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VARIATIONS PATTERN IN SELECTED MECHANICAL PROPERTIES OF STEM AND BRANCH WOODS OF *Khaya grandifoliola* (Welw.) C. DC.

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ABSTRACT
This study was conducted to evaluate variations pattern in selected mechanical properties of stem and branch woods of Khaya grandifoliola with a view to identifying its utilization potentials. Wood samples were collected from Khaya grandifoliola in the Department of Forest Resources Management, University of Ibadan, Nigeria. Khaya grandifoliola tree was felled and sectioned into main boles, primary and secondary branch woods. Fifty centimetres (50cm) length bolts were obtained from the base, middle and top of the stem, two (2) primary branch woods and four (4) secondary branch woods. Bolts from the main bole were partitioned into innerwood, middlewood and outerwood sections of the radial and longitudinal positions at base 10, middle 50 and top 90% of the tree height. Planks were also obtained from the central portion of the bolts of primary and secondary branch and were further converted into test samples. Data obtained were analysed using descriptive statistics and ANOVA. The mean value of impact bending strength of stem wood was 1970.62 J/m^2. Primary and secondary branch woods had mean values of 1778 J/m^2 and 1812.93 J/m^2, respectively. The mean value of maximum compressive strength parallel to the grain of stem wood was 43.13 N/mm^2. Primary branch wood had mean value of 43.41N/mm^2, while the secondary branch wood had mean value of 44.31N/mm^2.The mean value of Modulus of Rupture of stem wood was 65.46 N/mm^2. Primary branch woods were 66.57N/mm while the secondary branch woods were 62.88 N/mm^2. The mean value of Modulus of Elasticity of stem wood was 11468.29 N/mm^2. Secondary and Primary branch woods had mean values of 13599.76N/mm^2 and 12069.82N/mm^2 respectively. The study revealed that wood from tree branches had similar characteristics with stem wood; and would perform same functions in wooden structures.

Keywords: Impact bending strength, maximum compressive strength, modulus of elasticity, modulus of rupture, utilization.

INTRODUCTION

The demand for wood, inefficient logging and processing practices, and misuse of wood secondary resources like branch woods, shrubs, and twigs, has negatively affected the forest ecosystem, citizens and the economy of countries. The situation, has led to the turning of some forest and wood lands into deserts. The shortage of raw wood materials has subjected some wood processing and furniture production companies to either withdraw or not operating at full capacity. It has also led to loss of jobs and income to individuals, firms and the nation at large. As a result of these negative effects, search for alternatives has become one top priority problem to stakeholders in the wood industries (Cionca *et al*., 2006). The alternatives will reduce the high depletion rate of forests, woodlands and also provide raw materials to keep the remaining wood industries in business. One way of tackling the depletion rate of forest and woodlands has been the pursuit of plantation forestry which is a long term solution because even a fast-growing plantation trees take many years to mature (El-Lakany, 2004). Therefore, in addition to plantation, it is necessary for some immediate and short-term optional sources of materials like logging residues which include; branch wood, twigs, roots and shrubs. They are always available and have the potential for high value application to append stem wood and ensure complete tree utilisation, hence the need to use wood more effectively. Branch wood is a secondary resource which has a potential for high-value applications, but has been inadequately explored. Several times, branch woods of ample volume and worth are abandoned in the harvest sites partially because of inadequate knowledge of their properties and perhaps, mistaken notions on low qualities of branch wood. According to Okai *et al.* (2003), for every tree that is felled, up to 50% of its volume is left in the forest as residues in the form of branch wood, crown wood, stumps, roots and twigs. Understanding the properties of stem and branch woods will enhance its effective utilization. It is against this that this study on evaluation of selected mechanical properties of stem and branch wood of *Khaya grandifoliola* was embanked on. A study as this will contribute in widening our horizon and also open a new vista of knowledge on the usefulness of *Khaya grandifoliola* and its utilization potentials. Although, literatures contain a number of studies concerning the microscopic and macroscopic structure of branch wood compared with stem wood, there are almost no reports regarding the mechanical properties of branch wood. The utilization of stem and branches rely on their dimensions, physical and mechanical properties. Amoah and Becker (2009) conducted a study on the assessment of logging efficiency at three logging sites in Ghana and found that the Small-End Diameter (SED) of the branches, stems and main stem left at the logging sites averaged between 31 and 60 cm while the average length of the residues varied from 3.0m to 8.5 m. If the mechanical properties of branch wood are known and understood, it could potentially serve as a substitute for stem wood (Cionca *et al.,* 2006). If stem wood is a high quality material for manufacturing solid wood panels, branch wood may be used in new added-value products as an alternative to stem wood if its mechanical properties are known and understood. The knowledge of the mechanical properties of wood allows for less use of raw materials and for better optimization (Van de Kuilen *et al* 2005). The study of the properties of timber species is therefore indispensable if the species are to be selected and used in the various domains of engineering. Effective utilisation of branch wood will require knowledge of stem wood, to determine if branch wood can perform equal task as stem wood. To date, no study has been reported on the variations pattern in mechanical properties of stem and branch wood of *Khaya grandifoliola* in Nigeria. This shortcoming prompted the investigation on variations pattern of selected mechanical properties of stem and branch wood of *Khaya grandifoliola* with a view to providing database information for future utilization potentials.

