POTENTIAL UTILIZATION OF Blighia sapida K. Koenig WOOD AS EXPLAINED BY SELECTED ANATOMICAL PROPERTIES

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February 22, 2024

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ABSTRACT

The wood of *Blighia sapida* when its anatomical properties are known could serve as an alternative for the exorbitant economic timber species. However, there is little information provided on the anatomical properties of the lesser-used species which could trigger its optimum utilization and wide range acceptability by timber marketers and end-users. There is, therefore, the need to evaluate the anatomical properties of the wood species.

Three *Blighia sapida* trees were selected and felled. Wood discs were obtained at the base, middle, and top of the trees, from which billets of 500 mm long were also obtained from pith to bark and then split into three zones; the innerwood, the middlewood, and the outerwood sections. By the specified standard for the anatomical property tests (Fibre length, Fibre diameter, Lumen width, and Cell wall thickness which were used for the estimation of derived morphological features; Slenderness coefficient, Flexibility ratio, Runkel ratio, Rigidity coefficient, Form factor, and Muhlsteph ratio as well as vessel length, vessel diameter, and vessel frequency) were all evaluated.

B. sapida was found to have thick cell walls which might be a setback to the production of quality paper, but a comparison of the cell wall thickness with that of the pines validated *B. sapida* wood fibre suitability for the pulp and paper industries if other morphological indices meet up with the requirements for the production of paper. However, the fibre length was short and the mean Runkel ratio, one of the major determinants of a fibrous material's appropriateness for production of quality paper, recorded for *B. sapida* wood was higher than 1 which makes it not suitable for quality paper production but other fibrous utilisation purposes could be explored, such as the production of intermediate papers that require strength. The species vessel length observed was within the category of short length vessels and vessel diameter was within the category of medium vessels, which is an indication that the wood will be denser, thereby having considerable mechanical strength that compared well with other economic timbers species, which could be used for medium to heavy construction works and the use of fillers will not also be employed to produce smooth the surface of quality paper during production.

Keywords: Lesser-used species, pulp and paper, Runkel ratio, wood anatomy.

INTRODUCTION

Wood serves as the resultant effect of the activity of the vascular cambium in a living plant, which produces wood (xylem) to the inner part and bark (phloem) to the outer portion of the cylindrical stem of a tree. Olayanu *et al.* (2022) opined that the rigid portion that exists between the bark of a tree and the pith, having various chemical compositions, with diverse properties that make it best fit for various end uses is referred to as the wood. In the construction industry, wood has proven to be indispensable owing to its fibrous nature and its ability to withstand a load to a reasonable extent when under applied forces. The viscoelasticity nature of wood has made it possible for wood to be stretched under applied load and still regain its original state or shape when the load is withdrawn.

However, the wanton clear felling of trees on forest lands to pave way for urbanization, cultivation of crops, charcoal production, and the desirous preference for durable and highly dense wood species has brought about scarcity and reduction in the availability of economic timber species, which has made Lesser Used Species to be improvised as the alternate source of wood for end-users; the rejected stone that has now become the cornerstone.

Blighia sapida is a tropical lesser-used hardwood tree species, which could also be employed for diverse uses when the anatomical properties are evaluated and known. According to Olayanu *et al.* (2022) who reported that *B. sapida* lesser used timber species, which is mainly cultivated for fruit production could also be converted by wood processors to sawn timber, in a bid to meet up the quest for wood, in the absence of the most sought-after ones.

Anatomical properties show the cellular morphological features of the wood and they vary greatly within and between tree species. Various methods could be employed for studying the anatomical properties of wood, which include the use of the light microscope, hand lens, and scanning electron microscope (Quartey 2015). The more common technique employed is the use of the light microscope which can help to survey several minutes' structures in a wood material within a short period whilst exploring the distribution of cells and the variations that exist in wood.

For wood species to be effectively utilized especially the lesser-used tree species, knowledge of their anatomical properties is very essential in determining utilization potential.

As reported by the Forestry Research Institute of Nigeria (1992) and as corroborated by Areo and Omole (2020) that the study of various timber species' anatomical structures, most especially the proportion of the cell, is to enhance the effective use of diverse wood species, for the purpose with which they are best used for. The study of anatomical features and structures of wood gives a better explanation of the properties of the wood species. It could be possible to make certain predictions about wood properties from careful anatomical examinations. *Ceiba petandra*, a tropical hardwood species, for instance, falls in the category of light density wood as a result of large vessels in its anatomical framework as research has proven that when the wood has large pores and high vessel frequency, it impacts negatively on wood density. The more the pores, the lesser the fibre which reduces the wood density and more fibres greatly impact the strength of wood. According to Quartey (2015), woods having cells with thicker walls would tend to be stiffer, heavier, and stronger than wood with thin-walled cells. Some anatomical features of wood such as the fibre cell wall thickness affect the bending strength of wood species.

