

PHYSICAL AND MECHANICAL PROPERTIES OF WITHIN AND BETWEEN TREES OF *GLIRICIDIA SEPIUM* (JACQ.) STEUD WOOD GROWN FOR TIMBER

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Abstract:

Wood properties of *Gliricidia sepium* were evaluated in this study. Three stands of trees were sampled at the base (10%), middle (50%) and top (90%) along merchantable length and were radially partitioned into inner wood, middle wood and outer wood, on the basis of distance from pith. The test samples were prepared in accordance to ASTM D 4442-84 (1984). Results obtained were analyzed using ANOVA at 5% level. Mean values of physical properties (Moisture content, Wood density and volumetric shrinkage) were 36.87%, 726.60kg/m³ and 7.35% respectively and mechanical properties (Modulus of Rupture, Modulus of Elasticity and Maximum Compressive strength) were 447.49, 10739.80 and 32.89N/mm² accordingly. All properties studied except moisture content decreased from base to top along longitudinal direction. Also, across the radial plane strength properties decreased from corewood to outerwood. Woods of *G. sepium* varied significantly across the radial plane and among sampled trees ($p < 0.05$) and should be treated as such in their conversion and utilization strategies. All the properties can be compared favourably with other economic species. *G. sepium* potential to be a major lesser used specie (LUS) timber and could substitute some economic species in Nigeria timber market.

Key words: *Gliricidia sepium*; Lesser-used species; radial position; axial direction; strength properties.

INTRODUCTION

Wood is a unique material that has established itself for a variety of applications despite the advent of more modern materials such as plastic, metals and concrete for being a relatively lightweight building material, wood outperforms even steel when it comes to breaking length (or self-support length), wood has a natural resistance to electrical conduction when dried to standard moisture content (MC) levels, its acoustic properties make it ideal for minimizing echo in living or office spaces and wood presents an incredible range of aesthetic options as well as provides varied mechanical, acoustic, thermal properties along with others that can be selected based on the need of the building project. It is a raw material for lumber, poles, plywood, particle board and fibreboard production (Oyagade and Fasulu 2005).

The increasing demand and dwindling supplies of tropical timber wood species in many developing countries necessitates the need to introduce lesser-used species to serve as substitutes. Accordingly, the utilization of lesser-used species is being promoted in many countries to widen the species base of the industry and to reduce the pressure mounted on the forest due to harvesting of the few currently demanded species (Shupe *et al.* 2005). The tropical forest of Nigeria, which serve as a raw material for the wood-based industry in Nigeria is decreasing at an alarming rate today and the demand for wood has continued to increase in proportion due to human population and advancement in technology. It is expected that there would continue to be high demand for wood due to its versatility and affordability over and above other construction materials. The high demand for wood would result in over-exploitation of both the natural and plantation forest with its attendant environmental consequences (Falemara 2012).

Physical properties are the quantitative characteristics of wood and its behavior to external influences other than applied forces. Familiarity with physical properties is important because they can significantly influence the performance and strength of wood used in structural applications (Jamala *et al.* 2013).

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Mechanical properties are the characteristics of a material in response to externally applied forces. They include elastic properties, which characterize resistance to deformation and distortion, and strength properties, which characterize resistance to applied loads (ASTM 1991; Jamala *et al.* 2013). With wood, strength varies significantly depending on species, loading condition, load duration, and a number of assorted material and environmental factors.

Gliricidia sepium is an exotic species introduced into Nigeria as a source of fuelwood. However, its use has been mainly for fodder, life-fencing, manure and shades (Stewart and Simons 1996). It can grow to a height of 15m if not pollarded, tolerate dry season and fire and can be propagated easily from seeds and branches (Lavin 1996 and Simons 1996). It has a distinctly dark brown heartwood and yellowish band of sapwood (Elevitch and Francis 2006). It has been mentioned by Elevitch and Francis (2006), Greijmans (2007) and Oluwadare and Somorin (2007) that the wood is good for building, construction and furniture making however there are no much quantitative data to support this claims. The provision of such data on the physical and mechanical properties of the specie will be of great significance to knowing the uses that this species could be put to. The dearth of information on the technical properties of this species perhaps is responsible for its non-availability in the timber market in Nigeria (Oluwadare and Somorin 2007).

In order to contribute to the existing knowledge, this study aims to investigate selected physical and mechanical properties of within and between trees of *Gliricidia sepium* (Jacq.) Steud wood grown in Nigeria for timber with a view to advancing technical properties for building and construction purposes.

MATERIALS AND METHODS

Three stands of trees of *G. sepium* were selected and felled based on superior phenotypic characteristics such as straight bole and absence of natural defects in the month of April, 2018 from the University of Ibadan main campus, Ibadan, Nigeria which is situated at about 5km North of Ibadan city on latitudes 7° and 27'N and longitudes 3° 54'E at an altitude of 200m. The mean annual rainfall is 1200mm with distinct wet (April - October) and dry (November - March) seasons. Mean monthly temperature is between 26-28°C with February being the hottest month (UIMP 2013). The estimated ages of the trees are 19, 20 and 21 years with a merchantable length of 4.15, 4.42 and 3.44m and diameter at breast height (DBH), 67.00, 81.10 and 70.00cm for T1, T2 and T3, respectively. Three bolts of 60cm long were collected and cross-cut into billets at base (10%), middle (50%) and top (90%) of the stems. Three (3) Discs were obtained from each billet and partitioned into corewood, middlewood and outerwood along the radial plane on the basis of position from the pith (Ogunsanwo and Onilude 2001) for determination of selected Physical properties (Moisture content, Density and Volumetric shrinkage) and Mechanical properties (Modulus of Rupture, Modulus of Elasticity and Maximum Compressive Strength). A total of 27 test samples from three (3) stands were used for the study.