MATERIALS AND METHODS

Sourcing of materials

Species for the study were obtained from the Department of Forest Resources Management, University of Ibadan, Nigeria. The experiment was conducted at normal room temperature (27±2 ^{o}C). Forest Resources Management lies between latitude 7°27′29″ and 07°26′55.87″ North and longitude 3°53′43.81″ and 3°53′54.62″ East (Adeyemi and Adesoye, 2012).

Sampling strategy

Fifty two year old *Khaya grandifoliola* tree with a height of 40 m and bole diameter of 120 cm was sectioned into main boles, primary branches and secondary branches. Fifty centimeter (50 cm) length bolts were obtained from the base, middle and top of the stem, two (2) main branches and four (4) secondary branches, which gave a total of 21 bolts. Bolts from the main bole were partitioned into inner wood, middle wood and outer wood. Central planks were also obtained from the bolts of primary and secondary branches which were further converted into test samples.

Sample preparation for mechanical properties

Wood samples of 20×20×50 cm were obtained from each central plank of *Khaya grandifoliola* stem and branch woods. Ten (10) clear specimens were selected from each zone, for the physical and mechanical properties evaluation. This gave a total of 90 samples from the stem, 60 samples from the two primary branches and 120 samples from the four secondary branches.

Plate 1: Examination of sample specimen during cross-cutting

Plate 2: Central planks where samples were obtained

Plate 3: Test Samples converted into different dimensions

The test samples were conditioned to 12% moisture content in a controlled laboratory as used by Ogunsanwo and Onilude, (2000).

Mechanical properties

The impact bending test was carried out using the Hatt-turner impact testing machine in Forestry Research Institute of Nigeria, Ibadan; following the British Standard BS 373. Standard test specimens of 20 × 20 × 300 mm were supported over a span of 240 mm on a support radius of 15 mm with spring restricted yokes fitted to arrest rebounce. The specimens were subjected to repeated blow from a weight of 1.5 kg at increasing height initially from 50.8mm, at every 25.4mm, until complete failure occurred. The height at which failure occurred was recorded in metre as height of maximum hammer drop.

The Modulus of Rupture was carried out in accordance with British Standard Method BS 373. This involves the use of standard test specimens (20 mm x 20 mm x 300 mm) after which a test sample of 20 mm x 20 mm x 20 mm were prepared to be tested for on Instron 3369 model Universal Testing Machine (UTM). The load was applied at the rate of 0.1mm/sec with the grain parallel to the direction of loading, that is, specimens were loaded on the radial face. The bending strength of wood usually expressed as b (MOR) which is the equivalent fibre stress in the extreme fibres of the specimen at the point of failure was determined from the machine. Load at failure was recorded and the corresponding PC monitored values were taken directly from the machine. The unit of MOR is N/mm^2. MOR was calculated using the formula;

$$MOR = \frac{3PL}{2bd^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where:

MOR – Modulus of Rupture (MOR)

P - Maximum load at failure (N)

L - pan of the material between the supports (mm)

b - Width of the material (mm)

d - Thickness of the material (mm)

The Modulus of Elasticity (MOE) was carried out in accordance with British Standard Method BS 373 using Instron 3369 model Universal Testing Machine (UTM). This involves the use of standard test specimens (20 mm x 20 mm x 300 mm). From the MOR test, the corresponding MOE was recorded. Load at failure was recorded and the corresponding PC monitored values were taken directly from the machine. The MOE was calculated using the formula:

$$MOE = \frac{PL^3}{4bd3\Delta} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where

P - Maximum load at failure (N)

L - Span in (mm) or Length of sample (mm)

B - Width of the sample (mm)

D - Depth or thickness of the sample in (mm)

H - thickness of the sample (mm)

Δ - the deflection at beam centre at proportional load

Delta (Δ) which is the deflection of beam centre at proportional limit is calculated as the gradient of load-deformation curve plotted during MOR test or slope of the graph.