An all-encompassing knowledge of the properties of tree species is germane for their effective utilization if they are to be employed for any engineering purposes. Through the exploration of the lesser-used tree species, it is believed that will not only reduce pressure on the economic and relatively scarce species but also help in the efficient management of the ecosystem (Ajala and Ogunsanwo 2011).

However, there is a dearth of information on the anatomical properties of the wood which would better suggest its usefulness in the production of pulp and paper and to better predict and substantiate the physical as well as strength properties of the wood species, because of efficient use of wood species is greatly determined by the anatomical properties' knowledge among others (Quartey 2015).

OBJECTIVE

This objective of this study is to evaluate the selected anatomical properties of *B. sapida* wood as a lesser-used timber species to provide technical information on its properties as well as provide possible utilization potentials, with a view of improvising for the scarce and exorbitant economic wood species and to enhance its optimum acceptability in the timber market.

MATERIALS AND METHODS

DETERMINATION OF FIBRE DIMENSION

From individual discs taken at various sampling positions purposively felled for the research work, central planks were obtained from pith to bark as used by H'ng Paik San *et al*. (2000) and were split into three zones: innerwood, middlewood, and outerwood.

MACERATION OF WOOD TEST SAMPLES

Wood slivers parallel to the grain were obtained from wooden cubes of 2 mm x 2 mm x 2 mm, which were obtained radially from the three zones; innerwood, middlewood, and outerwood as well as axially, from the base, middle and topmost section of the tree (Majekobaje 2018), macerated in equal volumes of hydrogen (1:1) of 10% glacial acetic acid and 30% hydrogen peroxide in an oven at about 100ºC for 2 hours according to the method of Franklin (1945). The fibres then become fully macerated with the colour changing to pure white and softened. The macerated fibres were placed in a petri dish with the addition of water and then agitated to enable segregation into individual fibres. On each slide, the macerated fibre samples were then viewed and measured under the microscope. The microscopy was done according to the American Society for Testing and Materials D1413-61 (2007) standard.

FIBRE MEASUREMENT

A macerated fibre was placed on a slide of 7.5 cm x 2.5 cm standard, using a dropper and the cells were measured following the process adopted by (Ogbonnaya *et al*. 1997). Under the Zeiss light microscope, fibre length, fibre diameter, and lumen width parameters were viewed under 10x magnification and recorded.

DERIVED MORPHOLOGICAL INDICES

Based on the method adopted by Oluwadare and Sotannde (2006), derived morphological indices were determined using these equations;

$$\text{Cell wall thickness} = \frac{Fibre\ diameter - Lumen\ width}{2} \quad (1)$$

$$\text{Slenderness} = \frac{Fibre\ length}{Fibre\ diameter} \quad (2)$$

$$\text{Flexibility Ratio} = \frac{Lumen\ width}{Fibre\ diameter} x\ 100 \quad (3)$$

$$\text{Runkel Ratio} = \frac{2\ x\ Cell\ wall\ thickness}{Lumen\ width} \quad (4)$$

$$\text{Rigidity} = \frac{Cell\ wall\ thickness}{Fibre\ diameter}\ x\ 100 \quad (5)$$

$$\text{F} - \text{factor} = \frac{Fibre\ length}{Fibre\ cell\ wall\ thickness} \quad (6)$$

$$\text{Muhlsteph Ratio} = \frac{Fibre\ width^2 - Fibre\ lumen\ width^2}{Fibre\ width^2}\ x\ 100 \quad (7)$$

SECTIONING

The determination of anatomical properties of wood species starts with sectioning of the wood materials. Sectioning could be referred to as the cutting of a thin slice of wood material. It was carried out with the use of a microtome. Before this, the 20 mm x 20 mm x 20 mm sample of woodblocks was treated in preparation for dissection based on the density collected. Specimens were boiled in water until they sank to the bottom of the beaker to be softened. In a way to display the dimensional planes, the woodblocks were oriented to show the transverse, radial as well as tangential sections. The thickness of the wooden parts eventually used and viewed under the microscope was 0.02 mm.

The measures taken in slide preparation are as follows:

- The wood segments were subjected to microtome for sectioning. The best wood sectioned for each sample location were picked i.e. the tiniest.
- The sectioned wood representatives for the transverse, radial, and tangential sections were stained with Safranine dye solution and left for about 5 minutes.
- The stained wood sections were then rinsed in water until the water becomes coulourless.
- Drops of ethanol were then added for dehydration.

- The sectioned wood portions were then subjected to droppings of clove oil to extract the ethanol solvent for a few minutes and to enhance easy trimming on the slides. Thereafter, they are covered with filter paper to get rid of the oil.
- With the use of Canadian balsam, the sectioned portions of the wood were mounted on the slides and covered with clips. The use of the Canadian balsam was to ensure the permanency of the slides, prevent collapsing, and stay clearer for a long period.

After the slide preparation, the representative slides of the samples were viewed under the microscope at the base, middle, and top as well as the innerwood, middlewood, and outerwood for all the sample trees. The dimensional planes were then observed, the vessels' photomicrographs were captured, and the vessel morphological indices were counted and measured.

