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Comparative Studies of the Shear Strength Property of Two Members of the Fabaceae Family with Respect to Their Fibres

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Authors' contributions

This work was carried out in collaboration among all authors. Author AEN managed the analyses of the study, edited the draft of the manuscript. Authors EOO and IEN managed the literature searches, performed the statistical analysis and wrote the first draft of the manuscript. Author GCA designed the study, wrote the protocol and edited the draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aim: The shear strength of wood is a very significant parameter required in describing the potential of woods in making wooden structure. This study is aimed at comparing the shear strength of *Pentaclethra macrophylla* and *Erythrophleum suaveolens* with respect to their fibre. This is to determine the suitability of including *Erythrophleum suaveolens* in making traditional motars in order to reduce the demand load on *Pentaclethra macrophylla.*
Methods: The heartwood samples of *Pentaclethra macrophylla* and *Erythrophleum suaveolens* for maceration were fixed in specimen bottles containing formalin-acetic-alcohol (FAA) in the ratio 90:5:5 to prevent fungal growth. The preparations involved cutting small clear samples of the heartwood of the two timber species of fabaceae family. The shear strength parallel to the grain test was conducted using a Hounsfield Tensometer.
Results: Significant differences were recorded across the fibre characteristics of the two plant species. The share strength of the 25 wood samples from the two plants each fluctuate around 100 to 200 N/mm^2. On the average, *P. macrophylla* recorded higher shear strength as compared to

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E. suaveolens however no significant difference was recorded between the means when tested for significant differences using independent sample t-test.

Conclusion: Since the shear strength of *E. suaveolens* is comparable to that of *P. macrophylla,* it is therefore recommended its substitute for the manufacturing of wood based products where *P. macrophylla* has been in continual usage in order to relieve the pressure and demand on *P. macrophylla*.

Keywords: Shear strength; hounsfield tensometer; wood fibres; wood products; wood.

1. INTRODUCTION

The shear strength of wood is a very significant parameter required in describing the potential of wood in making wooden structure [1,2]. For example, the ability of a wood to withstand nailing and screwing, the ability of a motar to withstand pounding, are largely controlled by the shear strength.

Alternatively, tensile, compression, and shear stresses are usually present in load-bearing applications of wood products, making the shear stresses and shear strength important factors also in structural applications [2-5]. Therefore, when inspecting the timbers, the majority of the attention has to be focused on the strength and elasticity characteristics of wood perpendicular to the grain [6]. The shear is the separation of the fibers by a parallel stress applied to them. The test consists of applying and measuring the stress on the wood fibers, to cause the separation between them [7].

Traditionally, the wood of various trees possess structural, physical and mechanical properties that will allow their use in the manufacturing of assorted wood based food contact materials including motar, pestle, wooden spoons, chopping board, grinding pestle grinding bowl, and roller banku ladle. The force exerted on the mortar by the pestle due to constant pounding generally results in some wood tissues sliding over others thereby causing the central part motar to deepen, as generally encountered in the rural communities of the South-eastern Nigeria. This eventually leads to a crack and an ultimate splitting of the mortar. *P. macrophylla* is one of the widely used woody species in the construction of mortars in Nigeria. The tree produces edible fruits which is a highly priced delicacy in the country, both as food condiments and a major food. There is then the need to look for other species, which could effectively substitute *P. macrophylla* in mortar, in order to reduce the logging pressure on it. One of the reasons claimed for it as a good material in mortar-making is the wavy nature of its grains. However, this study is aimed at comparing the shear strength of *P. macrophylla* to *E. suaveolens,* another species with similar physical characteristics and observable wavy natured grains. This work is aimed at determining the suitability of *E. suaveolens* in making traditional motars in order to reduce the demand load on *P. macrophylla.*

2. MATERIALS AND METHODS

2.1 Collection of Samples

The heartwood of *P. macrophylla* was obtained from its timber collected from Nara Unateze in Nkanu East L.G.A., Enugu State, Nigeria with the help of chain-saw operator, while that of *E. suaveolens* was collected from the Nsukka Timber Shade in Nsukka (Ugwunkwo) Urban Area. The samples for maceration were fixed in specimen bottles containing formalin-acetic-alcohol (FAA) in the ratio 90:5:5 to prevent fungal growth.

