ASSESSMENT OF PHYSICAL AND MECHANICAL PROPERTIES OF THREE HARDWOOD SPECIES FROM TIMBER SHEDS IN MAKURDI, BENUE STATE, NIGERIA

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Abstract

This study investigated the physical and mechanical properties of selected hardwood species from Timber Sheds in Makurdi, Benue State, Nigeria. The selected wood species are Vitellaria paradoxa, Khaya senegalensis and Anogeissus leiocarpus and they were tested for physical and mechanical properties. Vitellaria paradoxa had highest density (1.27 g.cm^{-3}) while, Anogeissus leiocarpus and Khaya senegalensis had density of 1.15 g.cm^{-3} and 1.09 g.cm^{-3} respectively. Vitellaria paradoxa had highest (15.17%) Volumetric Shrinkage and Volumetric Swelling of 6.61%. Compression parallel to the grain was highest (0.23 N.mm$^{-2)}$ in Anogeissus leiocarpus while Vitellaria paradoxa and Khaya senegalensis had 0.17 N.mm^{-2} respectively. Vitellaria paradoxa had the maximum (10.78 N.mm^{-2}) compression perpendicular to grain and Khaya senegalensis had the least of 0.73 N.mm^{-2}. Anogeissus leiocarpus had highest (17,511.61 N.mm^{-2}) mean of MOE, Vitellaria paradoxa (14,916.90 N.mm^{-2}) and Khaya senegalensis (4,020.72 N.mm^{-2}). Impact bending was highest (0.68 N.mm^{-2}) in Anogeisus leiocarpus. MOR mean was 110.33 N.mm^{-2} in Khaya senegalensis, 100.18 N.mm^{-2} and 59.21 N.mm^{-2} in Vitellaria paradoxa. In conclusion, Khaya senegalensis and Anogeissus leiocarpus lower shrinkage and can be applied for outdoor uses and in high temperature areas.

Keywords: *Density, swelling, shrinkage, compression, impact bending, wood species.*

Introduction

Wood is recognized as the fibrous rigid material of plant origin (Fuwape, 2000), It is the oldest material used by humans for construction after stones. Wood is a complex tissue composed of three main cell types namely: vessels that transport water, fibres responsible for mechanical strength and parenchyma that stores and transport nutrients. These tissues have different structural characteristics and their relative proportions within wood influence wood density. Although lumens of vessels have essentially zero density, fibre, vessel walls and parenchyma have positive density.

Vessel fraction has variously shown either negative or no correlation with wood density (Ziemin´ *et al.,* 2013). Despite it complex chemical nature, wood have excellent properties that that of interest to man's utilization. It is always available, cost-effective and can effortlessly be converted by machines. Wood it also easily fabricated into variable products of shapes and sizes with the use of simple on-site building technology. Wood is a natural product that can be limited in supply (Madison *et al*., 2010). There are essentially two classes of wood which are softwoods and hardwoods. These names are obtained from the source of tree the timber are obtained. As softwoods derived from coniferous trees, hardwoods are from deciduous tree (Aydin *et al.,* 2007). Hardwood trees are more varied than softwoods. They are about 100 times more species of hardwood than they are of softwoods. Hardwoods have enclosed nuts or seeds, where softwoods are gymnosperms with naked seed plants (Allen, 2010).

Wood like other building material has intrinsic advantages that make it especially attractive in specific applications (Afolayan *et al.,* 1998). One of the major demands for timber application is for structural purposes. This requires strength and stiffness properties that must be maintained to sustain applied load (Larsen *et al.,* 2001). The utilization of timber for the purpose of structure has always been influenced by absence of or inappropriate design codes and accurate well-established standards (Zziwa *et al*., 2011). Sometimes the choice of a wood for a desired purpose does not always depend on its strength or mechanical properties. It however requires a careful assessment of fibre, physical and mechanical properties of the wood material so as to meet the standard for which the wood is planned for.