EXPERIMENTAL DESIGN

The experiment was analysed using the two-factor split-plot design in a Randomized Complete Block Design (RCBD), with the three trees felled standing as replicates. The variables representing the functions are listed below:

a. The Base, Middle, and Top of the tree represented the sampling height

b. The Radial Position- Innerwood, Middlewood, and Outer wood

RESULTS

FIBRE LENGTH

The mean fibre length of *Blighia sapida* was 1.13 ± 0.01 mm. Axially, it slightly increased towards the middle and then decreased towards the top, with the base having 1.15 ± 0.01 mm, the middle having 1.17 ± 0.01 mm, and the top having 26.52 ± 0.01 mm as presented in Table 1.

Radially, fibre length decreased from the innerwood to the middlewood and then increased towards the outerwood. The innerwood had an average value of 1.16 ± 0.01 mm, the middlewood had 1.11 ± 0.01 mm, and the outerwood had a mean value of 1.13 ± 0.01 mm. At the base, fibre length decreased from the innerwood to the middlewood and then increased towards the outerwood. The innerwood had an average value of 1.15 ± 0.01 mm, the middlewood had 1.13 ± 0.02 mm and the outerwood had 1.17 ± 0.02 mm. In the middle, fibre length increased from the innerwood to the middlewood and then decreased towards the outerwood. The innerwood had 1.14 ± 0.02 mm, the middlewood was 1.21 ± 0.02 mm and the top had an average value of 1.18 ± 0.02 mm. At the top, fibre length decreased from the innerwood to the middlewood and then slightly increased towards the outerwood. The innerwood had an average value of 1.18 ± 0.02 mm, the middlewood 0.98 ± 0.01mm, and outerwood had a mean value of 1.07 ± 0.01mm as presented in Table 1.

The analysis of variance presented in Table 2 showed that there were significant differences within and between the trees (<0.05). The follow-up test further showed the level of significant differences at 0.05 in Table 1.

Table 1

Fibre Length, Fibre Diameter, Lumen Width, and Cell wall Thickness of Blighia sapida Wood

Sampling Height	**Radial Direction**	**Fibre length Mm**	**Fibre Diameter µm**	**Lumen width µm**	**Cell wall Thickness µm**
Base	Innerwood	1.17 ± 0.02^{a}	23.12 ± 0.35$_{a}$	9.80 ± 0.26$_{a}$	6.65 ± 0.17^{b}
	Middlewood	1.13 ± 0.02^{a}	23.47 ± 0.28^{a}	9.38 ± 0.30$_{ab}$	7.04 ± 0.15^{ab}
	Outerwood	1.15 ± 0.01^{a}	23.62 ± 0.24^{a}	9.03 ± 0.22^{b}	7.29 ± 0.14^{a}
Pooled Mean		**1.15 ± 0.01**	**23.40 ± 0.17**	**9.40 ± 0.15**	**7.00 ± 0.09**
Middle	Innerwood	1.14 ± 0.02^{a}	23.03 ± 0.47^{a}	12.87 ± 0.38^{a}	5.08 ± 0.22^{a}
	Middlewood	1.21 ± 0.02^{a}	23.91 ± 0.35^{ab}	12.78 ± 0.24^{a}	5.56 ± 0.16^{a}
	Outerwood	1.14 ± 0.02^{a}	21.88 ± 0.55^{b}	11.23 ± 0.36^{b}	5.32 ± 0.26^{a}
Pooled Mean		**1.17 ± 0.01**	**22.94 ± 0.27**	**12.29 ± 0.20**	**5.32 ± 0.12**
Top	Innerwood	1.07 ± 0.01^{b}	23.39 ± 0.34^{a}	14.44 ± 0.33^{a}	4.47 ± 0.10^{b}
	Middlewood	0.98 ± 0.01^{c}	23.60 ± 0.93^{a}	13.48 ± 0.50^{a}	5.06 ± 0.28^{a}
	Outerwood	1.18 ± 0.02^{a}	23.20 ± 0.27^{a}	12.07 ± 0.31^{b}	5.56 ± 0.12^{a}
Pooled Mean		**1.08 ± 0.01**	**23.40 ± 0.34**	**13.33 ± 0.23**	**5.03 ± 0.11**
Total Mean		**1.13 ± 0.01**	**23.25 ± 0.15**	**11.68 ± 0.13**	**5.78 ± 0.07**

Means ± Standard mean error of 20 replicate samples. Values with the same superscript on the same section (base, middle and top) were not significantly different at 5% probability level.

