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CHARACTERISATION AND GRADING OF TWO SELECTED TIMBER SPECIES GROWN IN KWARA STATE NIGERIA

A. A. Jimoh[1] and S. T. Aina[2,*]
[1,2] DEPARTMENT OF CIVIL ENGINEERING, UNIVERSITY OF ILORIN, ILORIN, KWARA STATE, NIGERIA
***E-mail addresses**:* [1] *aajimoh4real@yahoo.com,* [2] *ainasam000@gmail.com*

ABSTRACT
This study investigates the physical and mechanical properties of two timber species for structural use. Three logs of each specie were obtained at different areas of Kwara State, of Nigeria which is located north in the periphery of the south-western rain forest area, sliced into 2" by 12" size before seasoning naturally and their structural/strength properties were determined at a moisture content of 18%. These logs were cut into test samples for the determination of their properties. A total of 351 samples (45 samples for each test) free from visible defects was used for each specie. Basic physical properties of the samples like moisture content, specific gravity and density was determined. Tensile strength, modulus of rupture, modulus of elasticity, compression, shear and hardness were the mechanical tests carried out according to BS 373 (1957), CP112 (1971), NCP2 (1973), EC5 (1995) and BS 5268 (2002) specifications on Universal Testing Machine (UTM). Results were analysed statistically using Analysis of Variance (ANOVA). A. Indica was graded into strength class D40 while X. Aethiopica was grade into strength class D70.

Keywords: *Azadirachta indica, Characterisation, Grading, Mechanical properties, Physical properties, Structural timber, Xylopia aethiopica,*

1. INTRODUCTION

Timber is a complex building material owing to its heterogeneity and species diversity. Timber does not have consistent, predictable, reproducible and uniform properties as the properties vary with species, age, soil and environmental conditions. The need for local content in construction of engineering infrastructure is now a serious challenge in Nigeria. This is because vast quantities of local raw materials which must be processed and used for cost effective construction abound. Construction activities based on these locally available raw materials are major steps towards industrialization and economic independence for developing countries. This explains huge interest and considerable intellectual resources being invested in understanding the mechanical or structural properties of the Nigerian timber [1].

The primary goal of engineered construction is to produce a structure that optimally combines safety, economy, functionality and aesthetics. Timber, like other building materials, has inherent advantages that make it especially attractive in specific applications [2]. Structural timber is the timber used in framing and load bearing structures, where strength is the major factor in its selection and use. The main issue is to find design methods ensuring that the relevant performance criteria are met with certain desired level of confidence. That means that the risk of non-performance should be sufficiently low.

The main challenge in design with timber as structural member is to be acquainted with sufficient data about a given species of timber to ensure that the relevant performance criteria are met, as specified in relevant standards and codes. This implies that failure risk is reduced to the extent to which structural information about a given species of timber is readily available to timber designers, specifiers and construction regulators. A significant element of uncertainty is associated with lack of information on the physical variability as well as structural behaviour of material under load, [3]. The question of strength characteristic of these timber species is therefore aimed at reducing the structural risk of using them for supporting and sustaining loads in structural systems.

*** Corresponding author, tel: +234 – 703 – 241 - 2668**

1.1 Background of Study

The tree, *Azadirachta indica* is of the mahogany family Maliaceae*;* popularly known as neem tree or dogonyaro (Hausa). It is an evergreen tree. Neem is native to east India and Burma and grows much in South East Asia (SEA) and West Africa; and it is cultivated in Pakistan, Peninsular Malaysia, Singapore, Philippines, Australia. Plantations of Neem in small scale in Europe and United States of America have shown success [4]. It has been in use since ancient times to treat a number of human ailments and also as household pesticide [5],[6],[7],[8],[9].

Neem tree is about 12-18 metres in height when fully grown with a circumference ranging between 1.8 and 2.4 metres. Neem is a flowering plant which produces flower at 3-5 years of age [10] in which the flowers are 4-7mm in length and 6-10mm in width [11]. The flower has a jasmine like odour and white in colour. The leaves are dark green in colour up to 30cm in length [10] and have 3 lobed stigmata and seeded drupes [12]. The fruit of Neem is about 2cm long with white kernels and when mature its able to produce 50kg of fruit yearly [10]. The branch of Neem is dense with up to 10cm in length and has a dark brown bark [11]. Furthermore, Neem tree is able to adapt to very dry condition [10], [11] which is up to 120°C with minimal rain fall of 18 inches per year [4]. Besides that, these plant can grow well in calcareous soil with the pH up to 8.5 [13].

