STATISTICAL ANALYSIS OF PROPERTIES OF TIMBER SPECIES FOR STRUCTURAL USE

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ABSTRACT

This study investigated the physical and mechanical properties of two Nigerian timber species- Azadirachta indica and Xylopia aethiopica for structural use. Three logs of each species were obtained at different locations of the country, seasoned naturally and their structural strength properties were determined and converted to strength at moisture content of 18%. These logs were cut into specimens to facilitate the determination of the properties of the timber. A total of 45 specimens for each property, free from visible defects were used. Basic physical properties of the samples like moisture content, specific gravity and density were evaluated. Tensile strength, modulus of rupture, modulus of elasticity, compression, shear and hardness were the mechanical properties determined with specimen shapes prepared following BS 373 (1957) specifications and specimen tested using a Universal Testing Machine (UTM). Results were analysed statistically to evaluate the mean, standard deviation, statistical significant difference and confidence limits. Using these statistical results and based on BS 5268-2 (2002), Azadirachta indica and Xylopia aethiopica species were characterized and fell into strength classes D30 and D70, respectively.

Keywords:Azadirachta, indica, Xylopia aethiopica, Properties

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 [1]. The need for local content in construction of engineering infrastructure is now a serious challenge. 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 [2].

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 [3]. Structural timber is the timber used in framing and loadbearing 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 a 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 the 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 behavior of material under load, [4]. 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.

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. Plantation of Neem in small scale in Europe and United States of America has shown success [5]. It has been in use since ancient times to treat a number of human ailments and also as household pesticide [6, 7,8,9,10] . Neem tree is about 12-18 metres in height with a circumference ranging between 1.8 and 2.4 metres. Neem is a flowering plant which will produce flower on 3-5 years of age [11] in which the flowers are 4-7mm in length and 6-10mm in width [12]. The flower has a jasmine like odour and white in colour. The leaves are dark green in colour up to 30 cm in length [11] and has 3 lobed stigmata and seeded drupes [13] . The fruit of Neem is about 2cm long with white kernels and when mature it is able to produce 50kg of fruit yearly [11]. The branch of Neem is dense with up to 10cm in length and has a dark brown bark [12]. Furthermore, Neem tree is able to adapt to very dry condition [11, 12] which is up to 120°C with minimal rainfall of 18 25 mm per year [5]. Besides that, the plant can grow well in calcareous soil with the pH up to 8.5 [14]. *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 [15] .

X. *aethiopica* is a member of the family Annonaceae, it is 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 [16 , 17]. 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 length with a yellow papery aril. The hull is aromatic, but not the seed itself [18].

John-Dewole et al. [19] 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 [20]. In Senegal, the dried root crushed into powder is used as mouthwash for toothache 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 [21]. *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 [22] . The crude extract exhibit a strong anti-feedant activity on subterranean termite, Reticulitermes speratus [19].

Stress grading is the process of assigning 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 in reference [23] . 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 i.e. 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. In 2015, 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 BS 5268. It was part of his recommendation that tree species like Neem tree should be characterized for structural use.

Zziwa *et al*., [26] characterized timbers for building construction in Uganda. Seventeen timber species were characterized according to the 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 aim at characterising A. Indica and X. Aethiopica by examining their physical and mechanical properties.

MATERIALS AND METHODS

Three stems of each timber species were gotten from different areas of Nigeria and transported to a sawmill 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 and seasoned in open air to equilibrium moisture content with the environment. Samples were taken along the stem and marked top, middle and bottom as shown in Figure 1. It was ensured that the selected timber was free of defects and was as straight as possible.

Specimens were cut from the stem for the physical properties (moisture content, specific gravity and density) and mechanical properties (tensile strength, modulus of rupture, and modulus of elasticity, compression, shear and hardness).