Table 2

Analysis of Variance of Fibre Length, Fibre Diameter, Lumen Width, and Cellwall Thickness of Blighia sapida Wood

Sources of variation	**Df**	**Fibre Length**	**Fibre Diameter**	**Lumen Width**	**Cellwall Thickness**
Tree	2	0.0000*	0.0000*	0.0336*	0.0000*
Sampling Height (SH)	2	0.0000*	0.3557^{ns}	0.0000*	0.0000*
Main plot error	4				
Radial Direction(RD)	2	0.0249*	0.1117ns	0.0000*	0.0000*
SH x RD	4	0.0000*	0.1413^{ns}	0.0900^{ns}	0.1209^{ns}
Subplot error	525				
Total	539				

ns = not significant (p-values > 0.05), while * = significant (p-values < 0.05)

FIBRE DIAMETER

The mean fibre diameter of *Blighia sapida* wood was 23.25 ± 0.15 µm. Axially, it decreased from the base to the middle and then increased towards the top, with the base having an average value of 23.40 ± 0.17 µm, the middle 22.94 ± 0.27 µm, and the top 23.40 ± 0.34 µm as shown in Table 1.

Radially, it increased from innerwood towards the middlewood and then decreased towards the outerwood. The innerwood had an average value of 23.18 ± 0.22 µm, the middlewood 23.66 ± 0.34 µm, and the outerwood had 22.90 ± 0.22 µm. At the base, it increased from the innerwood towards the outerwood, whereby the innerwood had an average value of 23.12 ± 0.3 µm, the middlewood 23.47 ± 0.28 µm, and an average value of 23.62 ± 0.24 µm for the outerwood. In the middle, there was an increment from the innerwood to the middlewood and then decreased towards the outerwood, whereby the innerwood had an average value of 23.03 ± 0.47 µm, the middlewood 23.91 ± 0.35 µm, and the outerwood had a mean value of 21.88 ± 0.55 µm. At the top, an increment from the innerwood towards the middle wood and then a slight decrease towards the outerwood, where the innerwood had an average value of 23.39 ± 0.34 µm, the middlewood 23.60 ± 0.93 µm, and 23.20 ± 0.27 µm average value for the outerwood as presented in Table 1.

The analysis of variance in Table 2 revealed the significant differences that exist among the Fibre diameter of the trees and no significant differences were observed along the sampling height and radial direction as well as their interaction. The follow-up test using the Duncan multiple range test further revealed the level of significant differences at 5% probability level.

LUMEN WIDTH

The *Blighia sapida* wood fibre had an average value of 11.68 ± 0.13 µm. Axially, an increment from the base to the top was observed with the base recording an average value of 9.40 ± 0.15 µm, the middle 12.29 ± 0.20 µm, and the top had an average value of 13.33 ± 0.23 µm as presented in Table 1.

Radially, a decrease from the innerwood to the outerwood was recorded, with the innerwood having an average value of 12.37 ± 0.23 µm, the middlewood had 11.88 ± 0.24 µm and the outerwood had 10.78 ± 0.20 µm. At the base, it decreased from the innerwood to the outerwood, with the innerwood having an average value of 9.80 ± 0.26 µm, the middlewood 9.38 ± 0.30 µm and the outerwood 9.03 ± 0.22 µm. In the middle, it also decreased from the innerwood to the outerwood, where the innerwood had an average value of 12.87 ± 0.38 µm, the middlewood had 12.78 ± 0.24 µm and an average value of 11.23 ± 0.36 µm for the outerwood. At the top, it also decreased from the innerwood to the outerwood, with the innerwood having an average value of 14.44 ± 0.33 µm, the middlewood 13.48 ± 0.50 µm, and the outerwood had 12.07 ± 0.31 µm as shown in Table 1.

The analysis of variance revealed in Table 2 presented the significant differences in the Lumen Width of *Blighia sapida* wood fibre, along the sampling heights and as well the radial direction. The interaction between the sampling height and the radial levels showed no significant difference. The follow-up test at a probability level of 0.05 percent further showed the level of significant differences in Table 1.

CELL WALL THICKNESS

The wood fibre of *Blighia sapida* recorded was 5.78 ± 0.07 μm with an increment from the base to the top axially, where the base had an average value of 7.00 ± 0.09 μm, the middle 5.32 ± 0.12 μm, and the top had an average value of 5.03 ± 0.11 μm as presented in Table 1. Radially, it increased from the innerwood to the outerwood, with the innerwood having an average value of 5.40 ± 0.12 μm, the middlewood 5.89 ± 0.13 μm, and the outerwood had a value of 6.06 ± 0.12 μm. At the base, an increment from the innerwood to the outerwood, where the innerwood had an average value of 6.65 ± 0.17 μm, the middlewood 7.04 ± 0.15 μm, and the outerwood had 7.29 ± 0.14 μm. In the middle, an increment from the innerwood to the middlewood and then a slight decrease towards the outerwood, where the innerwood had an average value of 5.08 ± 0.22 μm, the middlewood had 5.56 ± 0.16 μm and the outerwood had a mean value of 5.32 ± 0.26 μm. At the top, it also increased from the innerwood to the outerwood, where the innerwood had an average value of 4.47 ± 0.10 μm, the middlewood 5.06 ± 0.28 μm, and the outerwood had an average value of 5.56 ± 0.12 μm as shown in Table 1.