Xylopia aethiopica commonly known as "African guinea pepper" or "Ethiopian pepper" is wide spread in tropical Africa, Zambia, Mozambique and Angola. In Nigeria, it is found all over the lowland rain forest and most fringe forest in the Savanna zones of Nigeria [14].

X. *aethiopica* is a member of the family Annonaceae, its a tree of more than 20 m of height and 60 to 75 cm in diameter. It grows in the forest zone and especially along the rivers and in arid areas. The fruit is a slightly hooked cylindrical pod reaching 2 to 3 mm in width. The mature fruits of green colour take a brown - black colouration after drying and they are commonly used as spices. [15], [16].

The leaves simple, alternate, oblong, elliptic to ovate, 8-16.5 by 2.8-6.5 cm, leathery, bluish-green and without hairs above, but with fine brownish hairs below, margin entire, and glabrous; petiole 0.3-0.6 cm, thickset and dark-coloured. Flowers are bisexual, solitary or in 3-5 flowered fasicles or in strange, sinuous, branched spikes, or cymes, up to 5.5 by 0.4 cm and creamy-green. The fruits are small, carpels 7-24, forming dense cluster, twisted bean-like pods, dark brown, cylindrical, 1.5-6 cm long and 4-7 mm thick; the contours of the seeds are visible from outside. Seeds are black, 5-8 per pod, kidney-shaped seeds of approximately 10 mm in length with a yellow papery aril. The hull is aromatic, but not the seed itself [17].

John-Dewole [18] reported the medicinal uses of the fruit extract of *X.aethiopica* in the treatment of bronchitis, oedema, dysentery and febrile pains. In Congo, the infusion of the extract of the bark of the tree into palm wine is used in the treatment of asthmatic attack, stomach aches and rheumatism at dosage rate of one or two glasses per day [19]. In Senegal, the dried root crushed into powder is used as mouth wash for tooth ache and pyorrhoea. In Cote D'ivoire, the fruits are recommended as a source of blood tonic to women, after baby delivery, for blood replenishment. It is used as antihelminthic and also as analgesic for chest pain [20]. *X.aethiopica* is used locally in Nigeria for the treatment of cancer and ulcers. The powdered bark of the tree is dusted onto ulcerous wounds, while a decoction of the leaves and roots is a general tonic for fever in Nigeria [21]. The crude extract exhibit a strong anti-feedant activity on subterranean termite, Reticulitermes speratus [18].

Stress grading is the process of assigning a timber specie to a predefined strength/stress class or grade provided in available codes of practice. Strength class is the classification of timber based on particular values of grade stress, modulus of elasticity and density [22]. Over the years, stress grading has usually been done in two ways;

(i) Visual grading: This method sorts timber into grades on the attributes of visual characteristics that is, knots, pith, sloping grain.
(ii) Machine grading: This assigns stress grade to timber according to its stiffness. The grade is assigned by slotting the minimum local stiffness into thresholds ranges. The thresholds are selected so that populations of the timber meet or exceed characteristic strength and stiffness for the grade.

This means that machine-graded timber will generally have a higher stiffness for a given strength than will visually graded timber of the same species. In practice, it is the stiffness property (Modulus of Elasticity or MOE or Young's Modulus), that is limiting in the design of most timber structures for everyday use. Hence machine grading is the more relevant grading method [23].

Ataguba, *et al* [24], did a comparative study of the mechanical properties of *Gmelina Arborea*, *Parkia Biglobosa* and *Prosopis Africana* timbers for structural use and concluded that the three species proved to have physical and mechanical properties that make them suitable for structural engineering use as hardwoods by grading them into strength classes between D30 – D70 when compared with Table 8 of [22]. It was part of his recommendation that tree species like Neem tree should be characterized for structural use.

Zziwa, *et al* [25] characterized timbers for building construction in Uganda. Seventeen timber species were characterized according to relevant Ugandan code of practice. After the study, four strength groups namely SG4, SG8, SG12 and SG16 were derived in view of the anticipated loading categories in building construction.

It is on this back-drop that this study aims at characterising and grading *A. Indica* and *X. Aethiopica* by examining their physical and mechanical properties.

