strength (IMS), Compression Strength Parallel to Grain (CS//G) Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) of *Allanbackia florinunda* wood. Dimensioned specimens were tested in accordance to BS 373 (1957). The results showed that there was significant difference (P<0.05) between MOR in the axial and radial directions within trees: highest MOR at the top (63.12±1.04N/mm^2) followed by bottom (48.75±0.76N/mm^2), middle was the lowest (28.32±0.43N/mm^2): outer wood had the highest MOR of 78.75±2.21N/mm^2 followed by core wood (67.50±1.77N/mm^2) and middle wood lowest (50.63±1.32N/mm^2). MOE was highest at bottom (25836.96±2443N/mm^2) followed by top (23991.00±2258N/mm^2), middle was the lowest (13289.12±1032N/mm^2) with no significant difference (P>0.05) in the axial direction. MOE was highest at the middle wood and core wood (33219.00±1504N/mm^2) followed by outer wood (16609.41±1044N/mm^2) in the radial direction. IMS was highest at the top (0.50m), middle (0.47m), bottom (0.35m) in the axial direction with no significant difference (P>0.05) in IMS in axial direction and within trees. IMS at tangential plane showed that core wood had the highest (0.60m) followed by outer wood (0.45m) while the middle wood recorded the lowest (0.37m) with significant difference (P<0.05). Compression Strength Parallel to Grain (CS//G) was highest at middle (26.00N/mm^2) followed by bottom (20.25N/mm^2) and the top was lowest (17.97N/mm^2) axially. Tangentially, middle wood had highest CS//G of 25.50N/mm^2 followed by core wood (23.25N/mm^2) and outer wood had the lowest (18.75N/mm^2) with no significant difference (P>0.05).With these mechanical properties exhibited by the wood, it could be used where high strength in service is needed.

Keywords*:* *Modulus of Rupture, Modulus of Elasticity, Impact Strength, and Compression Strength Parallel to Grain.*

Introduction
Allanblackia floribunda is a species of flowering plant in the *Clusiaceae* family known in English as tallow tree and in Igbo as Awarra ocha that has been long used in traditional Africa medicine to treat hypertension (Bilanda, *et al.,* 2014). It is a common understory tree in rain-forests in Western Central Africa from Sierra Leone to Western Cameroon, on to the DR Congo and Uganda. The medium-size tree grows up to 30 meters tall and is evergreen and dioecious (male and female flower on another of the same species (Bilanda, *et al.,* (2014). *Allanblackia floribunda* had a straight bole, bark dark brown, patchy, slash thin, reddish at the surface, yellow beneath, exuding a sticky yellow juice and occasionally fruited (Orwa *et al.,* 2009).

Wood behaved differently under modified condition in a number of ways especially mechanical properties which confer strength on wood under applied forces, depending upon the kind of force exerted on the wood and the basic differences in the organization of wood cell (Panshin and Dezeeuw, 1980). Jessome (2007) defined force (stress) on the basis of unit area or volume. Mechanical properties of wood are its fitness and ability to resist applied or external forces (Samuel, 2004). This is any force applied outside of a given piece of material which tends to deform it. Such properties determine the use of wood for structural and building purposes and other uses of which furniture, vehicles implements, and tool handles are a few common examples.
The over-exploitation and utilization of such species at alarming rate are on the increase in Nigeria. *Allanblackia floribunda* is a lesser-used and lesser known wood species that needs to be studied to determine its suitability for structural purposes. Mechanical properties of *Allanblackia floribunda* wood at the axial and radial planes was evaluated in this study.

Material and Methods

The Study Area

The study was carried out in Marihu Ndoki at Oyigbo Local Government Area of Rivers State, Nigeria. Three matured *Allanblackia floribunda* trees were selected randomly and felled; samples collected from the bottom, middle and top along the tree merchantable height-axial direction. Some were cross-sectioned-core wood, middle wood and outer wood in radial section across the stem trimmed to 20x20x20mm, 20x20x60mm and 20x20x300m sizes-Modulus of Rupture and Elasticity, compressive strength//to grain and impact strength respectively. The samples were taken to Forestry Research Institute of Nigeria (FRIN), Ibadan for mechanical properties evaluation. The wood specimens were oven dried at 105^{o}C and conditioned to required moisture content of 19-21% in order to minimize dimensional instabilities.

Impact strength

The impact bending test was done using Hatt-Turner impact tester in accordance to BS 373 (1957). The procedure described in this project is given after Hatt-Turner impact tester BS 373.