Physical and mechanical properties of wood are very significant characteristics often used in predicting the suitability and application of wood materials. These features in turn rely on the wood species (Jamala *et al.,* 2013). Physical properties are the quantitative attributes of wood and its behaviour to environmental influences apart from applied forces. A good knowledge of physical properties is essential because they can considerably affect the behaviour and strength of wood utilized in structural applications (Winandy, 1994). Wood density is regarded as one of the most important characteristics of wood, significantly influencing the majority of its other physical and mechanical properties (Zobel and Van Buitenen, 1989). Density is often perceived as one of the main indicators of wood quality (Barnett and Jeronimidis, 2003). There is a very close correlation between density and the strength characteristics of wood (Sonderegger *et al*., 2008). Therefore, it can be used as an indicator for the primary assessment of mechanical properties (Vikram *et al*., 2011). Unlike for other materials, density of wood fluctuates depending on moisture.

Compressive strength of wood is the ability of a piece wood sample to resist the impacts of forces or loads acting along the same axis and trying to shorten a dimension or reduce the volume of the wood. The results of compressive strength test of wood are important for predicting wood used in columns and structural materials. Timbers which are high in density have high compression strength across the grain (Akpan, 2006). Studies have revealed that wood is weaker in compression perpendicular to the grain than it is in compression parallel to the grain (Malami *et al*., 2013).

Modulus of Rupture (MOR), is also known as bending strength, it shows the load the wood can withstand perpendicular to the grain. It is used to determine the wood species overall strength. MOR is expressed in Newton per millimeter square (N/mm^2). According to Gurfinkel, (1993) Modulus of Rupture measures the ability of a beam to support a slowly applied load for a short time in the case of beams, joists, flooring, furniture and timbers subjected to transverse bending. The strength of wood in bending is one of the most important properties because of the major use made in construction of flexural elements for roofs and floors of buildings, and as stringers and girders in bridges (Kayuma, 2015).

Hence, the objective of this work was to determine the physical and mechanical properties of three selected hardwood species frequently sold in Makurdi Timber Sheds in order to ascertain their suitability for structural timber use. The physical and mechanical properties

Materials and Methods

The Study Area

The research was conducted in Makurdi, Benue State Nigeria. Makurdi being the capital of Benue State Nigeria is a town is located along the Benue River. In 2007 Makurdi was estimated to be 500,797 in population. Makurdi lies between latitudes 7°38' - 7° 50' North and Longitude 8°24' - 8°38' East (Tyubee and Anyadike, (2015). The area covered by Makurdi is 34,059 km ^{2} (13,150 square meter). Makurdi Local Government Area has over 380 persons per km^2 with males are 49.8% while females constitute 50.2%. The town is located in the valley of river Benue hence experiences warm temperature most of the year. The vegetation of Makurdi is typically guinea savannah and this coupled with the climate of Makurdi favours the cultivation and extraction of agricultural and forest products such as cassava, yam, banana, sweet potatoes, rice, maize and general timber produce (Aguoru *et al*., 2014).

Experimental Design

Three Timber Sheds were purposively selected within Makurdi based on the volume of Timber sold. First, all wood species sold and their sources were identified. From the identified wood species, the most commonly sold and utilized in Makurdi were documented. Data was collected with use of questionnaire administration. Copies of semi-structured questionnaire were administered to 20 Timber traders to elicit information on the common Timber sold. Of the identified common wood species sold in the Timber Sheds, 3 wood species were chosen for physical and mechanical tests. Results on demographic characteristics of respondents in the three Makurdi Timber Sheds will be pooled. The physical properties of wood done were: density, volumetric, shrinkage, volumetric swelling, while the mechanical tested in were: Compression Parallel to the Grain, Compression Perpendicular to the Grain, Impact Bending, Modulus of Rupture (MOR) and Modulus of Elasticity (MOE). Three samples each of selected wood species were used for each of these tests as spelt out above and average values were thus computed. The values of the various Physical and Mechanical properties were determined at the Civil Engineering Laboratory University of Agriculture Makurdi.

Determination of Physical Properties of Selected Wood Species

Timber samples were obtained and converted into pieces of 600 mm x 20 mm x 20 mm for the purpose of density, swelling, shrinkage and for modulus of elasticity tests.