2. MATERIALS AND METHODS

Three stems of the timber species were gotten from different areas of Kwara state and transported to Irewolede estate's sawmill in Ilorin for processing. The tree stems were 3.8m to 4.1m long and varied from 0.32m to 0.39m in diameter. The stems were sawn into commercial sizes in green state and seasoned in open air. Samples were taken along the stem and marked top, middle and bottom as in Figure 1. It was ensured that the selected timber was free of defects and was as straight as possible.

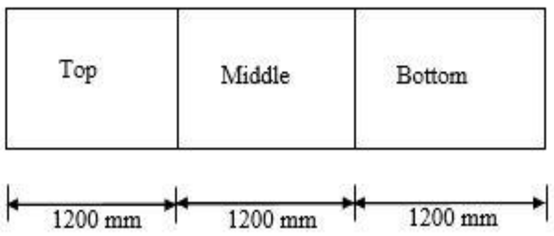

Figure 1: Schematic diagram of Sample Preparation

A total of 418 samples were prepared but 351 samples were used for this study for each timber specie. For the physical properties, there were 18 samples for each test (6 samples each from the top, middle and bottom position). 45 samples was used for each mechanical test which equates to 15 samples each from the top, middle and bottom position). The specimens were prepared in accordance with [22, 26 - 29]. The codes stated both the 20mm (2cm) and 550mm (2inch) standard of testing small clear specimens. The specifications for 20mm were used in this work.The test was done using Universal Testing Machine (UTM) of capacity 100kN at National Centre for Agricultural Mechanization (NCAM) in Ilorin, Kwara State, Nigeria.

The physio-mechanical properties of wood should be determined at the moisture content of 12% as standard. Reduction of the failure strength at given moisture content to the strength at a moisture content of 12%, is given as

$$F_{12} = F_w(1 + \alpha(W - 12) \qquad (1)$$

where F_{12} is the failure stress at 12% moisture content, W is the moisture content at the time of testing, F_w is the failure stress at the moisture content at the time of testing, α is a correction factor given in Table (1). The reduction formula is valid for moisture content of 8% to 23%.

Table 1: Correction Factor, α

State of stress	α (for all wood species)
Compression parallel to the grain	0.05
Static bending	0.04
Shearing parallel to the grain	0.03

Source: [25]

Equation (1) converts the failure stress of the mechanical properties at the existing moisture content to values at moisture content of 12% and these values were thereafter converted to their respective values at moisture content of 18% using equation (2) (this is the acceptable moisture content of timber to be used in Nigeria) while equations (3) to (8) gives the basic stresses.

$$\text{Stress at 18\% moisture content} = \frac{F_{12}\text{x}18}{12} \qquad (2)$$

In (2), F_{12} is the failure stress at 12% moisture content. Eighty percent (80%) grade stress of the timbers was calculated as well as 95% and 99% confidence limits of the failure stress. Analysis of Variance (ANOVA) was used to determine if there is significance difference between the top, middle and bottom positions of the timber species.

The basic bending stresses parallel to the grain for the species were determined using the failure stresses from tests by [30, 31] as:

$$f_{b\,par} = \frac{f_m - 2.33\sigma}{2.25} \qquad (3)$$

Where $f_{b\ par}$ is the basic bending stress parallel to the grain, f_m is the mean value of the failure stresses and σ is the standard deviation of the failure stresses

The basic tensile stresses parallel to the grain for the species were determined using the failure stresses from tests by [30, 31] as:

$$t_{b\,par} = \frac{f_m - 2.33\sigma}{2.25} \qquad (4)$$

The basic compressive stresses parallel to the grain for the species were determined using the failure stresses from tests by [30, 31] as:

$$c_{b\ par} = \frac{f_m - 2.33\sigma}{1.4} \quad (5)$$

The basic compressive stresses perpendicular to the grain for the species were determined using the failure stresses from tests by [30] as:

$$c_{b\ per} = \frac{f_m - 1.96\sigma}{1.2} \quad (6)$$

The basic shear stresses parallel to the grain for the species were determined using the failure stresses from tests by [30, 31] as:

$$v_{b\ par} = \frac{f_m - 2.33\sigma}{2.25} \quad (7)$$

The formula below gives the relationship between the E_{mean} and the statistical minimum value of E appropriate to the number of species acting together, [30] as:

$$E_N = E_{mean} - \frac{2.33\sigma}{\sqrt{N}} \quad (8)$$

where E_N is the statistical minimum value of E appropriate to the number of pieces N acting together (where N=1, E_N becomes the value for E_{min}) and σ is the standard deviation.