The analysis of variance in Table 2 revealed that there were significant differences in the Cell wall Thickness of the wood fibre from the trees, both along the sampling heights as well as across the radial direction (<0.05). The interaction between the sampling height and radial levels showed no significant differences. The follow-up test in Table 1 at a probability level of 5% further showed the level of significant differences.

SLENDERNESS RATIO

The mean slenderness ratio of *Blighia sapida* wood fibre was 49.9 ± 0.45. Axially, an increment from the base towards the middle and then a decrease towards the top, with the base having the average value of 49.72 ± 0.58, the middle had 52.63 ± 0.99 and the top had an average value of 47.41 ± 0.69 as shown in Table 3.

Radially, the Slenderness ratio decreased from the innerwood to the middlewood and then increased slightly towards the outerwood, with the innerwood having an average value of 51.90 ± 0.86, the middlewood 48.24 ± 0.75, and the outerwood 49.62 ± 0.73. At the base, the slenderness ratio decreased from innerwood towards the middlewood and then increased slightly towards the outerwood. The innerwood had an average value of 51.22 ± 1.13, the middlewood had 48.80 ± 0.96 and the outerwood had 49.12 ± 0.94. In the middle, the slenderness ratio increased from the innerwood to the outerwood, with the innerwood having an average value of 51.18 ± 1.56, the middlewood 51.55 ± 1.33, and the outerwood 55.14 ± 2.15. At the top, the slenderness ratio decreased from innerwood to the middlewood and then increased towards the outerwood, with the innerwood having an average value of 46.45 ± 0.95, and the middlewood 44.36 ± 1.43, while the outerwood is 51.43 ± 0.97 as presented in Table 3.

Table 4 presented the analysis of variance results that there were significant differences in the Fibre Slenderness ratio of *Blighia sapida* wood within and between the trees (<0.05). The follow-up test in Table 4 at a probability level of 0.05 further showed the level of significant differences.

Table 3

The mean values of Slenderness, Flexibility Ratio, Runkel Ratio, Rigidity coefficient, Form Factor and Muhlsteph Ratio along the sampling height and radial direction of Blighia sapida wood

SH*	**RD**	**Slenderness**	**Flexibility Ratio (%)**	**Runkel Ratio**	**Rigidity (%)**	**F-factor**	**Muhlsteph Ratio (%)**
Base	I	51.22±1.13[a]	42.60±1.06[a]	1.47±0.08[b]	28.69±0.53[b]	182.86±5.56[a]	81.18±0.82[b]
	M	48.80±0.96[a]	39.87±1.11[ab]	1.62±0.07[ab]	30.06±0.55[ab]	164.88±3.95[b]	83.36±0.97[ab]
	O	49.12±0.94[a]	38.35±0.96[b]	1.71±0.07[a]	30.82±0.48[a]	161.49±3.85[b]	84.74±0.74[a]
Pooled Mean		**49.72±0.58**	**40.27±0.61**	**1.60±0.04**	**29.86±0.30**	**169.74±2.69**	**83.09±0.50**
Middle	I	51.18±1.56[a]	56.37±1.52[a]	0.84±0.04[b]	21.81±0.76[a]	226.28±24.68[a]	66.85±2.04[a]
	M	51.55±1.33[a]	53.79±0.97[a]	0.89±0.03[ab]	23.10±0.48[a]	233.27±9.87[a]	70.49±1.06[a]
	O	55.14±2.15[a]	52.88±1.82[a]	1.04±0.08[a]	23.55±0.91[a]	285.17±25.95[a]	70.06±2.01[a]
Pooled Mean		**52.63±0.99**	**54.35±0.85**	**0.92±0.03**	**22.82±0.42**	**248.24±12.47**	**69.13±1.02**
Top	I	46.45±0.95[a]	61.60±0.84[a]	0.64±0.02[c]	19.19±0.42c	255.80±14.58[a]	61.62±1.12[a]
	M	44.36±1.43[a]	58.30±1.30[b]	0.76±0.03[b]	20.84±0.65[b]	246.67±20.07[a]	64.99±1.67[a]
	O	51.43±0.97[b]	51.87±1.10[c]	0.98±0.04[a]	24.06±0.55[a]	219.70±6.13[a]	72.36±1.17[b]
Pooled Mean		**47.41±0.69**	**57.25±0.70**	**0.79±0.02**	**21.37±0.35**	**240.72±8.55**	**66.33±0.84**
Total Mean		**49.92±0.45**	**50.63±0.52**	**1.10±0.02**	**24.68±0.26**	**219.57±5.33**	**72.85±0.56**

SH = Sampling height; RD= Radial Direction; I= Innerwood, M= Middlewood, O= Outerwood

Means ± Standard mean error of 20 replicate samples. Values with the same superscript on the same section (base, middle and top) were not significantly different at 5% probability level.