Determination of Physical Properties

The test wood samples of 20mmx20mmx60mm were weighed with an electronic weighing balance. The initial weight was recorded and the test wood samples were placed in the oven at 102°C±3 for 48 hours and cooled in a desiccator containing silica gel and weighed at an interval until a constant weight was obtained. The samples were calculated in accordance to ASTM D 4442-84 (1984) using the equation: Equations 1, 2 and 3 were used to calculate the moisture content, Density and Volumetric shrinkage.

Moisture Content

$$MC = \frac{W_m - W_o}{W_o} \times 100 \quad (1)$$

where:

MC = Moisture Content;

W_m = Weight of the test wood samples before oven-drying (g);

W_o = Weight of the test wood samples after oven-drying (g).

Wood Density

The density was calculated as follows:

$$P = \frac{W_o}{V_o} \quad (2)$$

were:

P = density (kg/m³);

W_o = oven-dry weight (kg);

V_o = volume (m³).

Volumetric Shrinkage

The volumetric shrinkage is the total shrinkage in wood volume (longitudinal, radial and tangential). The volumetric shrinkage (VS) of each sample was computed using the relationship below:

$$VS = 100 - \frac{(100-Lgs)(100-Rds)(100-Tgs)\%}{10^4} \quad (3)$$

where:

VS = Volumetric shrinkage;
Tgs =Tangential shrinkage;
Rds = Radial shrinkage;
Lgs = Longitudinal shrinkage.

Determination of Mechanical Properties

The static bending tests were carried out in accordance with British Standard Method BS 373. This involves the use of standard test specimens (20mmx20mmx300mm), in a Universal testing machine. The test samples were prepared in such a way that growth rings were made parallel to one edge. The bending strength of wood usually expressed as Modulus of Rapture (MOR) which is the equivalent fibre stress in the extreme fibres of the specimen at the point of failure, Modulus of Elasticity (MOE) and Maximum Compressive strength were then calculated using the expression below:

Modulus of Rupture (MOR)

$$MOR = \frac{3PL}{2bd^2} \quad (4)$$

where:

MOR = Modulus of Rupture (N/mm²);
P = Load needed for failure;
L = Span of the material between support (length);
b = Width of the material;
d = Thickness of the material.

Modulus of Elasticity (MOE)

$$MOE = \frac{3PL}{\Delta 4bd^3} \quad (5)$$

where:

MOE = Modulus of Elasticity (N/mm²);
P = The failing load (N);
L = The specimen span between centers of support (mm);
b = Width of the specimen (mm);
d = Thickness of the specimen (mm);
 Δ = the displacement at beam centre at proportional load (Slope from the graph).

Maximum Compressive Strength (MCS) Parallel to Grain

Wood samples were loaded at the rate of 0.01mm/sec, and the corresponding forces at the point of failure were taken directly. This was divided by the cross sectional area of the test specimen to obtain value for maximum compressive strength parallel to grain.

Statistical Analysis

A one-way analysis of variance (ANOVA) was used. Data were subjected to statistical analysis of 3x3x3 factorial experiment in a completely randomized design (CRD) and Mean \pm SEM. However, a follow-up test was carried out using the least significant difference test (LSD) at 5% level of probability.

RESULTS AND DISCUSSIONS

Physical Properties

Moisture Content

Analysis of variance presented in Table 2, revealed that sampling height and sampled trees does not significantly influenced moisture content ($p>0.05$). Effect of variation among species shows that TN1 had the highest moisture content with a mean of 38.90 \pm 8.97% followed by 36.50 \pm 6.69% in TN2 and the least was found in TN3 with an average mean of 35.22 \pm 10.30% (Table 1). It was also observed that moisture content increased from base to top and it accounted for 36.87 \pm 8.81% generally, in all the sampled trees as

presented in Table 3. Also, least significant Difference (LSD) at 5% was carried which showed that moisture content of the woods at the corewood, middlewood and outerwood are significantly different as it followed same trend by increasing from 32.75±6.89% at the corewood to 42.36±9.97% at the outerwood along the radial position (Table 3).

The moisture content (36.87%) observed in this study is greater than 8.63% in same *Gliricidia sepium* reported by Oluwadare and Somorin (2007) but have same pattern of variation across the radial plane. The axial pattern of variation of moisture content increased from base to the top and and similar trend was observed in *Khaya senegalensis* (Sotannde *et al.* 2015) which is normal for trees. The mean value of moisture content in this study is also, greater than 12% often reported in literature for most hardwood species (Ogunsanwo 2000). The high moisture content could be as a result of wood anatomy, tree age and specie hence, the need to dry wood before use for efficient handling, transportation and storage. Also, the closeness of the values obtained from base to the top and corewood to the outerwood suggests that the wood can be seasoned together to make them a suitable substitute for well-known commercially exploited timber species used for structural applications.

Wood Density

The average wood density of the sampled trees stood at 726.60±86.09kg/m³. Within tree, it decreased from 725.18±59.36kg/m³ at the base to 701.05±73.60kg/m³ at the top and consistent pattern of variation was observed across the radial position as it decreased from 789.25±93.53kg/m³ at the corewood to 667.11±63.78kg/m³ at the outerwood (Table 3). Among the sampled trees, TN2 had the highest density averaged 735.27±54.96kg/m³ while TN1 had the least density (714.06±119.39kg/m³) (Table 3). Table 2 shows that there is significant difference in the sampling height and radial plane of the sampled trees (P<0.05).