Analysis of Variance (ANOVA) with the help of SPSS software was used to check if a significant difference existed between the bottom, middle and top positions of each timber specie.

3. RESULTS AND DISCUSSION

Tables 2 and 3 shows the results obtained from the laboratory work carried out on the physical and mechanical properties of the timbers under investigation as well as the 80% grade stress with 95% and 99% confidence limits of the failure stress. Likewise, the results of the ANOVA statistical test is presented in Table 4 – Table 23. Similarly, Figures (2) and (3) show the typical Stress-Strain relationship of the timber species.

3.1 Test Results

3.1.1 Physical and mechanical properties: The physical and mechanical properties of the species of timber tested are shown in Table 2. As seen in Table 2, the densities obtained ranged from 740 to 1160 kg/m^3 signifying that the timbers investigated are hardwoods since the values obtained are greater than 640 kg/m^3 [32]. Likewise, moisture content results obtained showed that the values are below saturated moisture level of 25%.

3.1.2 Failure, basic and grade stresses: From Tables 2 and 3, *Xylopia aethiopica* has higher values of MOR, compressive strength parallel to grain, tensile strength parallel to grain, radial and tangential hardness as well as shear strength. However, *Azadirachta indica* has higher compressive strength perpendicular to grain. *Azadirachta indica* has higher compression strength when loaded parallel to the grains than when loaded perpendicular to the grains while *Xylopia aethiopica* is stronger in compression when loaded perpendicular to the grain. Compression strengths parallel to the grains ranged between 13.18 N/mm^2 to 26.31 N/mm^2 while the compression strengths perpendicular to the grains ranged between 10.65 N/mm^2 to 14.08 N/mm^2. Similarly, *Azadirachta indica* performed better in shear than in tension while *Xylopia aethiopica* did better in tension than in shear. The results of tensile strengths ranged between 0.78 N/mm^2 to 38.02 N/mm^2 while the shear ranged between 2.14 N/mm^2 to 2.95 N/mm^2.

Table 2: Physical and mechanical properties of Neem and Negro Pepper timber

Timber Name	Observed values	Moisture content (%)	Density (g/cm^3)	Specific gravity	Bending stress (N/mm^2)	Compressive stress parallel to grain (N/mm^2)	Compressive stress perpendicular to grain (N/mm^2)	Tensile stress (N/mm^2)	Radial Hardness (kgf)	Tangential Hardness (kgf)	Shear stress (N/mm^2)	Modulus of Elasticity (N/mm^2)
Neem Tree (*Azadirachta indica*)	Min.	10.87	0.74	0.79	5.66	15.93	15.18	3.02	418.42	399.28	3.74	2737
	Max.	15.67	0.90	0.94	44.58	22.04	26.09	9.26	546.67	544.09	11.28	5950
	Mean	12.59	0.83	0.88	19.04	19.38	19.65	5.53	478.28	468.92	7.27	4239
	SD	1.99	0.07	0.06	3.67	2.58	4.26	2.62	53.48	57.74	3.07	1367
Negro Pepper (*Xylopia aethiopica*)	Min.	10.4	0.79	0.99	43.99	39.7	11.92	71.87	606.63	620.09	7.75	6293
	Max.	21.91	1.16	1.20	131.92	67.7	17.56	74.55	764.52	786.24	17.45	14461
	Mean	16.7	1.15	1.09	80.36	53.52	14.56	73.55	704.84	684.91	12.3	10060
	SD	4.71	0.17	0.09	15.53	14.69	2.99	1.46	88.38	89.09	5.71	4278

Table 3: Failure , basic and grade stresses Neem and Negro Pepper timber at 18% moisture content