Table 4

Analysis of variance of means of Slenderness, Flexibility Ratio, Runkel Ratio, Rigidity coefficient, Form Factor, and Muhlsteph Ratio along the sampling height and radial direction of Blighia sapida Wood

Sources of variation	**df**	**Slenderness**	**Flexibility Ratio**	**Runkel Ratio**	**Rigidity**	**F-factor**	**Muhlsteph Ratio**
Tree	2	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
Sampling Height SH	2	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
Main plot error	4						
Radial Direction (RD)	2	0.0009*	0.0000*	0.0000*	0.0000*	0.7701[ns]	0.0000*
SH x RD	4	0.0116*	0.0209*	0.6294[ns]	0.0209*	0.0034*	0.0041*
Subplot error	525						
Total	539						

ns = not significant (p-values > 0.05), while * = significant (p-values < 0.05)

FLEXIBILITY RATIO

The mean flexibility ratio of *Blighia sapida* wood fibre was 50.63 ± 0.52. An increment from the base to the top was observed where the base had an average value of 40.27 ± 0.61, the middle had 54.35 ± 0.85 and the top had 57.25 ± 0.70 as presented in Table 3. Radially, the flexibility ratio decreased from the innerwood to the outerwood, where the innerwood had an average value of 53.52 ± 0.90, the middlewood had 50.66 ± 0.87 and the outerwood had 47.70 ± 0.92. At the base, a decrease from the innerwood to the outerwood was observed where the innerwood had an average value of 42.60 ± 1.06, the middlewood had 39.87 ± 1.11 and the outerwood had 38.35 ± 0.96. In the middle, there was a decrease from the innerwood towards the outerwood, where the innerwood had an average value of 56.37 ± 1.52, the middlewood had 53.79 ± 0.97 and the outerwood had a mean value of 52.88 ± 1.82. At the top, it decreased from the innerwood towards the outerwood, where the innerwood had an average value of 61.60 ± 0.84, the middlewood had 58.30 ± 1.30 and the outerwood had 51.87 ± 1.10 as shown in Table 3. The analysis of variance in Table 4 showed that at the tree level, along the sampling height, radial direction, as well as their interaction, were significantly different from one another (<0.05). The follow-up test of the Duncan multiple range test at a probability level of 0.05 further showed the level of significant differences.

RUNKEL RATIO

The mean value of runkel ratio of *Blighia sapida* wood fibre was 1.10 ± 0.02. Axially, it decreased from the base to the top, where the base had an average value of 1.60 ± 0.04, the middle 0.92 ± 0.03 and the top had 0.79 ± 0.02 as shown in Table 3.

Radially, the Runkel ratio increased from the innerwood towards the outerwood, where the average value observed for the innerwood was 0.98 ± 0.04, the middlewood was 1.09 ± 0.04 and the outerwood was 1.24 ± 0.04. At the base, it slightly increased from the innerwood to the outerwood, where the innerwood had an average value of 1.47 ± 0.08, the middlewood had 1.62 ± 0.07 and the outerwood had 1.71 ± 0.07. In the middle, it also increased slightly from innerwood to outerwood, where the innerwood had an average value of 0.84 ± 0.04, the middlewood 0.89 ± 0.03, and the average value of outerwood was 1.04 ± 0.08. At the top, it increased from the innerwood to the outerwood, where the innerwood had an average value of 0.64 ± 0.02, the middlewood had 0.76 ± 0.03 and the outerwood had 0.98 ± 0.04 as shown in Table 3

The analysis of variance presented in Table 4 showed that there were significant differences among the wood Fibre Runkel ratio of the trees, along the sampling heights and radial direction but the interaction of sampling height and radial direction was not significant. The follow-up test at a probability level of 0.05 further showed the level of significant differences.

RIGIDITY COEFFICIENT

The mean rigidity coefficient of *Blighia sapida* wood fibre was 24.68 ± 0.26. Axially, it decreased from the base to the top, where the base had an average value of 29.86 ± 0.30, the middle 22.82 ± 0.42 and the top had a mean value of 21.37 ± 0.35 as presented in Table 3.

Radially, a slight increment from the innerwood towards the outerwood was observed, where the innerwood had an average value of 23.23 ± 0.45, the middlewood 24.66 ± 0.43, and the outerwood had 26.14 ± 0.46. At the base it slightly increased from the innerwood to the outerwood, where the innerwood had an average value of 28.69 ± 0.53, the middlewood had 30.06 ± 0.55 and the outerwood had 30.82 ± 0.48. In the middle, it also slightly increased from the innerwood to the outerwood, where the innerwood had an average value of 21.81 ± 0.76, the middlewood had 23.10 ± 0.48 and the outerwood had 23.55 ± 0.91. At the top, it also increased from the innerwood to the outerwood, where the innerwood had the average value of 19.19 ± 0.42, the middlewood 20.84 ± 0.65 and outerwood average value 24.06 ± 0.55 as shown in Table 3.