The average value of 726.60kg/m³ in *G. sepium* was lower than the previous finding by Oluwadare and Somorin (2007), which reported the density to be 1025.3kg/m³ but followed same trend along the sampling height as it decreased from base to top and decreased from corewood to outerwood in the radial position. This relationship followed same pattern described by Akachukwu (1982) and Riki *et al.* (2019) who reported that wood density decreases from pith to bark axially and decreases from the corewood to the outerwood radially. The observed variation in the mean value of basic density in this study, may be due to the effect of tree age (age of cambium), environmental factor, genetic composition or silvicultural effects (Evans 1991). The mean of 726.60kg/m³ found in this study fall within the mean of most economic species in the timber market in Nigeria and West Africa coast (Ogunsanwo and Onilude 2002; Amartey *et al.* 2004).

Table 1

Mean Moisture Content and Density along the Sampling Height and Radial Position of the Sampled Trees

Parameter	Tree	Wood Type	Base	Middle	Top	Pooled Mean	
Moisture Content (%)	TN1	Corewood	33.61±3.06	34.16±3.97	34.41±7.70	34.06±4.61	
		Middlewood	36.38±3.22	35.94±3.89	35.16±4.46	35.83±3.41	
		Outerwood	53.55±12.12	41.90±8.80	45.02±12.21	46.82±10.99	
		Mean	41.18±11.37	37.33±6.28	38.19±9.13	38.90±8.97^a	
	TN2	Corewood	29.99±3.46	30.95±2.15	46.28±8.89	35.74±9.30	
		Middlewood	35.25±5.07	32.86±4.16	42.53±3.35	36.88±5.71	
		Outerwood	37.69±5.86	38.92±4.18	34.04±5.55	36.88±5.05	
		Mean	34.31±5.44	34.25±4.78	40.94±7.73	36.50±6.69^a	
	TN3	Corewood	27.64±6.75	28.37±1.62	29.33±2.05	28.45±3.69	
		Middlewood	35.22±12.56	29.46±11.10	36.80±2.52	33.83±9.11	
		Outerwood	43.53±13.43	38.31±10.30	48.33±10.77	43.39±10.93	
		Mean	35.46±11.97	32.05±8.96	38.15±10.02	35.22±10.30^a	
	Density (kg/m ³)	TN1	Corewood	736.14±16.63	953.33±217.98	728.95±31.73	806.14±156.19
			Middlewood	713.77±10.87	720.24±24.65	688.20±58.83	707.40±35.49
			Outerwood	637.77±40.81	630.30±49.00	617.87±84.45	628.64±53.63
Mean			695.89±50.08	767.96±182.97	678.34±72.58	714.06±119.39^a	
TN2		Corewood	801.59±35.52	763.63±55.44	775.88±49.64	780.37±44.51	
		Middlewood	739.54±42.01	746.20±49.48	687.94±9.70	724.56±42.89	
		Outerwood	733.74±44.86	717.68±29.78	651.27±19.25	700.90±47.46	
		Mean	758.29±48.17	742.50±44.78	705.0361.71	735.27±54.96^a	
TN3		Corewood	752.49±54.50	808.65±30.42	782.57±4.50	781.24±39.64	
		Middlewood	736.74±83.63	723.50±77.09	754.83±27.07	738.36±62.03	
		Outerwood	674.83±51.13	718.63±59.62	621.94±85.31	671.80±71.55	
		Mean	721.36±66.40	750.26±67.29	719.78±86.81	730.47±72.61^a	

*Means± Standard error of mean of 3 replicate samples. TN 1, 2 and 3 = Tree number 1, 2 and 3

Table 2

Anova results of Physical Properties of the Sampled Trees				
Sources of Variation	Degree of Freedom	MC (%)	Density (kg/m ³)	Vs (%)
Tree (T)	2	0.188 ^{ns}	0.445 ^{ns}	0.001 [*]
Sampling Height (SH)	2	0.086 ^{ns}	0.014 [*]	0.677 ^{ns}
Radial Position (RP)	2	0.001 [*]	0.001 [*]	0.017 [*]
T*SH	4	0.394 ^{ns}	0.261 ^{ns}	0.717 [*]
T*RP	4	0.044 ^{ns}	0.199 ^{ns}	0.890 ^{ns}
SH*RP	4	0.507 ^{ns}	0.288 ^{ns}	0.133 [*]
T*SH*RP	8	0.402 ^{ns}	0.089 ^{ns}	0.152 ^{ns}
Error	54			
Total	80			

*p-values > 0.05 are not significant

Table 3

Effect of Variation in sampled trees, Sampling Heights and Radial position of Physical Properties

Sources	MC (%)	Density (kg/m ³)	VS (%)
Sampling Height			
Base	36.98±10.12 ^a	725.18±59.36 ^{ab}	7.59±1.59 ^a
Middle	34.54±6.98 ^a	753.57±111.49 ^a	7.23±2.09 ^a
Top	39.10±8.76 ^a	701.05±73.60 ^b	7.24±2.39 ^a
Radial Position			
Corewood	32.75±6.89 ^a	789.25±93.53 ^a	6.73±2.07 ^a
Middlewood	35.51±6.39 ^a	723.44±47.21 ^b	7.23±1.76 ^b
Outerwood	42.36±9.97 ^b	667.11±63.78 ^c	8.10±2.07 ^b
Pooled Mean	36.87±8.81	726.60±86.09	7.35±2.03

MC= Moisture content, Density and Vs = Volumetric shrinkage. *Means± Standard error of mean of 3 replicate samples. Values with the same alphabet in each column are not significantly different at $\alpha = 0.05$

Volumetric shrinkage

The volumetric shrinkage is the total shrinkage in wood volume and it amounted to 7.35±2.03% of the stem wood volume. It decreased from 7.59±1.59% at the base to 7.23±2.09% at the middle and later increased to 7.24±2.39% at top of the stem height and followed similar trend as it increased from corewood (6.73±2.07%) to outerwood (8.10±2.07%) in Table 3. Among trees, TN3 had the highest volumetric shrinkage of 8.64±1.67% while TN1 had the least of 6.38±1.54% (Table 4). Table 2 show that there is significant difference in the sampled trees and radial direction ($P < 0.05$).