Determination of Density

Density is the mass per unit volume of the wood material. The initial weight of the representative samples was measured using a digital weighing balance. The density was calculated using the formula below:

$$\text{Density} = \frac{\text{Weight of oven dried wood (kg)}}{\text{volume of wood } (M^3)} \text{......... (1)}$$

Where:

Volume of wood = Length×Bbreadth × Height ..... (2)

Determination of percentage (%) volume shrinkage

Percentage (%) volume shrinkage of selected wood species was calculated thus:

$$\text{Percentage (\%) Volume Shrinkage} = \frac{\text{Initial volume of wood} - \text{Final volume of wood}}{\text{Initial volume of wood}} \text{ x 100......... (3)}$$

Determination of percentage (%) volume swelling

Percentage (%) volume swelling of selected wood species was calculated as follows:

$$\text{Percentage (\%) Volume swelling} = \frac{\text{Final volume of wood} - \text{initial volume of wood}}{\text{Initial volume of wood}} \text{ x 100 .... (4)}$$

Determination of Mechanical Properties

Mechanical properties of wood play an important role when used for different design applications as wood is widely used for structural purposes. The following mechanical properties were determined in this study.

Determination Modulus of Elasticity

Modulus of Elasticity (MOE) was carried out using 336 Model Universal Testing Machine (UTM).The dimension of sample used for this test was 300 mm x 20 mm x 20 mm. Load at failure was recorded and the corresponding PC monitor values were taken directly from the machine and the static Modulus of Elasticity was computed using the formula as:

$$\text{MOE} = \text{Stress/ Strain} = \text{P L/ Ae} \text{ .... (5)}$$

Where:

MOE = Modulus of Elasticity

P= load;

L= Length of wood;

A= Cross sectional area of wood;

e= extension.

Determination of Modulus of Rupture

Modulus of Rupture (MOR) was carried out on test sample of dimension 300 mm x 20 mm x 20 mm on Instron 3369 model in a Universal Testing Machine. Load was applied at the rate of 0.1mm/sec with the grain parallel to the direction of loading. The specimen was loaded on the radial face and the bending strength of the wood at point of failure was determined from the machine. Load at failure was recorded. The Modulus of Rupture (MOR) was calculated using the following formula:

$$\text{MOR} = \frac{3PL}{4bd^2} \text{.. (6)}$$

Where:

MOR = Modulus of Rupture

P = Load (N)

L = length of sample (mm)

b = width of the sample (mm)

d = thickness of the sample (mm)

Determination of Compression Parallel and Perpendicular to the Grain

The dimension of wood sample of 150 mm x 20 mm x 20 mm was used for this experiment. The velocity of loading was set so that every test was finished within 90 secs and the loading of the test specimen was done in such a way that the direction of the wood grain was perpendicular and parallel to the axis of the wood grain respectively. The values were used to calculate compressive strength according to ASTM 143standard (2009) using the equation below:

Maximum crushing strength = Pmax/ A…………… (7)

Where:

Pmax = Maximum crushing load

A= Area of the wood

Data Analysis

Data obtained were subjected to one-way Analysis of Variance (ANOVA). A follow up test was done by Duncan Multiple Range Test for where there is significant difference among means.

Results

Table 1 shows results of demographic characteristics of respondents in the three Makurdi Timber Sheds. The respondents were more of males (93.33 %) than females (6.67 %) and were mainly singles (50 %). The age of respondents was predominately youths (43.33%) which range between 21 – 30 years. The respondents were mostly Christians (83.33%) with tertiary education (61.67%) and having main occupation as Timber Trader (98.33%).

Table 1: Demographic characteristics of Respondents in Makurdi Timber Sheds

Variables	Frequency	Percentage (%)
Sex		
Male	56	93.33
Female	4	6.67
Total	60	100
Marital Status		
Married	24	40
Single	30	50
Divorced	6	10
Widow	0	0
Total	60	100
Age		
20 and below	13	21.67
21 - 30	26	43.33
31-40	7	11.67
41-50	12	20
51 and above	2	3.33
Total	60	100.00
Religion		
Christianity	50	83.33
Muslim	10	16.67
Total	60	100.00
Education		
Informal	0	0
Primary	0	0
Secondary	23	38.33
Tertiary	37	61.67
Total	60	100
Occupation		
Timber Dealer/logger	1	1.67
Timber Trader	59	98.33
Farming	0	0
Others	0	0
Total	60	100.00

Table 2 shows results on wood species sold in Timber Sheds, Makurdi. The table reveals that a total of fifteen wood species were found to be traded on in the Timber Sheds. Five of them which include *Daniellia oliveri, Anogeisus leiocarpus, Khaya senegalensis, Vitellaria paradoxa and Mangiferal indica* species found to be most common, whereas three of the wood species such as *Gmelina arborea, Vitex doniana and Ceiba pentandra* were common. The result also shows that three species of *Ptericarpus erinaceous, Tectonal grandis* and *Parkia biglobosa were* scarce while, four species of *Milicia excelsa, Triplochyton scleroxylon, Lannea schimperi* and *Elaeis guinensis* were very scarce in the Timber Sheds.