Timber Name	Observed values	Bending stress (N/mm^2)	Compressive stress parallel to grain (N/mm^2)	Compressive stress perpendicular to grain (N/mm^2)	Tensile stress (N/mm^2)	Shear stress (N/mm^2)	Modulus of Elasticity (N/mm^2)
Neem Tree *(Azadirachta indica)*	Failure stress	28.56	29.07	29.48	8.3	10.91	6258
	95% Confidence limit	17.2, 20.14	18.6, 20.16	18.37, 20.93	4.74, 6.32	6.35, 8.89	3828, 4649
	99% Confidence limit	17.57, 20.51	18.34, 20.42	17.94, 21.36	4.48, 6.58	6.04, 8.5	3690, 4787
	Basic stress	8.89	16.47	17.6	0.97	2.68	5296
	80% Grade stress	7.11	13.18	14.08	0.78	2.14	4237
Negro Pepper Tree *(Xylopia aethiopica)*	Failure stress	120.54	80.28	21.84	110.33	18.45	15089
	95% Confidence limit	75.69, 85.03	49.11, 57.93	13.66, 15.46	73.12, 73.99	10.59, 14.01	8774, 11345
	99% Confidence limit	74.13, 86.59	47.62, 59.42	13.36, 15.76	72.97, 74.14	10.01, 14.59	8343, 11776
	Basic stress	37.49	32.89	13.32	47.52	3.68	11767
	80% Grade stress	29.99	26.31	10.65	38.02	2.95	9414

The modulus of elasticity (MOE) and the static bending strengths (flexural strengths) also show that the timber types are hardwood of higher strength classes (between strength classes D30 – D70) when compared with Table 8 of BS 5268.

3.1.3 Result of ANOVA Statistical Test on Neem Timber:

The statistical tests on Neem timber are shown in Tables 4 to 10.

Table 4 ANOVA for static bending test

	Sum of Squares	df	Mean Square	F	Sig.
Between	1111.886	2	555.943	2.146	0.130
Within	10879.468	42	259.035		
Total	11991.354	44			

Table 5 ANOVA for compression parallel to grain

	Sum of Squares	Df	Mean Square	F	Sig.
Between	62.496	2	31.248	3.146	0.050
Within	417.201	42	9.933		
Total	479.697	44			

Table 6: ANOVA for compression perpendicular to grain

	Sum of Squares	df	Mean Square	F	Sig.
Between	98.902	2	49.451	3.685	0.034
Within	563.690	42	13.421		
Total	662.593	44			

Table 7 ANOVA for Tension parallel to grain

	Sum of Squares	Df	Mean Square	F	Sig.
Between	120.489	2	60.245	8.829	0.001
Within	286.602	42	6.824		
Total	407.091	44			

Table 8 ANOVA for hardness test (radial direction)

	Sum of Squares	Df	Mean Square	F	Sig.
Between	30828.749	2	15414.375	4.213	0.022
Within	153684.637	42	3659.158		
Total	184513.386	44			

Table 9 ANOVA for hardness test (tangential direction)

	Sum of Squares	df	Mean Square	F	Sig.
Between	615.470	2	307.735	0.078	0.925
Within	165700.349	42	3945.246		
Total	166315.819	44			

Table 10 ANOVA for Shear parallel to grain

	Sum of Squares	df	Mean Square	F	Sig.
Between	34.061	2	17.031	1.595	0.215
Within	448.426	42	10.677		
Total	482.487	44			

3.1.4 Result of ANOVA Statistical Test Performed on Negro Pepper Tree: The statistical tests on Negro Pepper timber are shown in Tables 11 to 17.

Table 11 ANOVA for static bending test

	Sum of Squares	df	Mean Square	F	Sig.
Between	5596.425	2	2798.212	1.095	0.393
Within	15334.433	42	2555.739		
Total	20930.858	44			

Table 12 ANOVA for compression parallel to grain test

	Sum of Squares	Df	Mean Square	F	Sig.
Between	523.707	2	261.854	1.063	0.403
Within	1477.892	42	246.315		
Total	2001.600	44			

Table 13 ANOVA for compression perpendicular to grain test

	Sum of Squares	df	Mean Square	F	Sig.
Between	19.797	2	9.898	.722	0.524
Within	82.265	42	13.711		
Total	102.061	44			

Table 14 ANOVA for Tension parallel to grain test

	Sum of Squares	df	Mean Square	F	Sig.
Between	18584.551	2	9292.3	2.634E3	0.000
Within	21.169	42	3.528		
Total	18605.720	44			

Table 15 ANOVA for hardness test (Radial direction)

	Sum of Squares	Df	Mean Square	F	Sig.
Between	115574.968	2	57787.5	5.283	0.051
Within	65633.456	42	10938.909		
Total	181208.424	44			

Table 16 ANOVA for hardness test (Tangential direction)

	Sum of Squares	Df	Mean Square	F	Sig.
Between	56599.1	2	28299.552	3.170	0.115
Within	53562.578	42	8927.096		
Total	110161.683	44			