The volumetric shrinkage of 7.35% in this study approximately agrees with 6.90% reported in same specie by Oluwadare and Somorin (2007). The pooled mean of volumetric shrinkage (7.35%) obtained is moderate for a denser wood like *G. sepium* compared to other lesser used species. It is most likely that the wood will be stable in service and this may be one of the reasons why the wood seasons very well with little or no defect. The pattern of variation along the longitudinal direction which decreased from base to top is not in consonance with the work of Riki *et al.* (2019) and Sotannde *et al.* (2015) in other hardwood species but the radiation pattern of variation agrees with the work of Oluwadare and Somorin (2007). This wood could be useful for exterior purposes as claimed by Quintanar *et al.* 1997, Elevitch and Francis (2007), Greijman, (2007) and Oluwadare and Somorin (2007).

Table 4

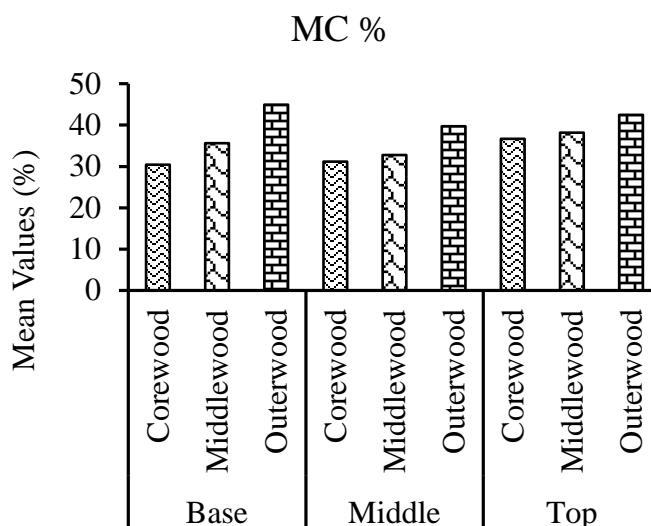
Mean Volumetric Shrinkage (Vs) and Modulus of Rupture (MOR) along the Sampling Height and Radial Position of the sampled trees

Parameter	Tree	Wood Type	Base	Middle	Top	Pooled Mean
Volumetric Shrinkage (%)						
TN1		Corewood	5.87±1.03	5.13±1.26	6.65±0.71	5.88±1.11
		Middlewood	7.13±0.69	4.84±0.76	7.05±1.93	6.34±1.57
		Outerwood	6.79±0.76	7.84±2.13	6.17±2.53	6.93±1.85
		Mean	6.60±0.92	5.94±1.93	6.62±1.67	6.38±1.54^a
TN2		Corewood	6.44±1.63	8.11±2.44	4.46±2.69	6.34±2.54
		Middlewood	7.78±1.62	5.63±1.70	6.44±1.85	6.62±1.77
		Outerwood	8.66±0.77	7.10±1.96	8.70±2.74	8.15±1.90
		Mean	7.63±1.55	6.95±2.09	6.53±2.82	7.04±2.17^a
TN3		Corewood	8.87±2.71	8.68±0.64	6.35±0.80	7.97±1.89

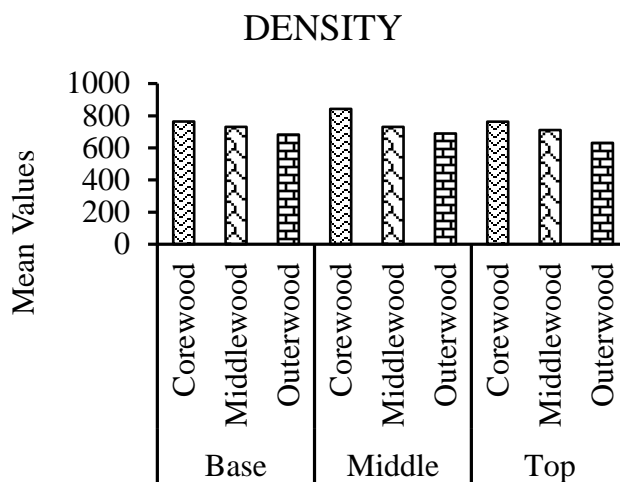
MOR (N/mm ²)		Middlewood	8.46±0.90	8.40±0.44	9.33±0.73	8.73±0.77
		Outerwood	8.33±1.74	9.32±2.01	10.01±2.57	9.22±1.99
		Mean	8.55±1.69	8.80±1.15	8.56±2.19	8.64±1.67^a
	TN1	Corewood	477.83±4.61	478.80±12.54	452.25±8.19	469.63±15.21
		Middlewood	462.98±20.93	455.25±6.73	447.53±19.01	455.25±16.00
		Outerwood	455.55±19.92	449.85±11.24	446.18±12.54	450.53±13.67
		Mean	465.45±17.62	461.30±16.12	448.65±12.41	458.47±16.61^a
	TN2	Corewood	445.58±20.40	445.28±15.92	454.05±18.95	448.30±16.50
		Middlewood	437.33±20.73	425.85±28.58	453.98±32.86	439.05±27.05
		Outerwood	433.50±24.17	412.88±18.00	449.48±18.85	431.95±23.84
	Mean	438.80±19.65	428.23±23.41	452.50±21.22	439.77±23.03^b	
TN3	Corewood	453.90±7.02	454.43±14.95	448.65±27.13	452.33±16.12	
	Middlewood	446.48±32.40	445.28±15.62	441.15±15.16	444.30±19.66	
	Outerwood	432.53±6.51	440.55±29.93	435.23±23.53	436.10±19.63	
	Mean	444.30±19.33	446.75±19.44	441.68±20.34	444.24±19.05^b	

