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The Relationship of Microstructure, Density and Bending Strength Properties of *Blighia sapida*

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Abstract

Wood anatomical structures of various tree species help identify the wood. The characteristics and composition of these structures affect their utilisation. In this work, the microstructure of *Blighia sapida* a lesser-known Ghanaian hardwood species using light microscope and scanning electron microscope (SEM) was studied. The relationship between the microstructure and some physical properties such as density, and bending strength were also studied. The anatomical features studied were fibre length, double fibre wall thickness, fibre proportion, vessel diameter and proportion, rays and axial parenchyma proportions. It was observed that the use of SEM in studying the anatomical or ultra-structural aspects of wood gives a clearer understanding of the features and structures found in wood. Anatomical features such as presence of crystals and absence of axial parenchyma in *Blighia sapida* are reported in the work. The study also established that *Blighia sapida* had a low water uptake even though it had vessel distribution of 12 vessels/mm^2. Having not very distinct axial parenchyma may have accounted for the low water uptake. The presence of occluded pits could also account for the low water uptake and the fibre wall thickness may also account for a medium bending strength of 62.8 N/mm^2 at 12% moisture content.

Keywords

Microstructure, *Blighia sapida*, Scanning Electron Microscope, Fibre Length, Axial Parenchyma, Density, Bending Strength, Absorption

1. Introduction

Blighia sapida is a tree moderately distributed in all forest zones and Savannah woodland of Ghana [1]. It is a lesser-known species of medium occurrence and is yet to be exploited. The prescribed minimum felling diameter is 90 cm and is cited by International Union for Conservation of Nature and Natural Resources [2] as a lower risk and least concern species. The tree grows up to 25 m high, 3 m in girth with a crooked bole of 16 m and heavy crown [1]. *Blighia sapida* is evergreen and is widely planted as a shade tree in villages in the forest and Savannah areas [3]. It is known to contain crystals around the trunk [4]. According to [5], after testing in the field, its natural durability is rated as moderately durable.

Many factors have contributed to the deforestation of tropical forest which has resulted in a loss of more than 52 million ha of forest cover over the last five decades [6]. One factor that contributes to depletion of tropical forest, and therefore timber trees is wrong identification of timbers of commerce. The heterogeneous nature of tropical forests of Africa, with many trees per unit area, has further compounded the problem of identification. Export of wrongly identified timber has resulted in penalties being imposed to the detriment of the exporter and exporting country. Furthermore, a wrongly identified timber species, when used in an application not intended for, may often lead to a shorter service life [6].

The lesser-known species are of acceptable quality and some of high strength but are irregularly exported because of low international market demand for them. According to [6], they are of variable occurrence in the forest and are generally of very low extraction rate. He explained that a comparison of harvested volume from 2000 to 2003 from the reserve forests shows that 16.92% of premium species were harvested with 6.09%, 3.20% and 0.18% for the commercial species, lesser utilised species (LUS) and lesser-known species (LKS), respectively. On the other hand, the lesser-known species are species whose properties and qualities are much less known [7] and have the potential to be promoted for use locally.

A reliable knowledge of wood anatomical properties and the behaviour of wood under stress are essential for engineers, architects, and carpenters for the efficient use of wood [8]. The anatomical structures of wood for example, play an important role in selecting the proper wood for particular usage because it affects strength properties, appearance, resistance to preservative treatment, and resistance to decay. In this work, anatomical features of *Blighia sapida* were studied using the light microscope as well as the scanning electron microscope to confirm some of the findings using manual identification tools. According to Dickson [9], resistance to applied forces is a function of the total amount and proportion of cell wall material (cellulose and lignin) in a wood sample and the number of extractives in the cell lumen. So, this study will also find the relationship between the microstructure and density and bending strength properties of the wood species.