The maximum compressive strength parallel to the grain was determined. Test specimens used for specific gravity determination were used for this test, that is, 20 mm x 20 mm x 60 mm according to BS 373, method of testing small clear specimen of timber, from where test samples of 20 mm x 20 mm x 20 mm were prepared to be used on Instron 3369 model Universal Testing Machine (UTM). Load at failure was recorded and the corresponding monitored values were taken directly from the machine. The Maximum compression parallel to grain MCS// was calculated using the formula:

$$CS = \frac{P\,max}{ab} \quad \ldots\ldots\ldots\ldots (3)$$

Where:

CS - Compressive strength

P max - Maximum load (N)

A - length of sample (mm)

B - breadth of sample (mm)

Experimental design

The experimental design adopted for the main bole was a two factor split plot with the main plot arranged in a Completely Randomised Design (CRD) with five replications. In this design, the main factor was longitudinal variations (Base, Middle and Top) while the sub-factor (B) was the radial zones (Inner, Middle and Outer) which was allotted on the main bole. Completely Randomised Design was used for the branches. Data obtained from the experiment were analysed using both inferential and descriptive analysis.

RESULTS

Impact bending strength

(Table 1) indicates the mean impact bending strength of wood samples of *khaya grandifoliola.* The mean impact bending strength recorded along the vertical axis of the main bole was 1970.62 J/m^2. The value increased from 1670.05 J/m^2 at the top to 2025.65J/m^2 at the base. While along the radial axis, the mean ranged from1847.85 J/m^2 in the outerwood to 2108.2J/m^2 in the innerwood (Table 1). Along the vertical axis, secondary branch woods recorded mean impact bending strength of 1812.93J/m^2 (Table 1). Primary branch woods recorded mean impact bending strength of 1778J/m^2 (Table 1).

Table 1: Mean Impact Bending Strength of *Khaya grandifoliola* stem wood, primary and secondary branch wood in Relation to Height and Positions in the tree

Wood Property	Wood Types	Sampling Height (%)			Pooled Mean
		Base (10%) Mean±SD	Middle (50%) Mean±SD	Top (90%) Mean±SD	
Impact Bending Strength					
	Outerwood	1885.9±828.73^{a}	2266.95±463.70^{a}	1390.65±511.17^{a}	1848±602.20
	Middlewood	1924.05±769.11^{a}	2381.25±451.81^{a}	1562.10±334.06^{ab}	1956±581.32
	Innerwood	2266.95±371.35^{a}	2000.25±398.46^{a}	2057.40b±360.19^{b}	2108±376.67
Pooled Mean		2025.65±660.37	2216.15±438.66	1670.05±478.78	1970±520.06
	Primary branch wood	1943.10±370.81^{b}	2057.40±426.44^{b}	1333.50±430.68^{a}	1778±511.00
	Secondary branch wood	1743.08±466.73^{ab}	1652.59±417.22^{a}	2043.11±542.77^{b}	1813±499.41

Values in the same column with the same letter do not differ significantly ($P \leq 0.05$).

Maximum compressive strength parallel to the grain (MCS//)

The result obtained indicates that Maximum Compressive Strength parallel to the grain (MCS//) had mean values of 43.13 N/mm^2 (Table 2). This value ranged from 45.28 N/mm^2 at the middle, 43.36 N/mm^2 at the top to 40.75N/m`m^2 at the base. Along the radial zones, MCS// ranged from 37.85N/mm^2 (innerwood), 45.39N/mm^2 (middlewood) to 46.14N/mm^2 (outerwood) respectively (Table 2). Secondary branch woods recorded mean values of 44.31% while primary branch woods recorded mean of 43.41N/mm^2 (Table 2).

Table 2: Mean Maximum Compressive Strength Parallel to the Grain of *Khaya grandifoliola* stem wood, primary and secondary branch wood in Relation to Height and Positions in the tree

Wood Property	Wood Types	Sampling Height (%)			Pooled Mean
		Base (10%) Mean±SD	Middle (50%) Mean±SD	Top (90%)	
Maximum Compressive Strength //					
	Outerwood	45.36±1.25^{b}	47.91±0.63^{b}	45.16±4.03^{a}	46.14±2.23
	Middlewood	46.04±0.32^{b}	45.9±1.04^{ab}	44.23±2.97^{a}	45.39±1.87
	Innerwood	30.84±3.30^{a}	42.02±1.81^{a}	40.7±6.29^{a}	37.85±4.55
Pooled Mean		40.75±7.50	45.28±0.94	43.36±4.73	43.13±2.88
Primary branch wood		44.64±4.52^{ab}	45.67±5.41^{b}	39.91±5.95^{a}	43.41±5.74
Secondary branch wood		44.94±8.51^{a}	43.68±8.07^{a}	44.4±5.09^{a}	44.31±7.27