^aMeans± Standard error of mean of 3 replicate samples. TN 1, 2 and 3 = Tree number 1, 2 and 3

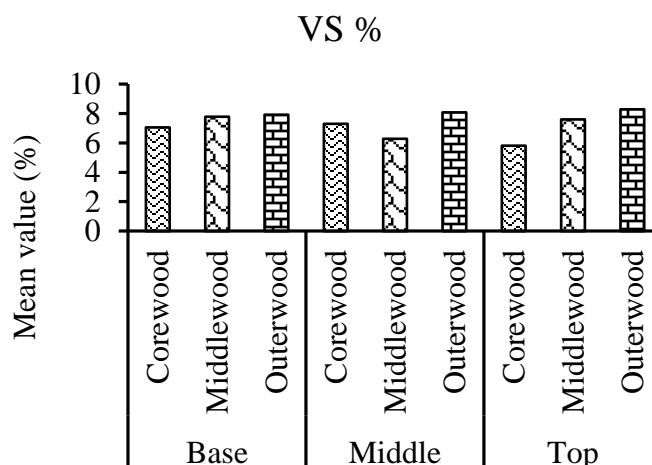
The trends of the variation in axial and radial directions within and between trees of *G. sepium* for physical properties are shown in the Fig. below to further support the claims of the results discussed in the Tables above.



a.



b.



c.

Fig. 1.

Trend showing the mean radial and axial variations in Moisture content (%) in: a. - Wood density (kg/m^3); b. - Volumetric shrinkage (%); c. - within and between trees of *G. sepium*.

Mechanical Properties

Modulus of Rupture (MOR)

As shown in Table 6, the sampled trees and radial plane varies considerably among the sample ($P < 0.05$). The averaged MOR did not follow a particular pattern as decreased from $449.52 \pm 21.59 \text{N/mm}^2$ at base to $445.35 \pm 23.62 \text{N/mm}^2$ at the middle and later increased to $447.61 \pm 18.28 \text{N/mm}^2$ at the top along the longitudinal direction but followed a consistent pattern of variation as decreased from $456.75 \pm 18.00 \text{N/mm}^2$ at the base to $439.53 \pm 20.41 \text{N/mm}^2$ at the top across the tree. Averagely bark accounted for $447.49 \pm 21.08 \text{N/mm}^2$ of the stem cross section (Table 7). Among the tree samples, TN1 has the highest MOR while TN2 had the least (Table 4).

The results obtained from the Modulus of Rupture (MOR) 447.49N/mm^2 is higher than 119N/mm^2 previously reported by Oluwadare and Somorin (2007) but followed same pattern of variation as it decreased from corewood to outerwood across the radial plane and it was also observed that MOR generally, decreased along the axial direction from base to top. The pattern of variation observed in this study conforms to the statement of Panshin and deZeeuw (1980) and the findings of Malan (1989), Biblis (1990), Onilude and Ogunsanwo (2002), Ogunsanwo and Akindede (2011) and Adejoba *et al.* 2016. The average value of MOR (447.49N/mm^2) in this study is greater when compared with that of the average value for *Celtis mildbraedii*, *Azelia Africana*, *Khaya ivorensis*, *Meliceae excels* and *Triplochiton scleroxylon* as *Milicia excelsa*, *Khaya senegalensis*, *Khaya Ivorensis* and *Cordia millenii* 149.94, 136.71, 94.82, 90.41 and 30.87N/mm^2 respectively as earlier reported by Jamala *et al.* (2013). This implies that *G. sepium* can substitute these species where stiffness of wood is important.

Modulus of Elasticity (MOE)

Similarly, there is significant difference in Modulus of Elasticity (MOE) and radial position among the tree samples ($P < 0.05$) (Table 6). The MOE decreased from the base to the top with values of 10788.40 ± 518.27 , 10688.40 ± 566.85 and $10742.60 \pm 438.69 \text{N/mm}^2$ obtained at the base, middle and top of the sampled stems respectively and consistent pattern of variation was observed across tree stems as it decreased from corewood ($10962.00 \pm 6.89 \text{N/mm}^2$) to outerwood ($10548.60 \pm 489.94 \text{N/mm}^2$) in Table 7. Overall, MOR accounted for $10739.80 \pm 505.93 \text{N/mm}^2$ of the stem (Table 7). Among trees, TN1 had the highest MOR ($11003.20 \pm 398.66 \text{N/mm}^2$) while TN2 had the least ($10554.40 \pm 552.67 \text{N/mm}^2$) (Table 5). Fig. 2 also, shows the averaged mean of MOE in all sampled trees both axially and radially.

G. sepium had a MOE with a mean value of 10739.80N/mm^2 which is also much higher than 6629.20N/mm^2 earlier reported in same specie by Oluwadare and Somorin (2007) but similar trend was observed across the radial position as the MOE decreased from corewood to outerwood. The pattern of variation observed in this study also, conforms to that of Onilude and Ogunsanwo (2002). It was observed that, samples collected at the base produced the highest mean as MOE decreased from base to top. It means samples collected at the base were the stiffest. These findings are similar to that of Ojo *et al.* (2012) and Asafu-Adjaye *et al.* (2013) that there is variation along and across the bole of *Borassus aethiopum* from Nigeria and Ghana, respectively. The variation at middle and top could be as a result of reaction wood.

Generally, the Modulus of elasticity (bending strength) of *G. sepium* is more superior to many hardwood species earlier reported by literatures. This implies that the wood is better implored when elasticity is considered important due to the nature of its elastic ability to resist plastic deformation or when materials needed that produced deformations by low stress with completely recoverable after loads are removed.