Standard test specimen 20 x 20 x 300mm is supported over a span of 240 mm on a support radius of 15mm with spring restricted yokes fitted to arrest rebounce.

Modulus of Rupture (MOR)

The MOR was calculated using:

$$MOR = \frac{3PL}{2bd^2}$$

Where:

P = maximum load at failure (N)
L = span of the material between the supports (mm)
b = width of the material (mm)
d = thickness of the material (mm)

Modulus of Elasticity (MOE)

The Modulus of Elasticity was calculated from the values obtained at the point of failure using:

$$MOE = \frac{PL^3}{\Delta bd^3}$$

Where

P = maximum load at failure (N)
L = span of the material between the supports (mm)
b = width of the material (mm)
d = depth in (mm)
Δ = the deflection of beam at proportional load

Assessment of Maximum Compressive Strength to Grain (Cs//G).

The maximum compressive strength parallel to grain was determined as load was applied at the rate of 0.01 mm/sec until failure occurred and the corresponding force at this point was recorded.

MCS is then calculated using the formula

$$CS = \frac{P_{\max}}{ab}$$

Where

CS = compressive strength (N/mm^2)
P_{max} = maximum load (N)
a = length of sample (mm)
b = breadth of sample (mm)

Experimental Design and Data Analysis

One way analysis of variance (ANOVA) (Completely Randomized Design with four treatments and three replicates per treatment) and descriptive statistics were used to analyze the data and standard error of mean was used for mean separation.

Results

Modulus of Rupture

The results of MOR in Table 1showed that values were highest at the top (63.12±1.04 N/mm^2) followed by bottom (48.75±0.76N/mm^2), middle was the lowest (28.32±0.43N/mm^2) in the axial direction. There was significant difference ($P<0.05$) in the MOR in the axial direction, but across the trees showed no significant difference ($P>0.05$). The result for tangential plane showed that outer wood had the highest MOR (78.75±2.21N/mm^2) followed by core wood (67.50±1.77N/mm^2) while the middle wood recorded the lowest (50.63±1.32N/mm^2) in the radial direction (Table 1). There was significant difference ($P<0.05$) in modulus of rupture in the tangential direction within trees and among trees. Results showed that the wood of *Allanblackia floribunda* can withstand load perpendicular to grain (MOR) which ranged from 28.32±0.43N/mm^2 to 63.12±1.04 N/mm^2 with averages-axial 46.73 N/mm^2 and tangential 65.62N/mm^2 which is lower than that of *Allanblackia parviflora* that had 85.00N/mm^2 to 94.00N/mm^2 (Kwaku, *et al.*, 2014).

Table 1: Modulus of Rupture in Axial Direction and Tangential Section

Axial Direction	**Modulus of Rupture**
Top	63.12±1.04
Middle	28.32±0.43
Bottom	48.75±0.76
Average	46.73
Radial Section	Modulus of Rupture
Outer wood	78.75±2.21
Middle wood	50.63±1.32
Core wood	67.5±1.77
Average	65.62

Modulus of Elasticity

The modulus of elasticity (MOE) was highest at the bottom (25836.96±2443 N/mm^2) followed by top (23991.00±2258N/mm^2) while the middle was the lowest (13289.12±1032N/mm^2) in the axial direction (Figure 3). There was no significant difference ($P>0.05$) in modulus of elasticity in the axial direction and within trees.

At radial plane, the modulus of elasticity (MOE) was highest at the middle wood and core wood with the same value of 33219.00±1504 N/mm^2 followed by outer wood (16609.41±1044N/mm^2) in the radial direction (Table 2). This showed that the middle wood and core wood deflected than the outer wood. There was significant difference ($P<0.05$) in modulus of elasticity in the tangential direction and within trees.

Table 2: Modulus of Elasticity in Axial Direction and Tangential Section

Axial Direction	Modulus of Elasticity
Top	23991.00±2258
Middle	13289.12±1032
Bottom	25836.96±2443
Average	21038.66
Radial Section	Modulus of Elasticity
Outer wood	16609.41±1044
Middle wood	33219.00±1504
Core wood	33219.00±1504
Average	±27682.33

Impact Strength-Axial Plane

The impact strength (IMS) was highest at the top (0.50m) followed by middle (0.47m) while the bottom had the lowest IMS with 0.35m in the axial direction (Figure 1). There was significant difference (P>0.05) in IMS in axial direction and within trees.