2. Methodology

2.1. Materials

Samples of trees of *Blighia sapida* were felled in the Fenaso Nkwanta Forest, which is 60 km south of Kumasi, near the gold mining town of Obuasi in the

Ashanti Region of Ghana. The trees were first identified by a technical officer from the Forestry. Leaves and seeds from the trees were collected and sent to the laboratory in Kumasi for the confirmation of the field identification using the field guide to the forest trees of Ghana by [1]. Each tree was of a diameter greater than 50 cm at breast height and lengths of 15 m. Discs of about 10 cm thickness were cut at breast height of each tree for anatomical investigations when the trees were harvested. Care was taken not to include the pith area in all the samples prepared for the tests (**Figure 1**). Additionally, 10 - 15 beams were prepared for each of the ten wood species for the bending tests (**Figure 2**). All test pieces were sawn and planed to the approprate size, and they were lightly sanded with medium or fine sandpaper so as to remove all rough edges. Test pieces with cracks or other defects were rejected and not included in the experiments.

2.1.1. Air Dry Density

The samples were conditioned under laboratory conditions. Their weights were taken. The samples were pinned to the holding device and immersed into the liquid. The balance shows the weight of the displaced volume.

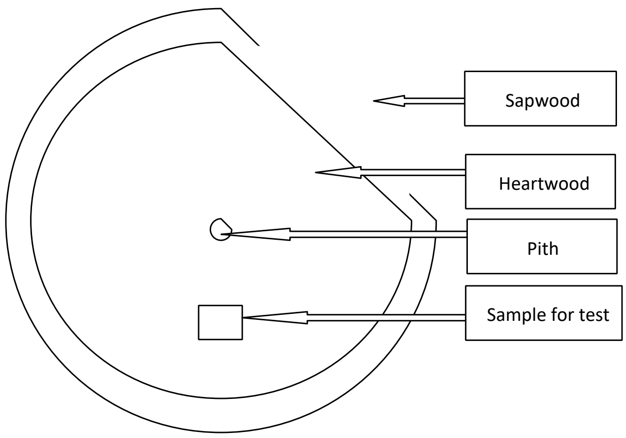


Figure 1. Schematic illustration showing the location of heartwood and sapwood samples in the disc.

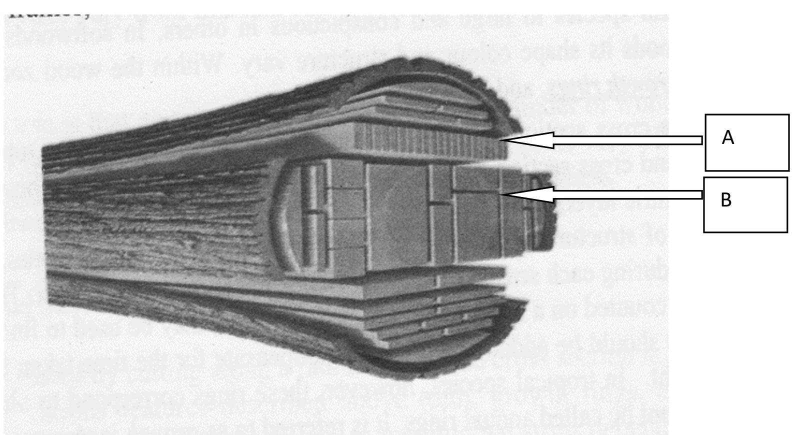


Figure 2. Log showing a diagrammatic sawing pattern. A = Section used for other tests B = Section for bending tests.

The air-dry density was then calculated with the formula in Equation (1) below.

Density calculated as defined in German standard [10] for oven dry density:

$$\rho_o \sim 0 = Mo/Vo$$

and according to German standard [11] for green density as:

$$\rho_u = Mu/Vu \qquad (1)$$

where Mo = oven dry weight of samples

Mu = weight of samples at moisture content u

Vo = oven dry volume

Vu = volume at moisure content u

Mu is measured after acclimatisation in standard clmate (50/23) until the weight is constant by 0.1%. Measurements taken every 24 hours.