Maximum Compression Strength (MCS) Parallel to Grain

As shows in Table 6, significant differences existed among the sampled trees ($P < 0.05$). The compressive strength increased from $32.26 \pm 6.95 \text{ N/mm}^2$ at the base to $34.38 \pm 5.88 \text{ N/mm}^2$ at the top with a slight decreased at the middle along the sampling height and followed same irregular pattern across the radial plane as decreased from $34.07 \pm 7.51 \text{ N/mm}^2$ at the corewood to $32.78 \pm 6.02 \text{ N/mm}^2$ at the outerwood. Overall, compressive strength accounted for 32.89 ± 6.88 of the sampled trees (Table 7). Among trees, TN1 had the largest compressive strength averaged $35.94 \pm 4.96 \text{ N/mm}^2$ while TN2 had the least averaged 28.36 ± 7.23 of the total stem (Table 5). Fig. 2 shows the trend of average mean of compressive strength in all the sampled trees.

The maximum compressive strength of *G. sepium* (32.89 N/mm^2) parallel to grain observed in this study is lower than 34.69, 46.35 and 51.51 N/mm^2 for age 18, 28 and 36 in Nigerian grown *Gmelina arborea* (Ogunsanwo and Akindele 2011). Contrary, there was general increased from base to top along the sampling height which could be as a result of environmental factors and similar decreased from corewood to outerwood was found in strength properties of *G. sepium* (Oluwadare and Somorin 2007), though opposes the trend observed in *Gmelina arborea* by Ogunsanwo and Akindele (2011) which increased from pith to bark. It should be noted however that there is increase in wood properties with age but some sections along the vertical axis of the trees in the lower age category would be found to be technically superior in quality than woods in older trees as a result of their position along the bole.

Table 5

Mean values for Modulus of Elasticity (MOE) and Compressive Strength along Sampling Height and Radial Position of the selected species

Paramter	Tree	Wood Type	Base	Middle	Top	Pooled Mean
MOE (N/mm²)						
TN1		Corewood	11467.80±110.71	11491.20±301.05	10854.00±196.49	11271.00±365.09
		Middlewood	11111.40±502.21	10926.00±161.49	10740.60±456.20	10926.00±383.90
		Outerwood	10933.20±477.96	10796.40±269.69	10708.20±301.05	10812.60±328.01
		Mean	11170.80±422.85	11071.20±386.96	10767.60±297.88	11003.20±398.66^a
TN2		Corewood	10693.80±489.60	10686.60±382.14	10897.20±446.11	10759.20±396.12
		Middlewood	10495.80±497.46	10220.40±685.83	10895.40±788.55	10537.20±649.08
		Outerwood	10404.00±580.15	9909.00±431.90	10787.40±452.32	10366.80±572.17
		Mean	10531.20±471.58	10272.00±561.79	10860.00±509.24	10554.40±552.67^b
TN3		Corewood	10893.60±168.56	10906.20±358.86	10767.60±651.12	10855.80±386.90
		Middlewood	10715.40±777.48	10686.60±374.86	10587.60±363.94	10663.20±471.94
		Outerwood	10380.60±156.17	10573.20±718.20	10445.40±564.72	10466.40±471.15
		Mean	10663.20±463.89	10722.00±466.66	10600.20±488.25	10661.80±457.32^b
Compressive Strength (N/mm²)						
TN1		Corewood	40.34±2.18	39.46±4.64	37.64±4.97	39.15±3.76
		Middlewood	34.94±7.85	36.41±5.60	29.73±4.48	33.69±6.12
		Outerwood	37.02±2.61	36.18±2.32	31.73±1.90	34.98±3.16
		Mean	37.43±4.88	37.35±4.14	33.03±4.98	35.94±4.96^a
TN2		Corewood	26.90±8.90	26.15±14.09	38.45±3.37	30.50±10.39
		Middlewood	26.31±2.23	22.99±2.91	31.23±0.72	26.84±4.05
		Outerwood	25.49±4.76	26.20±3.76	31.50±8.93	27.73±6.10
		Mean	26.23±5.20	25.11±7.60	33.73±5.96	28.36±7.23^b
TN3		Corewood	31.60±6.22	32.64±3.23	33.41±2.96	32.55±3.88
		Middlewood	29.64±2.42	32.63±8.28	42.66±5.47	34.98±8.23
		Outerwood	38.10±5.83	35.73±5.47	33.06±7.32	35.63±5.97
		Mean	33.12±5.83	33.67±5.44	36.38±6.73	34.39±5.97^a

*Means± Standard error of mean of 3 replicate samples. TN 1, 2 and 3 = Tree number 1, 2 and 3

Table 6

Anova results of Mechanical Properties (N/mm²) of the selected species

Sources of Variation	Degree of Freedom	MOR	MOE	Compressive Strength
Tree (T)	2	0.003	0.003	0.001
Sampling Height (SH)	2	0.738 ^{ns}	0.738 ^{ns}	0.259 ^{ns}
Radial Position (RP)	2	0.008*	0.008*	0.360 ^{ns}
T*SH	4	0.048 ^{ns}	0.048 ^{ns}	0.011*
T*RP	4	0.992 ^{ns}	0.992 ^{ns}	0.223 ^{ns}
SH*RP	4	0.748 ^{ns}	0.748 ^{ns}	0.555 ^{ns}
T*SH*RP	8	0.996 ^{ns}	0.996 ^{ns}	0.486 ^{ns}
Error	54			
Total	80			