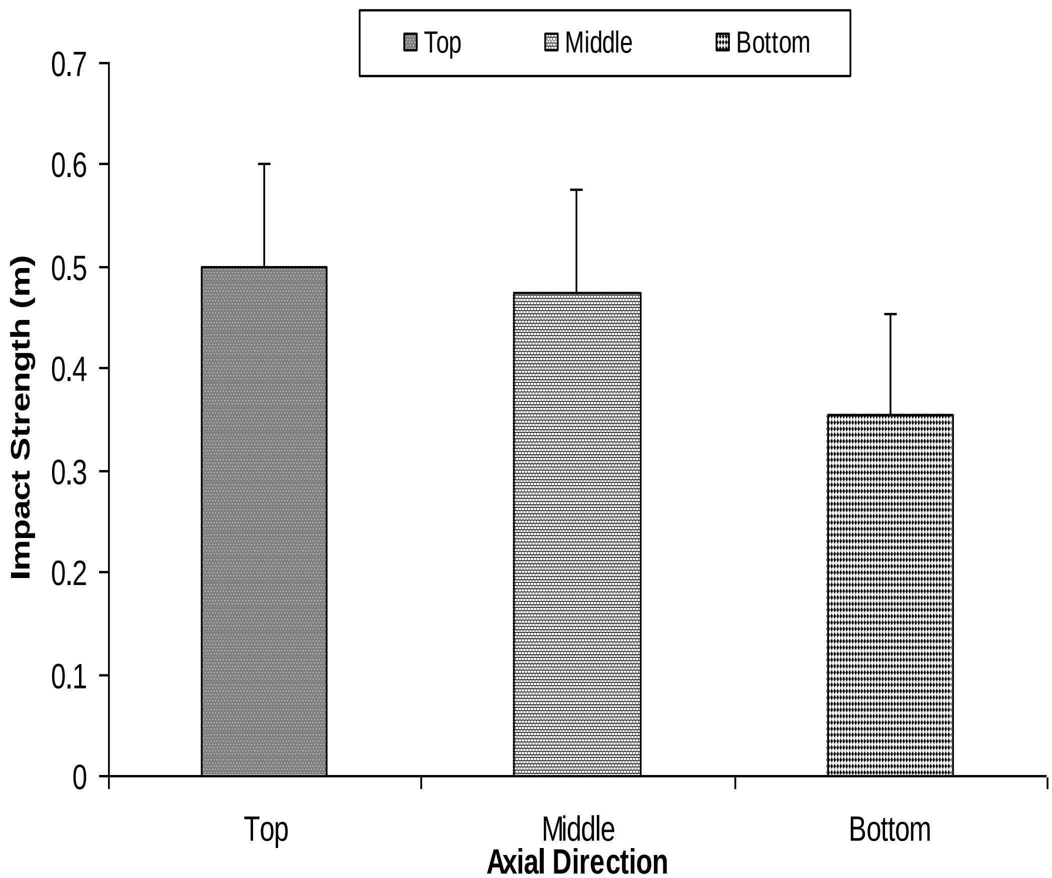

Figure 1: Impact strength in axial direction

Impact Strength Radial Plane

The IMS on the tangential plane was highest in the core wood (0.60m) followed by outer wood (0.45m) while the middle wood had the lowest (0.37m) as shown in Figure 2. There was no significant difference (P>0.05) in IMS in tangential section and within trees.