2.1.2. Microstructure Investigation

The anatomical study was carried out in the wood anatomy laboratory of University of Applied Science in Biel, Switzerland. From each disc samples of 1 cm × 3 cm were taken from the heartwood portion. The preparation of samples and experimental set up is as described by [8]. They were weighed and their densities determined by the oven dry methods. The samples were then softened by first saturating with water and later soaking them in mixture of ethanol and glycerol (1:1) in labelled containers for an average period of about 21 days. Thin sections, 20 - 30 μm thick produced on a Leica sliding microtome were first washed in water and then stained in 1% safranin in 50% ethanol solution for about 15 minutes. After staining they were washed in water and dehydrated in increasing concentration of ethanol: 30%, 50%, 70%, 85%, 90% and 100%. After dehydration, they were permanently mounted in Canada Balsam. Slides were examined using a Leica DMLM light microscope, and photographs taken using a Leica DFC 320 digital camera fitted to it.

The photomicrographs produced were then analysed with software Leica IM 1000 Version 4.0 Release 132 which enables measurements to be made. Vessel diameter was obtained by measuring 30 randomly selected pores, then taking an average. The frequency of vessels per mm^2 was calculated by counting the number of vessels in thirty 1-mm^2 fields, then taking an average. The micrographs were also analysed using the stereological technique described by [12] [13] for the proportion of the tissues. Thirty randomly selected micrographs for each tissue studied were used for the study and then the average taken. Dots grids were used to determine area fractions (P_p) of anatomical elements and oriented segments of predetermined length were used to determine the number of elements per unit length of the test line in the radial and tangential directions (NL_R, NL_T) (**Figure 3**). Standard areas were used to determine the number of elements per unit area (N_A). These basic counts were then used to derive other parameters such as proportion of elements in percentages. Splinters were also taken from the discs and macerated in a solution of equal parts of Acetic acid and hydrogen peroxide and heated in an oven at about 65˚C for 72 hours.

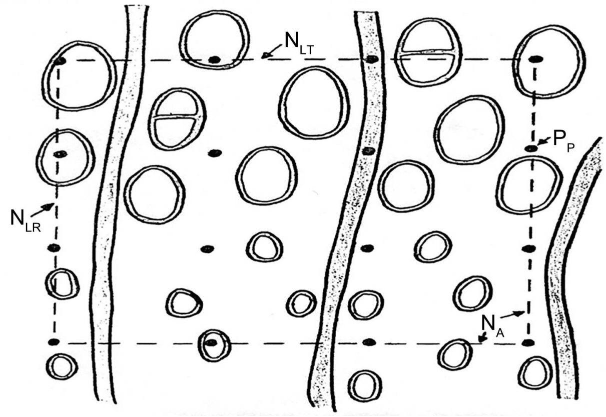


Figure 3. Counting grid used for stereological counts taken from Beery *et al.* 1982. P_P is area fractions of anatomical elements; NL_R and NL_T are the number of elements per unit length of the test line in the radial and tangential directions and N_A is the number of elements per unit area.

For the preparation of samples for the scanning electron microscope, small samples of wood of *Blighia sapida* were thoroughly impregnated with an alkyd or acrylic resin and then allowed to cure [14] [15]. The resin was known to be resistant to acids such as 72% sulfuric acid which was used to remove the cellulose and hemicelluloses from the sample, and to a 50:50 mixtures of 10% chromic and 10% nitric acids which dissolve the lignin. After careful washing with distilled water, the residue was a negative or cast of the openings in the wood which had been penetrated by the resin. After careful separation of the very small casts, they were dehydrated, mounted on a specimen stub, with a fixative solution of formalin. It was then coated with a thin layer of gold in a sputter coater. The prepared sample was then placed in the sample chamber of a scanning electron microscope with a spatial resolution of 8.0 nm at 5 kV. SEM photomicrographs were produced and analysed [15].