*p-values > 0.05 are not significant

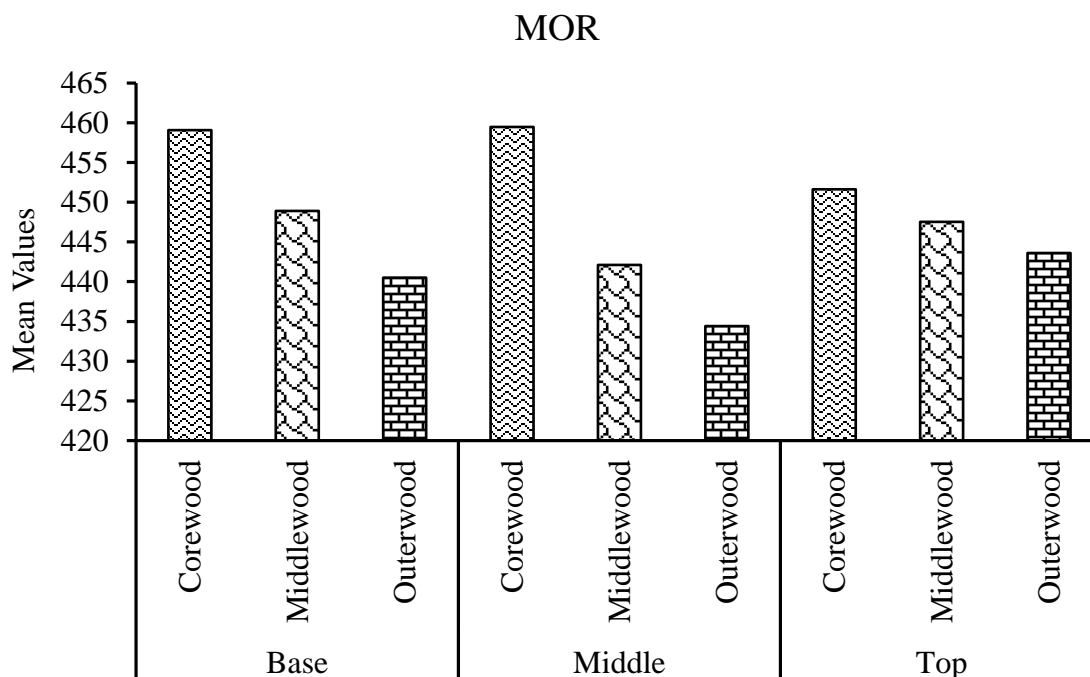
Table 7

Effect of Variation in Tree species, Sampling Heights and Radial position of Mechanical Properties (N/mm²) of the sampled trees

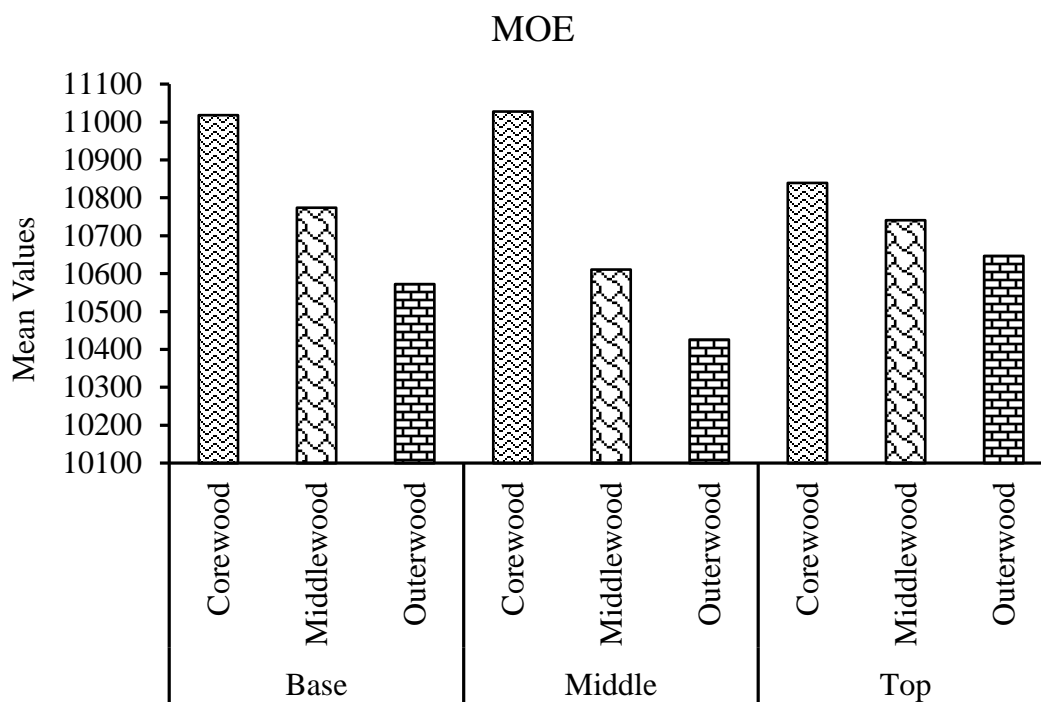
Sources	MOR	MOE	Compressive Strength
Sampling Height			
Base	449.52±21.59 ^a	10788.40±518.27 ^a	32.26±6.95 ^a
Middle	445.35±23.62 ^a	10688.40±566.85 ^a	32.04±7.71 ^a
Top	447.61±18.28 ^a	10742.60±438.69 ^a	34.38±5.88 ^a
Radial Position			
Corewood	456.75±18.00 ^a	10962.00±6.89 ^a	34.07±7.51 ^a
Middlewood	446.20±21.68 ^{ab}	10708.80±520.34 ^{ab}	31.84±7.12 ^a
Outerwood	439.53±20.41 ^b	10548.60±489.94 ^b	32.78±6.02 ^a
Pooled Mean	447.49±21.08	10739.80±505.93	32.89±6.88

MOR = Modulus of Rupture, MOE = Modulus of Elasticity and CS= Compressive strength. *Means± Standard error of mean of 3 replicate samples. Values with the same alphabet in each column are not significantly different at α = 0.05

The trends of the variation in axial and radial directions within and between trees of *G. sepium* for mechanical properties are shown in the Fig. below, which further support the claims of the result discussed in Tables above.