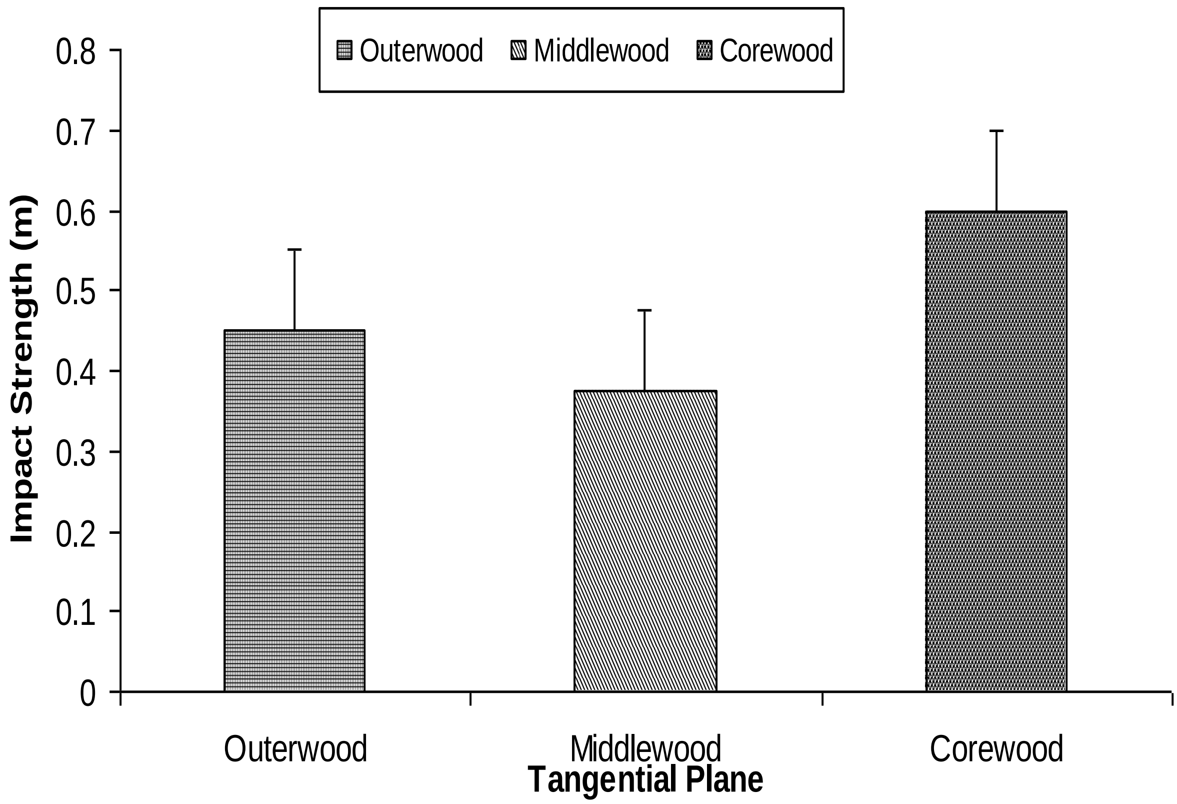

Figure 2: Impact strength in tangential plane

Compression Strength parallel to grain-Axial Plane

The compression strength parallel to grain (CS//G) was highest at middle of the trees with26.00N/mm^2 followed by bottom, 20.25N/mm^{2}while the top was lowest with 17.97N/mm^2 in the axial direction (Figure 3). There was significant difference (P<0.05) in CS//G in axial direction and within trees. Amongst the trees, tree 2 >tree 1>tree 3: 18.66, 18.56 and 17.96N/mm^2 respectively at top while in the middle tree 3>tree 1>tree 2 with 26.58, 25.91 and 25.50 N/mm^2 respectively and at the bottom tree 1>tree 2>tree 3; 20.66, 20.16 and 19.91N/mm^2 respectively (Table 1).

Table 1: Compressive strength parallel to grain in vertical direction

Tree No.	Top	Middle	Bottom
Tree 1	18.58	25.91	20.66
Tree 2	18.66	25.50	20.16
Tree 3	16.66	26.58	19.91
Average	17.96	25.99	20.34
Standard Error	2.06	1.09	1.17

Compression Strength parallel to grain-Radial Section: The result showed that compression strength parallel to grain (CS//G) was highest at middle wood with 25.50N/mm^2, followed by core wood 23.25N/mm^2 while the outer wood was lowest (18.75N/mm^2) in the radial direction (Figure 4). There was no significant difference (P>0.05) in CS//G in tangential direction and within trees.