As presented in Table 4 the analysis of variance showed that there were significant differences within and between the wood fibre of the tree species. The follow-up test at a probability level of 0.05 percent showed the level of significant differences.

FORM-FACTOR

The mean value of *Blighia sapida* wood fibre Form-Factor was 219.57 ± 5.33. Axially, it increased from the base to the middle and then decreased to the top, where the base had an average value of 169.74 ± 2.69, the middle 248.24 ± 12.47 and the top had 240.72 ± 8.55 as presented in Table 3. Radially, Form-factor decreased from the innerwood to the middlewood and then increased towards the outerwood, whereby the innerwood had a mean value of 221.65 ± 9.93, the middlewood 214.94 ± 7.99 and the outerwood had 222.12 ± 9.69 mean value. At the base, it decreased from the innerwood towards the outerwood, where the innerwood had an average value of 182.86 ± 5.56, the middlewood 164.88 ± 3.95, and the 161.49 ± 3.85 average value for the outerwood. In the middle, it increased from the innerwood to the outerwood, where the mean value of innerwood was 226.28 ± 24.68, the middlewood was 233.27 ± 9.87, and the outerwood was 285.17 ± 25.95. At the top, it decreased from the innerwood towards the outerwood, where the innerwood had an average value of 255.80 ± 14.58, the middlewood 246.67 ± 20.07, and the outerwood had 219.70 ± 6.13 as presented in Table 3.

The analysis of variance presented in Table 4 revealed significant differences at the tree level and sampling height but not significant in the radial direction. Also, the interaction between the sampling height and radial direction was not significant. The follow-up test revealed the level of significant differences at a probability level of 0.05.

MUHLSTEPH RATIO

The *Blighia sapida* wood fibre Muhlsteph ratio mean value recorded was 72.85 ± 0.56. Axially, it decreased from the base to the top, where the base had an average value of 83.09 ± 0.50, the middle 69.13 ± 1.02 and the top had an average value of 66.33 ± 0.84 as presented in Table 3.

Radially, Muhlsteph ratio increased from innerwood towards the outerwood, where the innerwood had an average value of 69.88 ± 1.02, 72.95 ± 0.93 was recorded for the middlewood, and the outerwood had 75.72 ± 0.94. At the base, it increased from the innerwood towards the outerwood, where the innerwood had an average value of 81.18 ± 0.82, the middlewood 83.36 ± 0.97 and the outerwood had a mean value of 84.74 ± 0.74. In the middle, it increased from the innerwood to the middlewood and slightly decreased to the outerwood, where innerwood recorded an average value of 66.85 ± 2.04, the middlewood 70.49 ± 1.06 and the mean value of outerwood was 70.06 ± 2.01. At the top, it increased from innerwood to outerwood, where the innerwood had an average value of 61.62 ± 1.12, the middlewood 64.99 ± 1.67, and the outerwood 72.36 ± 1.17 as shown in Table 3.

The analysis of variance in Table 4 showed significant differences within and between the trees. The follow up test at a probability level of 0.05 further revealed the level of significant differences.

Micrographic Sectioning Analysis of *Blighia sapida* (Ackee Apple) Wood

Table 5

The Mean Values of Vessel Length, Vessel Diameter, and Vessel Frequency of Blighia sapida Wood

Sampling Height	**Radial Direction**	**Vessel Length (μm)**	**Vessel Diameter (μm)**	**Vessel Frequency (μm)**
Base	Innerwood	$207.06±9.43^{ab}$	$119.28±4.37^{b}$	$2.25±0.13^{a}$
	Middlewood	$225.96±8.15^{a}$	$145.74 ± 4.65^{a}$	$2.05±0.09^{a}$
	Outerwood	$189.84±8.11^{b}$	$126.63±4.00^{b}$	$2.00±0.14^{a}$
Pooled Mean		**207.62±5.05**	**130.55±2.63**	**2.10±0.07**
Middle	Innerwood	$226.17±6.93^{b}$	$167.58±5.38^{a}$	$1.78±0.10^{a}$
	Middlewood	$244.65±10.51^{a}$	$163.38±6.81^{ab}$	$1.65±0.11^{a}$
	Outerwood	$215.25±9.30^{b}$	$149.73±4.30^{b}$	$1.86±0.14^{a}$
Pooled Mean		**228.48±5.28**	**160.23±3.26**	**1.76±0.07**
Top	Innerwood	$255.36±10.13^{a}$	$154.98±5.03^{a}$	$2.15±0.13^{b}$
	Middlewood	$214.83±8.32^{b}$	$155.82± 4.84^{a}$	$2.58±0.14^{a}$
	Outerwood	$224.07±9.13^{b}$	$160.65±5.07^{a}$	$2.00±0.11^{b}$
Pooled Mean		**231.42±5.45**	**157.15±2.86**	**2.25±0.07**
Total Mean		**222.57±3.06**	**149.31±1.78**	**2.04±0.04**

Means ± Standard mean error of 20 replicate samples. Values with the same superscript on the same section (base, middle and top) were not significantly different at 5% probability level.