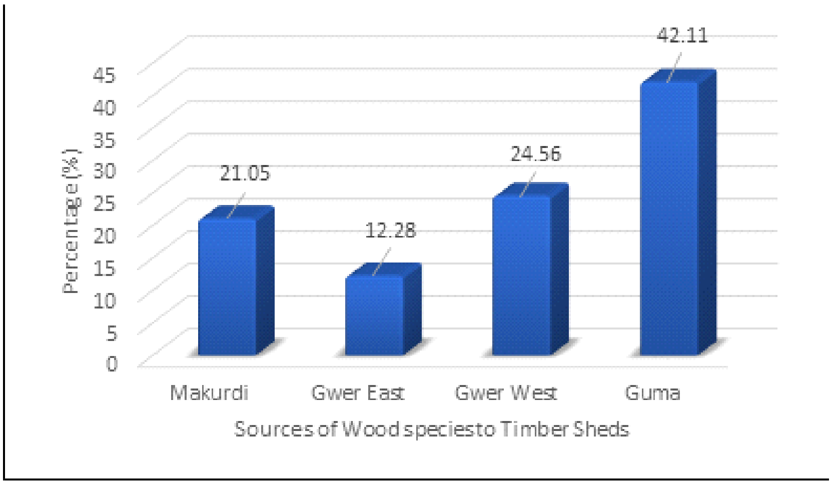

Table 2: Wood Species Sold in Makurdi Timber Sheds

S/No	Scientific names	English names	Native Names (Tiv)	Ranking of availability	Family name
1	*Daniellia oliveri*	African copaiba balsam	Agba/ chiha	1	Fabaceae
2	*Anogeissus leiocarpus*	African birch	Maaki	1	Combretaceae
3	*Khaya senegalensis*	Mahogany	Haa	1	Meliaceae
4	*Vitellaria paradoxa*	Shear butter tree	Chamegh	1	Plantae
5	*Mangifera indica*	Mango	Mongoo	1	Anacardiaceae
6	*Gmelina arborea*	Gmelina	Malina	2	Labiatae
7	*Vitex doniana*		Hulugh	2	Lamaceae
8	*Ceiba pentadra*	Kapok	Vambe	2	Bombacaceae
9	*Pterocarpus erinaceus*	African rosewood	Ngaji	3	Leguminosae, Papilinoideae
10	*Tectona grandis*	Teak	Kpaai	3	Verbenaceae
11	*Parkia biglobosa*	Local bean tree	Nune	3	Fabaceae
12	*Lannea schimperi*		Nimbiligh	4	Anacardiaceae
13	*Milicia excels*	Iroko tree		4	Plantae
14	*Elaeis guinensis*	Oil palm tree	Ivile/ ikye	4	Arecaceae
15	*Triplochiton scleroxylon*	Obeche		4	Malvaceae

Key*: 1- Most common, 2 – Common, 3- Scarce, 4 - Very scarce*

Figure 1 shows results on the sources of wood species to Timber Sheds in Makudi. The table reveals that wood species were basically obtained from four different Local Government Areas (Guma, Makurdi, Gwer East and Gwer West) all in Benue State. Guma LGA was the highest (42.11%) supplier of wood species, followed by Gwer West LGA (24.56%) and Makurdi LGA (21.05% while Gwer East had the lowest of 12.28% wood suppler to Makurdi Timber Sheds.

Figure 1: Sources of wood species sold in Makurdi Timber Sheds

Table 3 presents results of the mean values of density, percentage volumetric shrinkage and volumetric swelling for *Vitellaria paradoxa, Khaya senegalensis* and *Anogeisus leiocarpus.* From the results, *Vitellaria paradoxa* had the highest density (1.27 g.cm^{-3}) while, *Anogeissus leiocarpus* and *Khaya senegalensis* had density of 1.15 g.cm^{-3}and 1.09 g.cm^{-3}respectively. Similarly, *Vitellaria paradoxa* had the highest Volumetric Shrinkage (15.17%) and Volumetric Swelling of 6.61%. This was followed by *Khaya segensis* and *Anogeissus leiocarpus* with Volumetric Shrinkage and Swelling of 10.35% and 9.17%, 5.94% and 1.74% respectively. The table reveals that Density and percentage Volumetric Shrinkage are not significantly difference among wood species of $P \geq 0.05$. However, mean of volumetric swelling for *Vitellaria paradoxa* is significantly different from means of *Khaya senegalensis* and *Anogeissus leiocarpus* at $P \leq 0.05$.