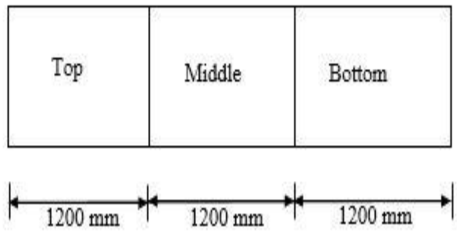

Figure 1 Schematic diagram of Sample stem Preparation

There were 18 test specimens for each physical property test (6 samples each from the top, middle and bottom position). Forty-five (45) specimens were used for each mechanical test (15 samples for each top, middle and bottom portions). The specimens were prepared in accordance with BS 373:1957 [27] (Methods of testing small clear specimens of timber). The code recommended 2cm standard size of testing small clear specimens. The test was done using a Universal Testing Machine (UTM) of capacity 100kN at National Centre for Agricultural Mechanization (NCAM) in Ilorin town, Nigeria.

The requirement is that the physio-mechanical properties of wood should be determined at the moisture content of 12% as standard. The equation relating the failure strength at a moisture content of test to the strength at the standard moisture content of 12%, is given by

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

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

Source: Wooden and Plastic Structures by Karlsen G. and Slitskouhov Yu [28]. Equation (1) converts the failure stress of the mechanical properties at the existing moisture content to values at moisture content of 12% . The computed stress 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 Northern Nigeria). From these stresses, the basic stress were computed using expressions in Table 2.

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

Where F_{12} = 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 properties of the top middle and bottom positions of the timber species.

Basic stresses

These are given by [29] as summarized in Table2

Table 2 Basic stress expressions

Basic stress	Expression for basic stress	Definition of terms
bending stress parallel to the grain	$f_{b\,par} = \frac{f_m - 2.33\sigma}{2.25}$	f_m = mean value of the failure stresses σ = standard deviation of the failure stresses
basic tensile stresses parallel to the grain	$t_{b\,par} = \frac{f_m - 2.33\sigma}{2.25}$	As above
basic compressive stresses parallel to grain	$c_{b\,par} = \frac{f_m - 2.33\sigma}{1.4}$	As above
basic compressive stresses perpendicular to the grain	$c_{b\,per} = \frac{f_m - 1.96\sigma}{1.2}$	As above
basic shear stresses parallel to the grain	$v_{b\,par} = \frac{f_m - 2.33\sigma}{2.25}$	As above
relationship between the E_{mean} and the statistical minimum value of E appropriate to the number of species acting together	$E_N = E_{mean} - \frac{2.33\sigma}{\sqrt{N}}$	E_N is the statistical minimum value of E appropriate to the number of pieces N acting together (N=1, E_N becomes the value for E_{min}) and σ is the standard deviation.

RESULTS AND DISCUSSION

Tables 3 and 4 show the results obtained from the laboratory for the physical and mechanical properties of the timbers 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 are presented in Tables 5 and 6 while Figures 2 and 3 show the typical Stress-Strain curves for the timber species.

Comparison of results

Comparison of the two timber strength is as follow. *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 than *Azadirachta indica*. The differences in strength may be due to the differences in density.

The mean relative density of aethiopica is 1.15 whereas that of indica is 0.83. Mechanical property of timber is reported to increase with increase in density [1]. However, with the lower density of *Azadirachta indica* it has higher mean compressive strength perpendicular to grain, which may suggest that this property is not density related.

Comparison of each timber properties indicate that *Azadirachta indica* mean compression strength parallel to grains is comparable to its mean strength perpendicular to the grains, whereas for *Xylopia aethiopica*, its compressive strength parallel to grain is three times higher than the strength in compression perpendicular to grain. This suggests that there is no definite pattern and similar way of behaviours in material properties. A high degree of variability in property has been demonstrated by these timber [1] . For example Compression strengths parallel to the grains ranged between 15.93 N/mm^2 and 22.04 N/mm^2 with standard deviation of 2.58 while the compression strengths perpendicular to the grains ranged between 15.18 N/mm^2 to 26.09 N/mm^2, with standard deviation of 4.26.

Similarly, *Azadirachta indica* performed better in shear (mean result is 7.27) than in tension of mean value 5.53 N/mm^2 while it is opposite for *Xylopia aethiopica* with mean tensile strength of 73.55 N/mm^2 than in shear of 12.3 N/mm^2. All these are as a result of variability in timber caused by its natural occurrence which is uncontrollable. Comparison of the two timbers with other timber especially the Greenheart reported as very strong [30] is as follow. Greenheart density is 977 kg/m^3 which shows a similar value with that of Negro Pepper (*Xylopia aethiopica)* but higher than for Neem timber. The modulus of rupture for Greenheart is 181 N/mm^2 [30] , which is 10 times that of Neem timber (19.04 N/mm^2) obtained in this study, but about 2 times that of Negro Pepper (80.36 N/mm^2). A timber that is in the same strength range with Negro Pepper is Gossweilerodendron balsamiferum Harms, popularly called Agba. Agba bending strength is 81 N/mm^2 , similar to 80.36 N/mm^2 obtained for Negro Pepper in this study.