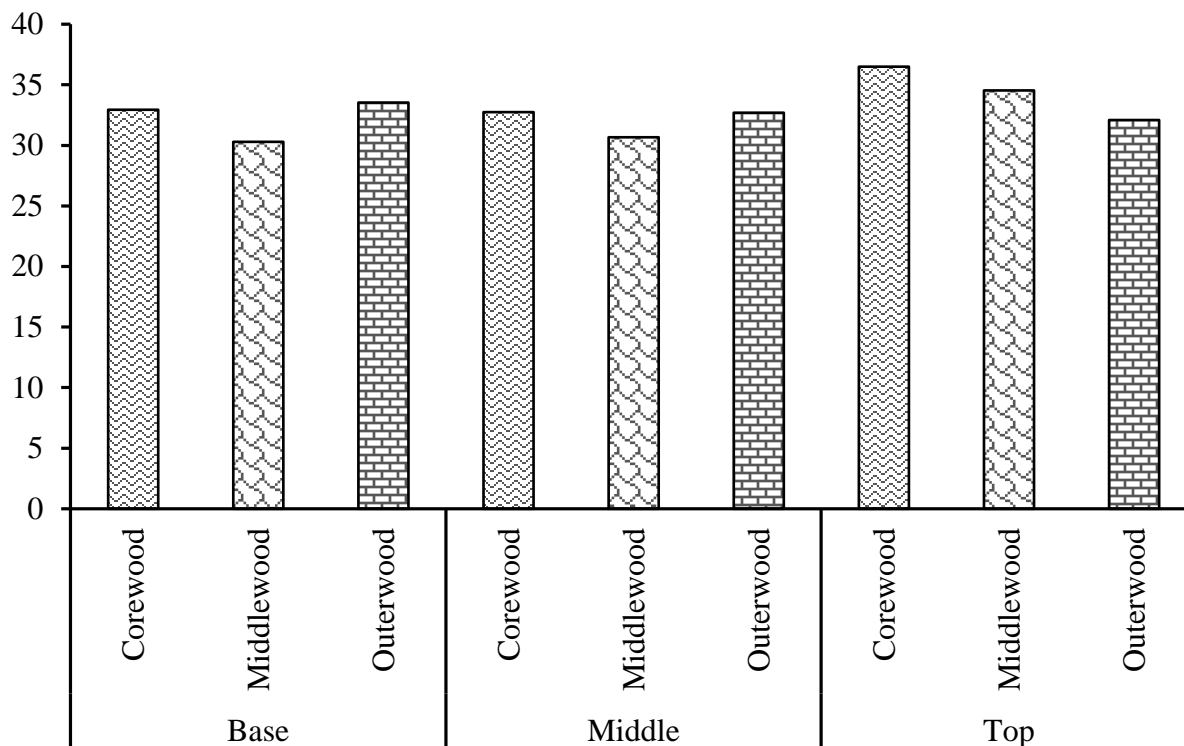


a.



b.

Maximum Compressive Strength



c.

Fig. 2.

Trend showing the mean radial and axial variations in Modulus of Rupture a., Modulus of Elasticity b. and Compressive strength c. (N/mm^2) within and between trees of *G. sepium*.

Comparison of mean values of *Gliricidia sepium* with other species

Table 8 shows a comparison of mean values of *G. sepium* with other durable wood species. The Density, MOR, MOE and MCS of the species compared favourable with other species except the moisture content which is high, Hence, the need to dry wood before use. The wood species shows that strength of a timber depends on its species and hence different wood species have different strength characteristics.

Wood increases in strength (physical and mechanical properties) as it dries. i.e the compressive strength is about twice as great for about moisture content 12% from green wood condition to any level about fibre saturation point (FSP) does not affect most strength properties (Brémaud *et al.* 2013).

Table 8

Comparison of mean values of *Gliricidia sepium* with other species

Parameter	<i>Gliricidia sepium</i>	<i>Azelia African*</i>	<i>Celtis mildbraedi*</i>	<i>Meliceae excels*</i>	<i>Khaya ivorensi*</i>	<i>Triplochiton scleroxylon *</i>	<i>Khaya senegalensis **</i>
MC (%)	36.87	12.3	12.4	12.6	13.3	12.2	NA
Density (kg/m³)	726.60	823.81	732.32	650.41	525.83	372.46	780
VS (%)	7.35	7.57	12.94	9.19	7.57	6.90	NA
MOR (N/mm²)	447.49	136.71	149.94	90.41	94.82	30.87	86
MOE (N/mm²)	10739.80	6313.58	7088.69	5765.63	8192.54	3937.5	8120
MCS (N/mm²)	32.89	NA	NA	NA	NA	NA	54

Sources: *Jamala *et al.* (2013), **CIRAD (2009). MC= Moisture content, MOR = modulus of rupture, MOE = modulus of elasticity, MCS = Maximum Compression strength parallel to grain.

CONCLUSION AND RECOMMENDATIONS

The study was able to show that wood properties of *G. sepium* decreased significantly from base to top along merchantable length and decreased from corewood to outerwood except for moisture content. Wood processors should take note of this important finding in strategising for efficient wood utilization. It may be necessary therefore to match wood of the same species on the basis of quality index so as to reduce variability within and between trees. The density of the wood is high and could be put into useful purposes where heavy wood is needed for construction. The mechanical properties were comparable and superior to other hardwood species and thus make it a potential substitute to those over-exploited species that are fast disappearing from the timber market for building and construction purposes. There would be need to investigate the anatomical and chemical properties of the wood and how this relate to strength properties.

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CONFLICT OF INTEREST STATEMENT

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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