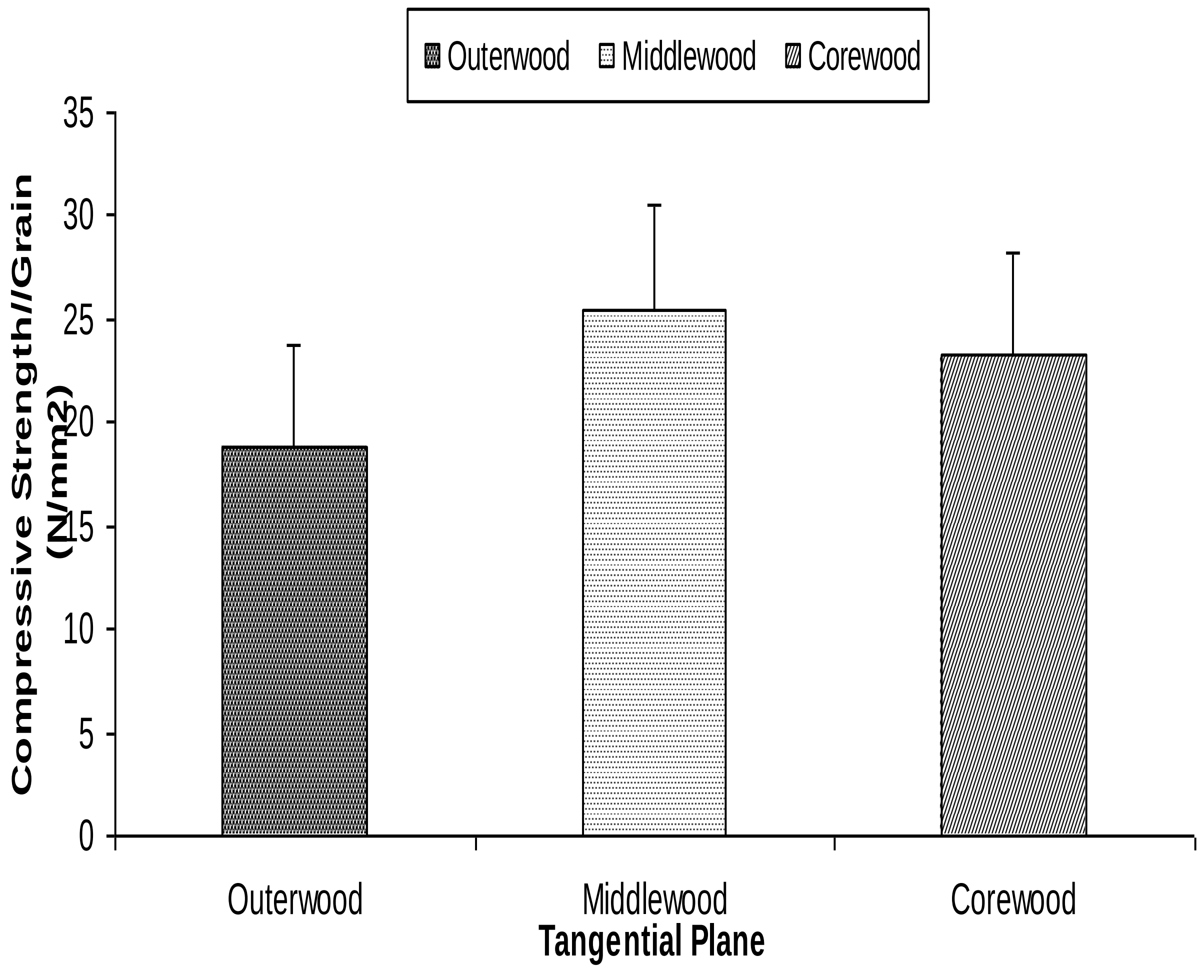

Figure 4: Compressive strength parallel to grain in radial plane

Discussion

Modulus of Rupture and Elasticity

This study showed that the topmost part of the wood is the strongest in terms of MOR and would carry much load without breaking than any other parts along the height or in vertical direction and the outer wood in radial plane equally strongest than the middle wood and core wood . This could be as a result of high sap content and growth physiological activities at the delicate and succulent parts of the tree at the top and near the bark. This was also observed in the impact strength as the top had the highest strength indicative of its capacity to withstand most pressure than other parts of the species axially.

Modulus of Elasticity which is the measure of resistance ranged from 13289.12N/mm^2 to 25836.00N/mm^2 of *Allanblacki floribunda* was higher than *Allanblackia parviflora* with 10381.00 N/mm^2 -11084.00N/mm^2 which was higher than *Terminalia ivorensis* with MOE of 8875.00N/mm^2 and 9300.00N/mm^2 respectively (Kwaku, *et al.*, 2014). There was no significant difference in the axial direction and within trees which indicated the stiffness or how much wood will deflect when a load is applied perpendicular to grain. The bottom, core wood and middle wood of the trees had the highest MOR in both axial and radial direction.