Features such as fibre length, double fibre wall thickness were also measured using the Leica light microscope and the software earlier described in the text. Anatomical features studied were fibre length, double fibre wall thickness, fibre proportion, vessel diameter and proportion, rays, and axial parenchyma proportions.

2.1.3. Determination of Bending Test

This test was conducted at the Civil Engineering Laboratory of Kwame Nkrumah University of Science and Technology. Ten to fifteen test specimens with dimensions 50 × 150 × 2900 mm were randomly sampled and loaded to failure by the three-point load according to European Standard [16]. The samples were obtained as shown in **Figure 2**. The test arrangement used (**Figure 4**), agreed with European testing standard [16] with two-point loads acting on the third point. According to testing standard [16] the worst defect possible to test was placed in the centre between the point loads and located randomly about the compression and tension side of the board. The position of the worst defect was determined based on visual inspection of the boards. After the MOE-values had

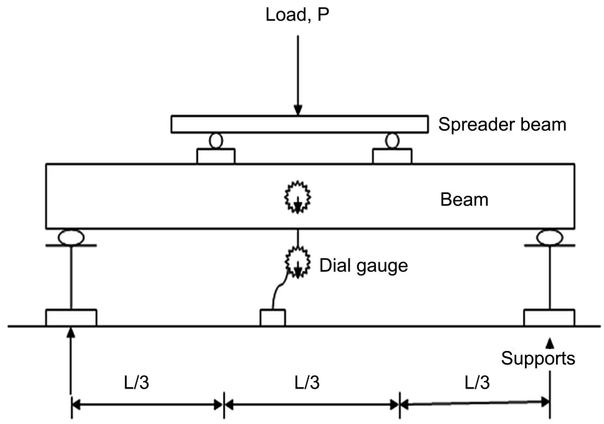


Figure 4. Test arrangements for determination of bending strength.

been determined, the boards were tested in bending to failure. For determination of moisture content ω and density small specimens were cut out close to the cross sections where failure occurred in the boards. In the testing standard [16] it is stated that the test pieces shall be conditioned at 20˚C and 65% relative humidity. The wood for testing had average moisture contents 29%.

3. Results and Discussion

3.1. Microstructure Analysis

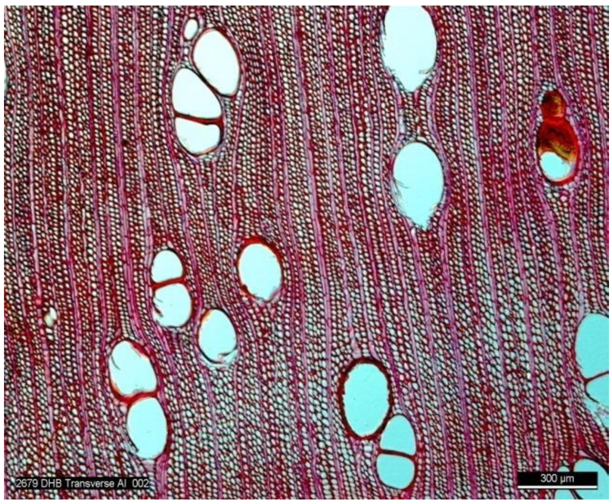
Stereological analysis of the microtome sections produced quantitative anatomical measurements presented in **Table 1**. *Blighia sapida* has 64.3% fibres, vessel proportion of 11.5% and a vessel density of 12 vessels/mm^2. It has an average vessel lumen diameter of 178 µm (maximum 281 µm, minimum 91 µm). Proportion of rays was of 24.3% and double fibre wall thickness of 432 µm with a mean vessel lumen diameter of 178 µm and a mean fibre length of between 1127 - 1303 µm.