2.2 Maceration of Wood Samples

The Schulzt's method of maceration as was adopted by Ajuziogu et al. [8]. In this method, the heartwood samples were cut about the size of a match stick to expose a large area of contact between the wood and chemicals used. The chips (about 50 pieces) of the heartwood about 1 mm x 1 mm x 10 mm of the two samples were placed differently in long test-tubes, and the test-tubes were labelled according to the name of the wood sample.

The test-tubes were secured in test-tube racks. Two grammes of 2% Potassium chlorate ($KClO_3$) crystals and 10mls of concentrated Nitric acid (Conc. HNO_3) were carefully introduced to the two test-tubes and allowed to react. Potassium Chlorate being a strong oxidizing agent caused an instant reaction with the Nitric acid to effect maceration. The set-up was allowed to react in a fume cupboard while standing on a test-tube rack until the chips are softened and bleached. In tubes when the reactions were slow, the racks were put in an oven and heated to 60°C until the maceration of the chips occurred. Distilled water was poured in each of the tubes, covered and shaken and allowed to stand in a rack till the pulp settles. Excess solutions were decanted from the test-tubes and the softened bleached chips were washed several times with distilled water till they become clear. The softened chips were then separately transferred to 15 mls vial bottles (A and B) for each sample. A drop each of Phenol and Glycerine was added into the bottles. The phenol protects the fibres from fungal decay while glycerine removes air bubbles from the bottles. The fibres were then stained with safranine and mounted on slides in 30% glycerine, carefully covered with cover slips. Examinations were made using a KAYOWA TOKYO JAPAN monocular light microscope [8,9].

2.3 Measurement of Fibre Dimensions

The fibre diamensions were measured by fitting an eye-piece micrometre in the eye-piece tube of the light microscope. The ocular micrometer was first calibrated using a stage micrometer placed on the stage of the microscope by aligning its zero mark with that of the ocular. The number of units of the ocular which aligns with a given unit of the stage micrometer, in a given magnification was noted. This was used as the conversion factor in the subsequent measurements. The conversion factors were worked out as follows [9]:

- At ×40 magnification (20 units of ocular = 0.55 mm; 1unit of ocular = 0.55 mm/20 = 0.0275 mm).
- The conversion factor at ×40 = 0.0275 mm.
- At ×100 magnification (40 units of ocular = 0.54 mm; 1unit of ocular = 0.54/40 = 0.0135 mm)
- The conversion factor at ×100 = 0.0135 mm
- At ×400 magnification (71 units of ocular = 0.25 mm; 1unit of the ocular = 0.25 mm/71 = 0.004 mm).
- The conversion factor at ×400 = 0.004 mm.

The measured fibre dimensions include: Fibre length (L), Fibre cell wall thickness (C), Fibre lumen diameter (l), and Fibre diameter (D). Twenty five fibres were measured for each of the specimens. Runkel ratio, Coefficient of flexibility and Slenderness ratio were derived using the formula:

Runkel ratio (RR) = $2C/l$

Coefficient of Flexibility (CF) = l/D

Slenderness Ratio (SR) = L/D

2.4 Shear Strength Test

2.4.1 Preparation of samples

The preparations involved cutting small clear samples of the heartwood of the two timber species of fabaceae family: *E. suaveolens* and *P. macrophylla*. Twenty five of the graded samples of 20 mm^3 were made from each timber of the two species. This was adopted from the British Standard 373 [10] which is the standard in current use in most International Timber Research Centres. Twenty five clear samples (free from defects) were cut to the above dimensions along the grain for the two timber species. These samples were air-dried for 3 months to stabilize the moisture content [10].

2.4.2 Test procedure

But in this study, 20 mm^3 samples (20×20×20 mm) were fitted into the shear test jig such that the hook held the samples along the end-grains i.e. the transverse section of the cubes. Twenty five clear samples of each species were subjected to shear strength test, using a hounsfield tensometer. The strength property determined was shear strength parallel to the grain. The amount of force (in Newtons), which caused the samples to split, was noted. This was read off from the graphs plotted on the MONSATO graph as the tests were performed.