Compressive Strength parallel to Grain

The compressive strength tells you how much of load a wood species can withstand parallel to grain. How much weight will the legs of a table support before they buckle? Engineers measure the compressive strength by loading a block of wood parallel to the grain until it breaks and the bending strength by loading a block perpendicular to grain. The reliability of any wood in construction and general utilization is dependent on strength especially compressive and impact strength. Consequently, lengthwise, compressive strength of the wood was highest in the middle which corresponds with the bowl or trunk of the tree and across the cross-sections of the stems, the middle wood in the tangential section is equally strong as outer wood and core wood nearest the pith which agrees with Hoadley (1990) that there is no difference between sapwood and heartwood in strength test within some species of wood. This shows that the resistance of middle wood of the stem to failure no higher than outer wood and core wood which disagrees with Kwaku, *et al.*, (2014) that the resistance to failure of core wood of *Allanblackia parviflora* was higher than that of sap wood.

It should be noted that tangential section of wood is a longitudinal section that does not go through the center of the stem. In boards made from tangential sections, growth rings are arranged in large, irregular patterns of concentric Vs, while radial section is a longitudinal section that goes through the center of the stem (Gordon, *et al*., 2001) and axial or vertical direction is the merchantable height of the tree.

Impact Strength

The impact strength measured the ability of wood to resist suddenly applied load. In the vertical direction, the top was highest indicating that it could resist any sudden application of force which means the slenderness or flexibility of the portion to withstand load without breaking while in radial direction core wood was higher than the outer and middle woods. The no significant difference of impact strength in tangential sections agrees with the findings of Hoadley (1990) that there is no difference between sapwood and heartwood in strength test within some species of wood. This implies that any part of the wood both in the tangential and radial sections of the affected species could be used.

The Compression strength parallel to grain of *Allanblackia floribunda* had average of 23.00N/mm^2 and 25.50N/mm^2 in the axial and radial directions respectively as compared with *Allanblackia parviflora* 28.00N/mm^2 and *Terminalia ivorensis* 35N/mm^2, Aningeria altissima-54N/mm^2 (Kwaku, *et al.*, 2014).

Conclusion

The species has showed some outstanding strength properties that would enhance its general utilization characteristics. The variation amongst the various trees was significant which indicate that site or location and individual tree characteristics perhaps influenced the compressive and impact strength. The study indicated that the middle of stem along the merchantable height shows slightly stronger than the top and bottom: resistance to failure than the other parts in terms of compressive strength. Literatures provide no information in the difference between the sap wood and heartwood within some given species which was equally observed in *Allanblackia floribunda* tree studied as there was no difference between core wood, middle wood and outer wood of the stem which shows that across the wood sections of the species irrespective of the tree location: all the portions across the stems are strong. Construction engineers, wood workers and general utility should use the species particularly the middle of the stem because of its resistance to failure or breakage. Value-addition and other strength evaluations and seasoning and preservation technology research should be studied in order to elucidate other properties of the species and suitability in furniture.

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Appendices

Appendix 1: ANOVA of Modulus of rupture-between trees and within tree

Source of Variation	SS	df	MS	F	P-value	F crit
Rows (Trees)	822.5438	8	102.818	1.400946	0.268789	2.591096
Columns (Axial)	1821.044	2	910.5219	12.40632	0.000558	3.633723
Error	1174.269	16	73.3918			
Total	3817.856	26				

Test of hypothesis

1. Ho accepted since $t_{cal} < t_{tab}$: there is no significant difference (P>0.05) in modulus of rupture within trees. P value=0.2687.

2. Ho rejected since $t_{cal} > t_{tab}$: there is significant difference (P>0.05) in modulus of rupture in the axial direction within trees. P value=0.0005.

Appendix 2: ANOVA of Modulus of elasticity-between trees and within tree

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows (trees)	6.95E+08	8	86850633	1.446809	0.251549	2.591096
Columns (Axial)	1.43E+08	2	71524050	1.191489	0.329331	3.633723
Error	9.6E+08	16	60029114			
Total	1.8E+09	26				

Test of hypothesis:

1. Ho accepted since $t_{cal} < t_{tab}$: there is no significant difference (P>0.05) in modulus of elasticity among trees. P value=0.2515.

2. Ho accepted since $t_{cal} < t_{tab}$: there is no significant difference (P>0.05) in modulus of elasticity in axial direction within trees. P value=0.3293.

Appendix 3: Summary table of ANOVA of wood mechanical properties

	MOR	**MOE**
Within trees	P>0.05NS	P>0.05NS
P-value	0.2687	0.2515
Axial direction	P<0.05*	P>0.05NS
P-value	0.0005	0.3293

Significant Difference at Probability level of 0.05. P-value-probability values