Qualitative analysis of the anatomical investigations are shown in micrographs in **Figures 5(a)-(g)**. Measurements were taken from the transverse, radial, and tangential sections

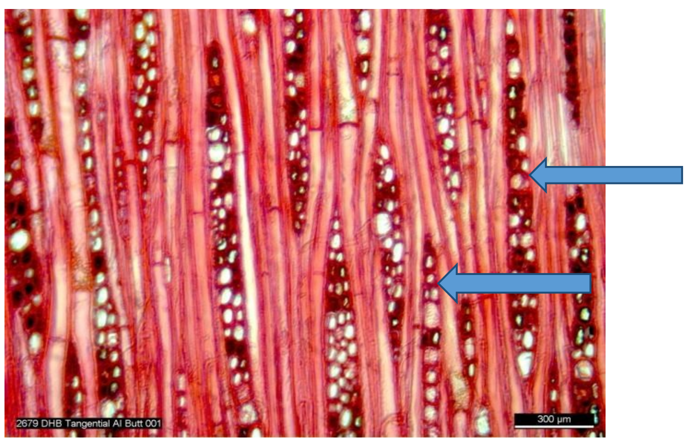
The features of *Blighi*a *sapida*, which were identified macroscopically by [7] and was also confirmed microscopically which were vessels distribution with inclusions, axial parenchyma not distinct and ray parenchyma not distinct. However, the microscopic tangential section (**Figure 5(b)**) gives a very distinct heterocellular ray parenchyma which are multiseriate and uniseriate. Furthermore, the SEM micrographs **Figures 5(e)-(g)** throws more light on how sculptured the vessels are, that there are not just inclusions in the vessels but some of the vessels are occluded as well as have prismatic substances in some of the vessel lumens. **Figure 5(f)** and **Figure 5(g)** will help to better understand the wood when in use. Vessel wall sculpturing as seen in **Figure 5(e)** agreed with the findings by [5]. According to [7] wood cells which serve principally as avenues of fluid conduction in living trees often form thick secondary walls which are important in providing mechanical support to stems in which they occur. Prismatic crystals occurring in the ray cells as depicted in Figure 5(c) and highlighted by SEM micrographs in Figure 5(g) was also confirmed by [5]. The presence of these substances could blunt tools when this species is being sawed and occupy sites where water could have occupied thereby contributing to lower water/moisture uptake.

Table 1. Proportion of tissues (and standard deviation SD) in *Blighia sapida.*

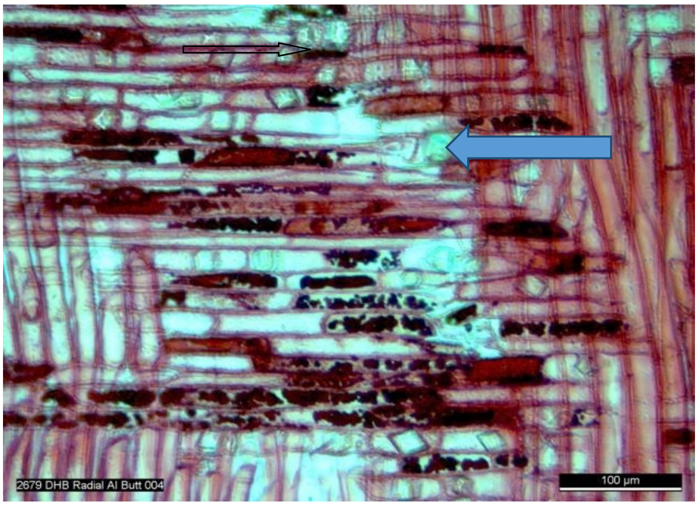
Anatomical features	µm (SD)	%
Fibres		64.3 (4.3)
Vessel		11.5 (4.5)
Vessel density		12 vessels/mm^2
Axial		-
Rays		24.3 (3.6)
Double Fibre Wall thickness	432 (0.9)	
Fibre length	1127 - 1303	
Vessel Lumen diameter	178 (91 - 281)	