2.4.3 Data analysis

The various measured anatomical characters of the samples were subjected to a T- test using IBM-SPSS ver 20. Fibre dimensions of the various samples were correlated against the shear strengths.

3. RESULTS

As presented in Plate 1 and 2, the fibres of the wood from two plant species were observed to be long however, the result on the fibre length showed that *P. macrophylla* had significantly longer ($P < 0.001$) fibre as compared to

E. suaveolens (Table 1). Alternatively, the wood fibre diameter of the two plants did not show significant differences. While *E. suaveolens* recorded significantly (P < 0.001) wider fibre lumen diameter and higher coefficient of flexibility, *P. macrophylla* had significantly (P < 0.001) thicker fibre cell wall, higher Runkel and slenderness ratios (Table 1).

The result on Fig. 1 shows the shear strength of the wood from the two plant species. The share strength of the 25 wood samples from the two plants each fluctuated around 100 to 200 N/mm^2. On the average, *P. macrophylla* recorded higher shear strength as compared to *E. suaveolens* however no significant difference was recorded between the means when tested for significant differences using independent sample t-test (Fig. 1).

The fibre dimensions and the share strength were correlated and the result as presented on Table 2 shows significant positive correlation between fibre length and fibre lumen diameter, cell wall thickness, Runkel and slenderness ratios, while coefficient of flexibility correlated negatively. The fibre diameter only had a significant positive relationship with lumen diameter and negative relationship with slenderness ratio. Although the shear strength of the wood showed very weak positive and negative relationships with the fibre dimensions, none was significant (Table 2).

4. DISCUSSION

In this present studies, the anatomical characteristics showed variations in fibre length; fibre diameter; fibre lumen diameter; fibre cell wall thickness and in the derived values: Runkel ratio; slenderness ratio; coefficient of flexibility. More so, variations similarly occurred within the different test wood pieces of the species in the strength parameter assessed. This corroborates the report of Ajuziogu et al. [11] who showed that no two pieces wood, even if cut from the same tree, are exactly alike. The strength parameters tested however did not varied significantly among the timber species.

According to Speck et al. [12], Spatz et al. [13], Niklas et al. [14] and Ajuziogu et al. [11], the relationship between anatomical and mechanical properties of plant tissues has been subjected to substantial speculation.

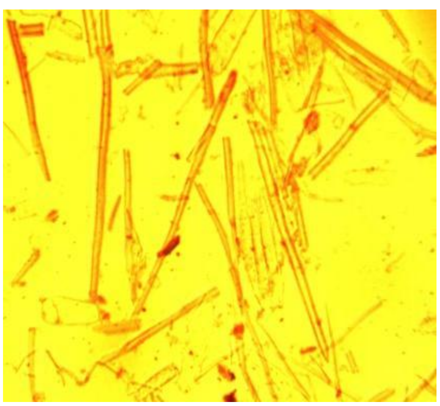

Plate 1. A microphotograph of *P. macrophylla suaveolens* fibre (×100)

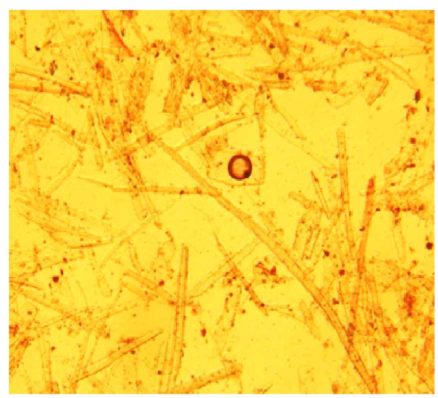

Plate 2. A microphotograph of *E.* fibre (×100)

Table 1. Comparison of *P. macrophylla* and *E. suaveolens* fibre characteristics