Table 3: Density, Volumetric Shrinkage and Swelling of *Vitellaria paradoxa, Khaya senegalensis* and *Anogeisus leiocarpus*

S/No.	Wood Species	Density ($g.cm^{-3}$)	Volumetric Shrinkage (%)	Volumetric Swelling (%)
		Mean ± SD	Mean ± Std	Mean ± Std
1	*Vitellaria paradoxa*	1.27±0.14[a]	15.17±0.90 [a]	6.61±1.29 [a]
2	*Khaya senegalensis*	1.09±0.16 [a]	10.35±3.17 [ab]	5.94±1.03 [b]
3	*Anogeisus leiocarpus*	1.15±0.05 [a]	9.17±3.64 [b]	1.74±0.71 [b]
Total		1.17±0.13	11.56±3.69	4.76±2.45

Table 4 indicates mechanical properties of *Vitellaria paradoxa, Khaya senegalensis* and *Anogeisus leiocarpus*. *Anogeisus leiocarpus*. Results reveals that compression parallel to grain was highest (0.23 $N.mm^{-2)}$in *Anogeissus leiocarpus* while *Vitellaria paradoxa* and *Khaya senegalensis* had 0.17 $N.mm^{-2}$respectively. Whereas, *Vitellaria paradoxa* had the maximum (10.78 $N.mm^{-2}$) compression perpendicular to grain, *Khaya senegalensis* had the least of 0.73 $N.mm^{-2}$.

Mean value of impact bending was 0.68 $N.mm^{-2}$ in *Anogeisus leiocarpus,* 0.60 $N.mm^{-2}$ in *Vitellaria paradoxa, and* 0.54 $N.mm^{-2}$ *Khaya senegalensis*. For MOE, *Anogeissus leiocarpus* again had the highest mean value of 17,511.61 $N.mm^{-2}$ followed by *Vitellaria paradoxa* (14,916.90 $N.mm^{-2}$) and *Khaya senegalensis* (4,020.72 $N.mm^{-2}$). MOR was 110.33 $N.mm^{-2}$ in *Khaya senegalensis,* 100.18 $N.mm^{-2}$ and 59.21 $N.mm^{-2}$ in *Vitellaria paradoxa.* Compression parallel and perpendicular to grain, impact bending, MOE and MOR are not significantly different among the wood species at $P \leq 0.05$.

Table 4: Mechanical Properties of *Vitellaria paradoxa, Khaya senegalensis* and *Anogeisus leiocarpus*

S/No.	Wood Species	Compression Parallel to the Grain ($N.mm^{-2}$)	Compression Perpendicular to the Grain ($N.mm^{-2}$)	Impact Bending ($N.mm^{-2}$)	Modulus of Elasticity (MOE) ($N.mm^{-2}$)	Modulus of Rupture (MOR) ($N.mm^{-2}$)
		Mean ± SD	Mean ± Std	Mean ± Std	Mean ± Std	Mean ± Std
1	*Vitellaria paradoxa*	0.17±0.04 [a]	10.78±17.27 [a]	0.60±0.06 [a]	14916.90±10549.76 [a]	59.21±7.00 [a]
2	*Khaya senegalensis*	0.17±0.02 [a]	0.73±0.09 [a]	0.54±0.07 [a]	4020.72±679.43 [a]	110.33±72.34 [a]
3	*Anogeisus leiocarpus*	0.23±0.04 [a]	0.98±0.06 [a]	0.68±0.15 [a]	17511.61±8008.80 [a]	100.18±76.34 [a]
	Total	**0.19±0.04**	**4.16±9.96**	**0.61±0.11**	**12149.74±9077.88**	**89.90±57.68**

Discussion

This study found out that males were predominantly involved in timber business in Makurdi Timber Sheds than women. The finding agrees with Sambe *et al.,* (2016); Ekhuemelo and Ojo (2016); Ekhuemelo and Ojo (2017) who reported in their separate studies on timber traders, sawmill and Timbre Sheds, that males were more than females in timber business in Benue state. Out of the twelve wood species found in Makurdi Timber Sheds, *Daniellia oliveri, Anogeisus leiocarpus, Khaya senegalensis, Vitellaria paradoxa and Mangifera indica* wood species found to be most common in Makurdi Timber Sheds.