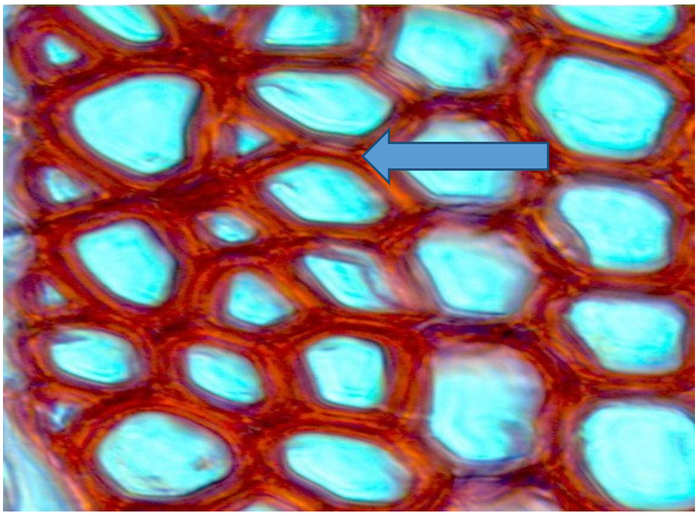
(a)



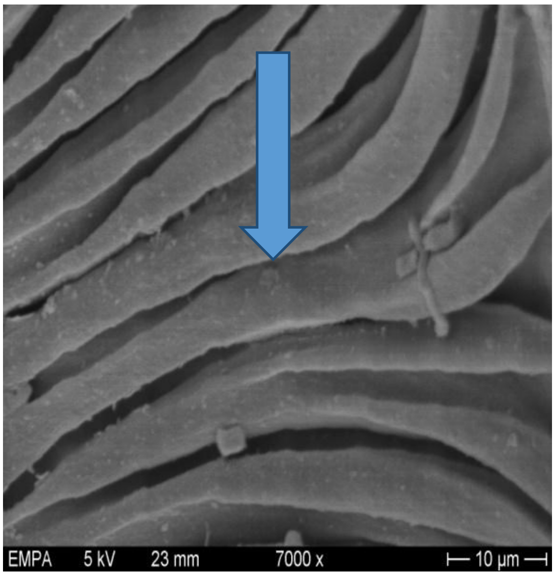
(b)



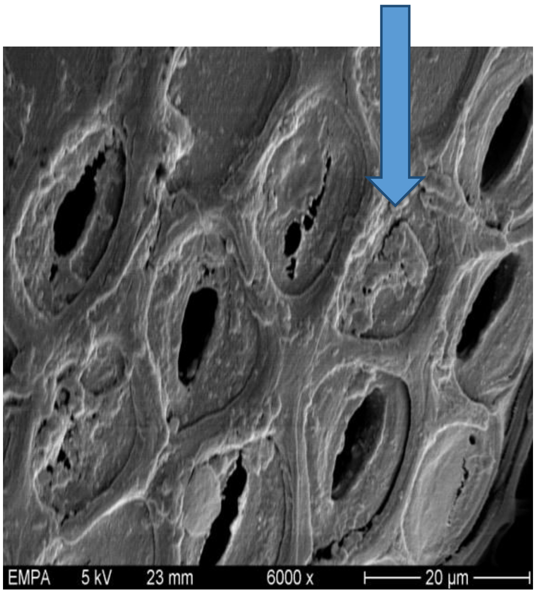
(c)