Values in the same column with the same letter do not differ significantly ($P \leq 0$

Modulus of Rupture

The result obtained indicates that modulus of rupture had mean values of 65.46 N/mm^2 (Table 3). The values obtained from the axial plane were 70.24 N/mm^2 at the top, 63.62 N/mm^2 at the middle and 62.52 N/mm^2 at the base. In the radial positions, the mean values obtained ranged from 66.93 N/mm^2 in the outerwood, 66.57 N/mm^2 in the middlewood and 62.88 N/mm^2 in the innerwood (Table 3). Secondary branch woods recorded mean of 62.34N/mm^2 while Primary branch woods recorded mean values of 66.57N/mm^2 (Table 3).

Table 3: **Mean Modulus of Rupture of *Khaya grandifoliola* stem wood, primary and secondary branch wood in Relation to Height and Positions in the tree**

Wood Property	Wood Types	Sampling Height (%)			Pooled Mean
		Base (10%) Mean±SD	Middle (50%) Mean±SD	Top (90%) Mean±SD	
Modulus of Rupture					
	Outerwood	67.30±7.19^{a}	61.78±4.62^{a}	71.71±6.76^{a}	66.93±6.19
	Middlewood	62.89±17.70^{a}	70.61±7.19^{a}	66.2±10.32^{a}	66.57±11.74
	Innerwood	57.37±13.85^{a}	58.47±16.36^{a}	72.81±2.47^{a}	62.88±10.89
Pooled Mean		62.52±13.30	63.62±11.20	70.24±7.36	65.46±9.61
	Primary branch wood	69.5±14.76^{a}	67.86±9.02^{a}	62.34±17.83^{a}	66.57±14.27
	Secondary branch wood	51.58±25.33^{a}	63.71±19.80^{ab}	71.71±9.80^{b}	62.34±20.42

Values in the same column with the same letter do not differ significantly ($P \leq 0$.

Modulus of Elasticity

Modulus of elasticity recorded mean of 11468.29 N/mm^2 (Table 4). The values ranged from 15355.3 N/mm^2 to 13567.67 N/mm^2 along the axial axis table. While along the radial position the values ranged from 15679.47 N/mm^2 in the outerwood, 13407.97 N/mm^2 in the middlewood and 5317.15 N/mm^2 in the innerwood (Table 4). Primary and secondary branch woods recorded mean values of 12069.82 N/mm^2 and 13599.76 N/mm^2 respectively (Table 4).

Table 4: Mean Modulus of Elasticity of *Khaya grandifoliola* stem wood, primary and secondary branch wood in Relation to Height and Positions in the tree

Wood Property	Wood Types	Base (10%) Mean±SD	Sampling Height (%) Middle (50%) Mean±SD	Top (90%) Mean±SD	Pooled Mean
Modulus of Elasticity					
	Outerwood	15818.2±1513.28[b]	14325.8±3312.07[a]	16894.4±2754.92[a]	15679±2526.75
	Middlewood	13290.4±1196.73[ab]	13256.8±2122.77[a]	13676.7±2132.22[a]	13408±1817.24
	Innerwood	11594.4±3207.30[a]	16611.1±2232.51[a]	15494.8±2124.55[a]	5317±2521.45
Pooled Mean		13567.67±2688.79	14731.23±2818.34	15355.3±2572.23	11468±2288.48
Primary branchwood		13549.18±3594.12[a]	7257.07±2176.31[a]	15403.23±6191.55[a]	12070±4332.30
Secondary branchwood		12170.83±5695.71[a]	13775.65±4518.88[a]	14852.8±3226.89[a]	13600±4648.80

Values in the same column with the same letter do not differ significantly ($P \leq 0.05$).

DISCUSSION

The pattern of variation showed that along the vertical axis of the stem wood, Impact bending strength was high in the base; it rapidly increased in the middle and then decreased in the top giving an inconsistent pattern of variation. Along the radial zone, variations pattern shows that impact bending strength increased gradually from bark; to pith. An inconsistent variation pattern was observed in both primary and secondary branch woods of *Khaya grandifoliola* at vertical axis. Impact Bending Strength increased from the middle to the top in secondary branch woods. While in primary branch wood, it increased from the top to the middle. Like all other strength properties, inconsistent variations were found along the axial plane. Impact bending strength in stem wood was higher than in branch woods. This is contrary to the findings of Hakkila (1989) who reported that impact bending strength is higher with regard to branch wood of hardwoods, in an extensive survey of tension wood on a large number of temperate and tropical species. Furthermore, the findings of this study correlate with the findings of Hakkila, (1989) and Bowyer *et al* (2003) that tension wood has lower compressive and bending strength than normal wood.