Although there was no significant difference p>0.05 among the mean densities of *Vitellaria paradoxa, Khaya senegalensis* and *Anogeissus leiocarpus,* however, *Vitellaria paradoxa* had the highest mean density. The mean values of density obtained in this work are higher than the ones reported by Jamala *et al.,* (2013). Low density wood has values under 540 kg/m^3. Such timber will feel light whereas, high density wood has values over 540 kg/m^3 (Sikkens, 2017). The mean results shows that there is no significant difference in wood density with respect to wood species hence the result indicates that all the three species of wood used (*Vitellaria paradoxa, Khaya senegalensis and Anogeisus leiocarpus*) for this research are hardwood of high density woods and can be used as structural materials such as beams and columns and other support work that requires high strength and this is in accordance with Ishengoma *et al*., (1998) who noted that density was the main criterion for prediction of clear wood strength properties.

Vitellaria paradoxa has the highest mean percentage volume shrinkage, hence possesses high ability to shrinkage when used outdoor and in high temperature conditions. *Khaya senegalensis and Anogeissus leiocarpus* have medium mean values of percentage shrinkage and can be applied for outdoor uses and in high temperature areas. Jamala *et al.,* (2013) reported % volume shrinkage for *Khaya ivorensis* (12.94 %), *Celtis mildbraedii (*12.29 %), *Meliceae excelsa* (9.19 %), *Afzelia africana* (7.57 %) and *Triplochiton scleroxylon* (6.90 %). These values fall within (9.17 % - 15.17 %) as obtained in this study. However, the values of % volume swelling obtained in this study (1.7 % - 6.61 %) are lower that the values reported by Jamala *et al.,* (2013) which ranged between 6.44 % – 11.36 %. *Vitellaria paradoxa* had the highest percentage mean volume of swelling followed by *Kyaya senegalensis*. This indicates that these wood species have the ability to swell when expose to moisture environment. *Anogeissus leiocarpus* had the lowest percentage mean volume swelling values and as such, its uses and application cannot be much affected by moisture or rainfall.

From the results obtained, the three timber types had higher compression strength when loaded perpendicular to the grain than when loaded parallel to the grains. The Modulus of Rupture (MOR), Modulus of Elasticity (MOE) and static bending strength also showed that the timber types are hardwood of higher strength classes with *Anogeissus leiocarpus* having the highest MOE and static, bending strength followed by *Vitellaria paradoxa* while *Khaya senegalensis* has the highest MOR followed by *Anogeissus leiocarpus* and *Vitellaria Paradoxa*.

Jamala *et al.,* (2013) again reported MOR ranging between 30 $N.mm^{-2}$ – 149 $N.mm^{-2}$ and MOE of between 3,937.5 $N.mm^{-2}$ – 8,192.54 $N.mm^{-2}$ in their study of five different species. Whereas, in this study, MOR and MOE ranged between 59.21 $N.mm^{-2}$ – 110 $N.mm^{-2}$ and 4,020 $N.mm^{-2}$ – 17,511 $N.mm^{-2}$ respectively. In both MOR and MOE, the values obtained in this study are higher than the one reported by Jamala *et al.,* (2013).

Conclusion

This study is concluded that *Daniellia oliveri Anogeisus leiocarpus, Khaya senegalensis, Vitellaria paradoxa* and *Mangifera indica* were the most common wood species sold in Makurdi Timber Sheds and that majority of the woods species are harvested from Guma LGA in Benue State. Among the three species investigated in this study, *Vitellaria paradoxa* had the highest density, shrinkage, swelling, compression perpendicular to grain and MOE, while *Anogeissus leiocarpus* had the highest compression parallel to grain and the impact bending. However, *Khaya senegalensis* had the highest MOR. Therefore, the findings from this study has revealed quantitative information on the physical and mechanical properties of *Vitellaria paradoxa, Anogeissus leiocarpus,* and *Khaya senegalensis* wood species which can be applied in determining the application of these species for heavy construction, for buildings structurs and also for other functions such as the manufacture of furniture.

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