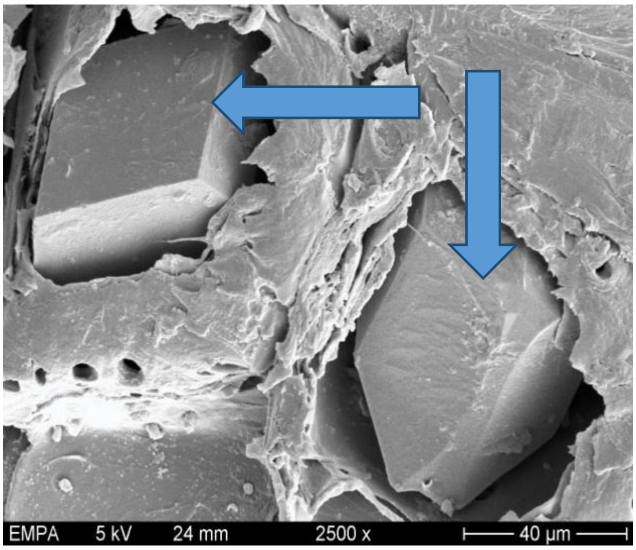
(d)



(e)



(f)



(g)

Figure 5. (a) Transverse section of *Blighia sapida showing* solitary vessels in radial multiples of 2 - 4. Scale bar = 300 µm Tylosis occluded some of the vessels. Axial parenchyma was not distinct; (b) Tangential section of *Blighia sapida* showing multiseriate (arrowed) and uniseriate (also arrowed) heterocellular rays with inclusions. Scale bar = 300 µm; (c) Radial section of *Blighia sapida* with ray cells containing some prismatic crystals (arrowed). Scale bar = 100 µm. (d) *Blighia sapida* medium walled fibers; (e) The sculptured vessel wall (arrowed) of *Blighia sapida*. 10 µm; (f) Some occluded pits (arrowed) of *Blighia sapida*. Scale bar = 20 µm. (g) Some crystals embedded in the rays of *Blighia sapida. (*arrowed) Scale bar = 40 µm.

3.2. Bending Test

The bending strength values of *Blighia sapida* is presented in Table 2. According to Table 2, *Blighia sapida* with air dry density of 900 kg/m^3 was found to have

Table 2. Bending strength at air dry moisture content and bending strength when adjusted to 12% moisture content (MC), moisture content at time of testing and density of the wood species.

Species	Bending strength (N/mm^2)		Moisture Content (%) at air dry	Density (kg/m^3) at air dry
	@Air dry	@12% MC		
Blighia sapida	41.4	42.08	29	900

a bending strength value of 41.4 N/mm^2 at a moisture content of 29%. When the bending strength values were adjusted to 12% moisture contents the strength values went higher which explains the fact that as wood dries it strength increases. *Blighia sapida* had its strength increasing from 41.4 N/mm^2 at 29% moisture content to 42.08 N/mm^2 at 12% moisture content. With the relatively shorter fibers belonging to *Blighia sapida* with lengths ranging from 1127 - 1303 µm. The shorter fibers may be responsible for the brittle behaviour *of Blighia sapida* observed under stress. According to Rowell [17], the density of wood varies with cell size, cell wall thickness, and the volume proportion of cells of a given type and this affects most wood utilisation. In particular, the strength of wood and its stiffness closely parallel changes in density. The denser a wood species the stronger its bending strength was established between the density and bending strength of *Blighia sapida* confirming the well-established fact that denser species because of thick-walled fibres and mass of wood tends to behave well under bending stress. Therefore, medium density will yield medium bending strength as in *Blighia sapida*.

4. Conclusion

Blighia sapida is a very useful plant. Its anatomical features studied were also unique. The identified cell wall sculpturing helps the species to survive in very difficult growing conditions and the presence of prismatic substances in the cell lumen of *Blighia sapida* which may affect transfer of substance between cells. The crystals may also affect machining of the wood by blunting the tools. The occluded pits of *Blighia sapida* could also hinder transportation of water and minerals between the cells. This study has enabled us to identify some of the features that were not visible macroscopically such as the presence of crystals and absence of axial parenchyma *in Blighia sapida* and established the relationship between the density of the wood and its bending strength. The medium density of *Blighia sapida* gives a medium bending strength.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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