The result obtained in this study, indicates that maximum compressive strength parallel to the grain (MCS//) was highest in the primary branch woods. It was also observed that branch wood had higher MCS// than stem wood (Table 4). Stephen *et al* (2014) reported that branch wood samples recorded compressive strength values ranging between 26.2N/mm and 52.38N/mm, with an average of 38.27N/mm in *Khaya ivorensis* branch wood. This result predicts the branch wood suitability for furniture production. Result obtained shows that MCS// increased from the base to the middle and decreased at the top along the vertical axis of the main bole. While along the radial zones, there was consistent variations pattern (Table 4). Maximum compressive strength decreased significantly from the innerwood to the outerwood. In both primary and secondary branch woods, MCS// was inconsistent in variation (Table 4). There are several causes for this radial variation pattern in the main bole, such as the relationship of strength to age of the cambium. Zobel and Buijtenen (1989) reported that juvenile wood if formed in the early stage of trees life; comprises growth rings that are formed close to the pith. Formation of juvenile wood near the pith is always associated with wood low density (Zobel and Buijetenen 1989).

It was observed that modulus of rupture generally increased from the base at merchantable height (MH) of 10% to the top at 90% merchantable height. While across the bole, Modulus of Rupture decreased gradually from outerwood to innerwood. The result of the present study also showed similar trend with species such as *A. exelsa* (Lathsamy 1998), *Michelia formosan* and *Cyclobalanopsis longinex* (Tang 1995). This radial and longitudinal variation pattern could be attributed to the relationship of strength to the age of the cambium (Zobel and Buijtenen 1989). The variations pattern along the vertical axis of the primary branch wood shows that modulus of rupture increased from the top to the base. In secondary branch wood, it increased from the base to the top (Table 6). Modulus of rupture was consistent along the vertical axis of the primary and secondary branch woods.

Results indicate that modulus of elasticity (MOE) increased from the base to the top along the vertical axis of the main bole. While along the radial zone, MOE decreased form outerwood to innerwood. The variation along the vertical axis of the branch wood indicates that modulus of elasticity increased from the middle to the top (Table 9). This shows that variation in MOR was inconsistent along the vertical axis of the primary branch wood. In secondary branch wood result indicates that modulus of rupture increased from the base to the top and it was also consistent (Table 9). The values obtained for modulus of elasticity was higher than the values recorded by Stephen *et al.* (2014) for *Khaya ivorensis.* The values of MOE from the stem wood and branch wood of *Khaya grandifoliola* were higher than that reported by Okai (2003) for *Anigeria robusta* from Ghana (12783N/mm^2). Wood maturity could have caused the big difference in value obtained from Ghana. The age of the tree sampled for this study was 52 years. The exceptionally high MOE noted at 70% sampling height is an indication of the unpredictable nature of the crown region of trees. The crown region is usually critical for lumber because wood obtained from this zone is knotty. Since it is also the region of photosynthetic activity, its properties are determined more compared with wood from the lower bole. Across the radial plane, sharp decrease in MOE from innerwood to outerwood was noted. This trend was reported by Onilude and Ogunsanwo (2002). It is believed to be determined by the extent of cell wall development. Similar trend has been observed in other hardwoods (Poku *et al*. 2001, Ogunsanwo and Onilude 2000).

CONCLUSION AND RECOMMENDATION

The study provided baseline data on the suitability of *Khaya grandifoliola* and its utilization potentials. It also provided basic useful information regarding the potentials of branch wood as a substitute for stem wood. According to Kityo and Plumptre (1997), timber for structural use should have modulus of rupture (MOR) of 39 -132 N/mm^2 and should be durable, easy to plane and nail. This implies that wood with high density and strength properties should be used for structural purposes where high strength is required. The higher the modulus of rupture values of a species, the higher the wood strength. In this study, modulus of rupture recorded mean values of 65.46 N/mm^2, 62.34N/mm^2 and 66.57N/mm^2 for stem wood, secondary branch woods and primary branch woods respectively. *khaya grandifoliola* stem wood and branch woods had properties within the specified ranges and thus can also be used for making structural elements such as tie beams, columns, rafters and purlins in house construction and other support work that requires high strength wood. Strength properties of other branch woods should be determined to find out whether they can be used as a structural raw material for furniture and other wood products. *Khaya grandifoliola* branch wood should be used by the local furniture makers and carpenters to produce furniture.

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