Classification of timber

In classification, the values of modulus of elasticity (MOE) and the static bending strengths also show that the timber types are hardwood of higher strength classes (between strength classes D30 and D70) when compared with the standard values for strength grades in Table 8 of BS 5268 [23]. The
densities obtained ranged from 740 to 1160 kg/m^3 also show that the timbers investigated belong to class of heavy timbers since values obtained are greater than minimum value 720 kg/m^3 specified for heavy timber class [31]. Basic stress given in Table 4 can be used in classification of the two timber species according to NCP 2 (1973) where classes are from the strongest N_1 to weakest N_7. While basic stress for Neem timber falls below the N_7 group, Negro Pepper fall into N_2 . In this group (N_2), basic stresses are : Bending and tension parallel to grain 28.0 N/mm^2,compression parallel to grain 22.4 N/mm^2, shear parallel to grain 3.55 N/mm^2 compression perpendicular to grain 5.0 N/mm^2 and mean value modulus of elasticity 12500 N/mm^2, which agree with the values in Table 4 for Negro pepper.

Statistical analysis

The variation in mechanical strength results are given in Table 3. In order to reduce failures as a result of the variations, results for confidence limits at 95 and 99 % are in some cases recommended in designs [1]. Therefore its computation is carried out and results are given in Table 4. Also the Basic strength results are also recommended [30]. It is obtained by dividing the confidence limits results by some factors. The grade stress is obtained by applying a factor of 0.8 (=80 %) to basic stress in order to take care of defects during application.

Analysis of variance (ANOVA)

Analysis of variance is carried out using the Null hypothesis that there is no significant different between the mean results and that of the population. Critical significance level α of 5 % was set. The null hypothesis is rejected if $P \leq \alpha$, that is, there is significant difference; or accepted if $P > \alpha$, that is, there is no significant difference. ANOVA results are shown in Tables 5. While some results show some significant difference some do not show the significant difference.

For *Azadirachta indica,* , P = 0.05 for compressive strength parallel to the grain, meaning that there is significant difference between the top, middle and bottom position. Similarly there is significant difference for 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 significant 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). The level or intensity of the significant differences is demonstrated by the respective different F values as shown in the table.

Stress-strain curve

The typical stress-strain curve in Figure 2 is for Neem timber. Values of stress and strain are obtained automatically as print out after each test from the computer attachment to the testing machine. The computer uses the input values of cross sectional areas to divide the experimental load on the specimens to obtain stress results and similarly, the initial length values input are used to divide the elongations of the specimen to obtain the strain values.

The curve in Figure 2 shows that for Neem timber, the yield point is around 6 N/mm^2 , while the ultimate stress is about 9.4 N/mm^2. At these two points the strains are 0.005 mm/mm and 0,02 mm/mm respectively. However, an arbitrary strain value of 0.05 mm/mm is taken as the dividing line between the brittle and ductile classes of materials [32,33]. The timber experimental strain values are less than the 0.05 , thus showing that the Neem timber is a brittle material. Also Figure 3 shows the stress strain curve for Negro Pepper timber. In this case the yield stress is around 35 N/mm^2 while the ultimate stress is 75 N/mm^2.

The strain values at these two points are 0.004 mm/mm and 0.013 mm/mm , respectively. These values show also that Negro Pepper timber belongs also to brittle materials. Using the timber species yield stress values and divide them by their respective strains, it gives the moduli of elasticity as 1200 N/mm^2 and 8750 N/mm^2 for Neem and Negro Pepper respectively.

That of Negro Pepper is about 7 times value for Neem timber. However, steel material possesses the modulus of elasticity of 200,000 N/mm^2 , about 167 times that of Neem timber and 23 times that of Negro Pepper. Greenheart timber modulus of elasticity is 21000 N/mm^2, about 1.4 times of Negro timber. Agba has modulus of elasticity of 7600 N/mm^2 about 0.87 that of Negro Pepper timber..