Mean values (mm)	*P. macrophylla*	*E. suaveolens*
Fibre Length	0.5621 ± 0.0169***	0.3978 ± 0.0143
Fibre diameter	0.0237 ± 0.0006	0.0174 ± 0.0008
Fibre Lumen Diameter	0 .0086 ± 0.0003	0.0109 ± 0.0005***
Fibre Cell Wall Thickness	0.0047 ± 0.0002***	0.0032 ± 0.0001
Runkel Ratio	1.1180 ± 0.0605***	0.6053 ± 0.0368
Coefficient of Flexibility	0.5320 ± 0.0181	0.6801 ± 0.0175***
Slenderness Ratio	34.0538 ± 1.3161***	25.1616 ± 1.0898

**Means with asterisk represent significantly higher at P < 0.001 using independent sample t- test*

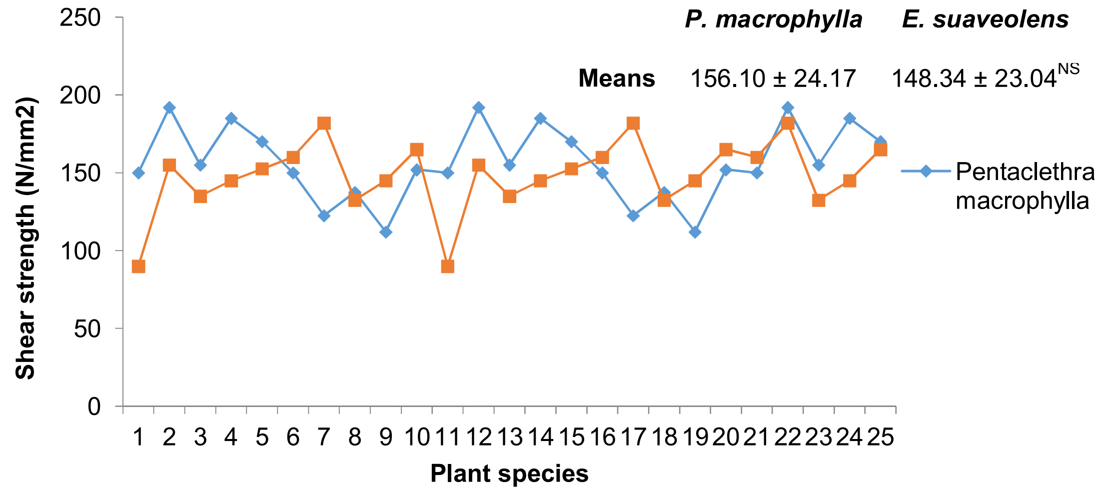

Fig. 1. Shear strength of the wood of two plant species

Table 2. Correlation coefficients of the fibre dimensions and shear strengths

	Fibre length	Fibre diameter	Fibre lumen diameter	Fibre Cell wall thickness	RR	CF	SR	Shear strength
Fibre length	1	.184	-.331*	.525**	.555**	-.565**	.821**	.159
Fibre diameter		1	.514**	.196	-.080	-.277	-.389**	-.079
Fibre lumen diameter			1	-.387**	-.717**	.666**	-.576**	-.156
Fibre cell wall thickness				1	.869**	-.588**	.371**	.106
RR					1	-.751**	.561**	.180
CF						1	-.354*	-.111
SR							1	.178
Shear strength								1

**. Correlation is significant at the 0.05 level (2-tailed); **. Correlation is significant at the 0.01 level (2-tailed)*

However, it is evident that, beside their physiological functions, every tissue type contributes in some way to the mechanical behavior of organs. The from the correlation analysis, the insignificant positive relationship observed between the fibre characters and shear strengths implies that the fibres positions do not add to the shear strength of the wood. This could explain the non-significant differences observed in the shear strength of the wood from the two species irrespective of the fact that the fibre characteristics evaluated differed significantly. This finding would therefore support the report of Grekin and Surini, [2] and Haller [15] who reported that the strength and stiffness of wood, predominantly along the grain, is decisively dependent on density.

5. CONCLUSION

In conclusion, since the shear strength of *E. suaveolens* is comparable to that of *P. macrophylla,* it is therefore recommended for use in the manufacturing of wood based food contact materials in order to relieve the pressure and demand on *P. macrophylla*.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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