Table 17 ANOVA for Shear parallel to grain test

	Sum of Squares	df	Mean Square	F	Sig.
Between	60.317	2	30.158	1.183	0.369
Within	152.920	42	25.487		
Total	213.236	44			

From the ANOVA results obtained, it has been observed that for *Azadirachta indica,* at a significance level of $P \leq 0.05$, there is a significant difference between the top, middle and bottom position in its compressive strength parallel to the grain (P = 0.05), compressive strength perpendicular to the grain (P = 0.034), tensile strength parallel to the grain (P = 0.001), radial hardness (P = 0.022), however, there were no difference in its MOR (P = 0.13), tangential hardness (P = 0.925), and shear strength parallel to the grain (P = 0.215). On the other hand, *Xylopia aethiopica* showed a significant difference between the top, middle and bottom position in its tensile strength parallel to the grain (P = 0.00), while there were no difference in its MOR (P = 0.393), compressive strength parallel to the grain (P = 0.403), compressive strength perpendicular to the grain (P = 0.524), radial hardness (P = 0.051), tangential hardness (P = 0.115), and shear strength parallel to the grain (P = 0.369).

3.1.5 Stress Strain Curves: The stress – strain relationships for the Neem and Negro Pepper timbers are shown in Figures 2 and 3.

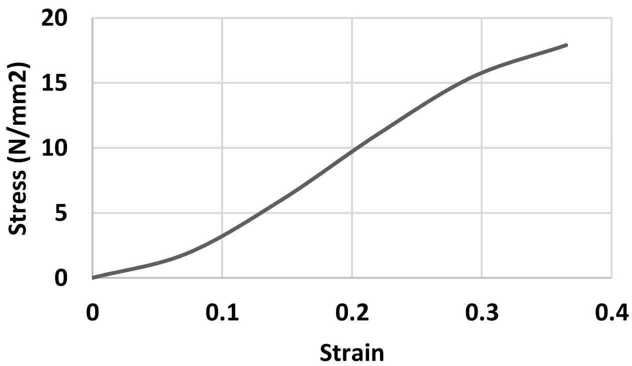

Figure 2: Typical Stress-Strain curve for Neem timber

The stress – strain relationship in Figure 2 shows that the material is brittle. Thus Neem timber is a brittle material and linearly elastic up to failure when subjected to loading.The stress-strain equation is given as:

$$Y = -598.04x^3 + 953.31x^2 - 437.48x + 77.293 \quad (9)$$

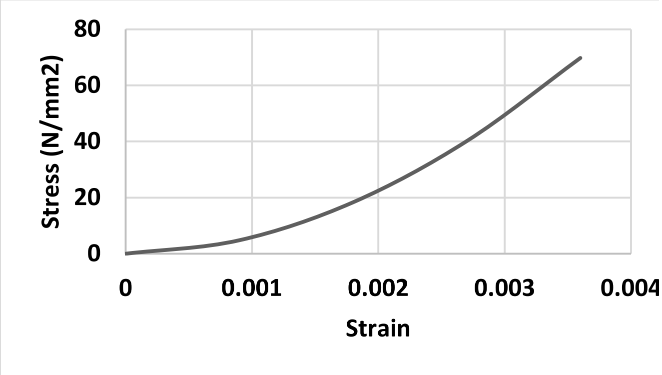

Figure 3: Typical Stress-Strain curve for Negro Pepper Tree

The stress – strain relationship in Figure 2 shows that the material is brittle. Thus Negro Pepper timber is a brittle material and linearly elastic up to failure when subjected to loading.The stress-strain equation is given as;

$$Y = -1E8x^3 + 7E6x^2 - 56594x + 1391 \quad (10)$$

These results obtained compared favorably with other known structural timbers such as mahogany, afara, iroko, obeche, owen, etc. which are commonly known timbers in use within the tropics.

4. CONCLUSION AND RECOMMENDATIONS

The timber types investigated *Azadirachta indica* and *Xylopia aethiopica* have been successfully characterized. The result of the physical and mechanical properties shows they are suitable for structural engineering use as hardwoods. Construction practitioners are encouraged to explore and use them for structural and non structural uses. In view of this, the mechanical properties can be enhanced with adequate seasoning and preservative treatment if these timbers are for structural purposes. More research work is needed in determining the suitability of other widely grown trees in this part of Nigeria for use as structural timbers in construction. Finally, massive afforestation practices should be promoted to reduce the dearth of these trees and other notable species of trees in the forest in this study area.

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