Table 3 Physical and mechanical properties test results

Timber Name	Statistical parameters	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 (N)	Tangential Hardness (N)	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 4: Failure stress, basic stress and grade stress 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

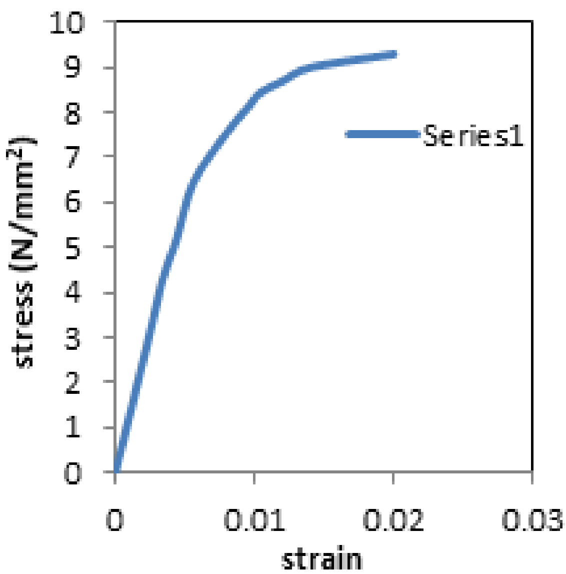

Figure 2 Typical Tensile Stress-Strain curves for Neem timber

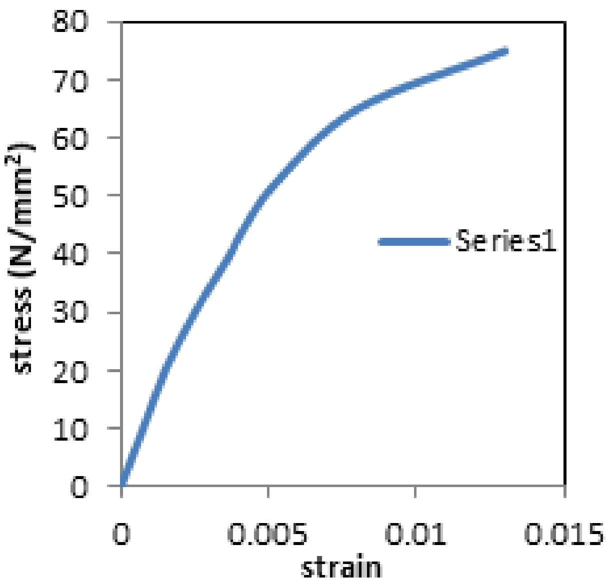

Figure 3 Typical Tensile Stress-Strain curve for Negro Pepper timber

Tables 5 Statistical significant result for Neem and Negro Pepper timber species

	Neem timber *(Azadirachta indica)*			Negro Pepper *(Xylopia aethiopica)*		
Mechanical property	Statistical F	Statistical P	Comment (significance difference at α=0.05)	Statistical F	Statistical P	Comment (significant difference at α=0.05)
Static bending	2.146	0.130	P>α not significant	1.095	0.393	P> α not significant
Compression parallel to grain test	3.146	0.050	P= α significant	1.063	0.403	P> α not significant
Compression perpendicular to grain test	3.685	0.034	P< α significant	0.722	0.524	P> α not significant
Tension parallel to grain test	8.829	0.001	P< α significant	2.634E03	0.000	P< α significant
Hardness test (Radial direction)	4.213	0.022	P< α significant	5.283	0.051	P> α not significant
Hardness test (Tangential direction)	0.078	0.925	P> α not significant	3.170	0.115	P> α not significant
Shear parallel to grain test	1.595	0.215	P> α not significant	1.183	0.369	P> α not significant

CONCLUSION

The timber species investigated, that is *Azadirachta indica* and *Xylopia aethiopica* possessed the physical and mechanical properties that are comparable to the properties of the existing timbers being used for construction purposes and therefore, the two timbers are suitable for structural engineering purposes. The various design values for the mechanical properties obtained will further promote the usage of the timbers in design and construction purposes.

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