Table 6

Analysis of Variance of Means of Vessel Length, Vessel Diameter, and Vessel Frequency of Blighia sapida Wood

Sources of variation	Df	Vessel Length	Vessel Diameter	Vessel Frequency
Tree	2	0.2167^{ns}	0.0000*	0.0127*
Sampling Height SH	2	0.0016*	0.0000*	0.0000*
Main plot error	4			
Radial Direction(RD)	2	0.0088*	0.0386*	0.4126^{ns}
SH x RD	4	0.0032*	0.0011*	0.0097*
Subplot error	525			
Total	539			

ns = not significant (p-values > 0.05), while * = significant (p-values < 0.05)

VESSEL LENGTH

The mean vessel length of *Blighia sapida* wood was 222.57 ± 3.06 µm. Axially, vessel length increased from the base to the top, where it had a mean value of 207.62 ± 5.05 µm at the base, the middle 228.69 ± 5.26 µm, and the top had 231.42 ± 5.45 µm as presented in Table 5.

Radially, Vessel length decreased from the innerwood to the outerwood, where the innerwood had an average value of 229.53 ± 5.34 µm, the middlewood 228.48 ± 5.28 µm, and the top had 209.72 ± 5.20 µm. At the base, it increased from the innerwood to the middlewood and then decreased towards the outerwood, where the innerwood had an average value of 207.06 ± 9.43 µm, the middlewood 225.96 ± 8.15 µm, and the outerwood had 189.84 ± 8.11 µm. In the middle, it increased from the innerwood to the middlewood and then decreased towards the outerwood, where the innerwood had an average value of 226.17 ± 6.93 µm, the middlewood 244.65 ± 10.51 µm, and the outerwood had 215.25 ± 9.30 µm. At the top, it decreased from the innerwood to the middlewood and then slightly increased towards the outerwood as shown in Table 5.

The analysis of variance presented in Table 6 showed no significant differences among the Vessel Length means of the trees but significant along the sampling heights, radial direction as well as their interaction. The follow-up test at a probability level of 0.05 further showed the level of significant differences.

VESSEL DIAMETER

As it was presented in Table 5, the *Blighia sapida* wood vessel diameter mean value was 149.31 ± 1.78 µm. Axially, it increased from the base to the middle and then slightly decreased towards the top, where the average value of 130.55 ± 2.63 µm was recorded at the base, 160.23 ± 3.26 µm at the middle, and 157.15 ± 2.86 µm at the top.

Radially, it increased slightly from innerwood to the middlewood and then decreased slightly towards the outerwood, where the innerwood had an average value of 147.28 ± 3.22 µm, the middlewood 154.98 ± 3.21 µm, and 145.67 ± 2.78 µm outerwood mean value. The vessel diameter increased from the innerwood towards the middlewood and then decreased towards the outerwood at the base, where the innerwood had an average value of 119.28 ± 4.37 µm, the middlewood 145.74 ± 4.65 µm, and the outerwood had 126.63 ± 4.00 µm. In the middle, it decreased from the innerwood to the outerwood, where the innerwood had an average value of 167.58 ± 5.38 µm, the middlewood 163.38 ± 6.81 µm, and the outerwood had 149.73 ± 4.30 µm. At the top, it increased from innerwood to the outerwood, where the innerwood had an average value of 154.98 ± 5.03 µm, the middlewood 155.82 ± 4.84 µm and the outerwood had 160.65 ± 5.07 µm as presented in Table 5.

The analysis of variance presented in Table 6 showed the significant differences between and within the trees. The follow up test at a probability level of 0.05 further showed the level of significant differences.

VESSEL FREQUENCY

The mean vessel frequency of *Blighia sapida* wood was 2.04 ± 0.04 mm^2. Axially, it decreased towards the middle and then increased towards the top of the tree, where the average value of 2.10 ± 0.07 mm^2 was recorded at the base, 1.76 ± 0.07 mm^2 at the middle, and 2.25 ± 0.07 mm^2 at the top as presented in Table 5.

Radially, it slightly increased from the innerwood towards the middlewood and then decreased towards the outerwood, where the innerwood had an average value of 2.06 ± 0.07 mm^2, the middlewood 2.09 ± 0.07 µm, and the outerwood had 1.96 ± 0.07 mm^2. The wood vessel frequency decreased from the innerwood to the outerwood, where the innerwood had an average value of 2.25 ± 0.13 mm^2, the middlewood had 2.05 ± 0.09 mm^2 and the outerwood had 2.0 ± 0.14 mm^2. In the middle, it slightly decreased from the innerwood towards the middlewood and then increased to the outerwood, where the innerwood had a mean value of 1.78 ± 0.10 mm^2, the middlewood 1.65 ± 0.11 mm^2 and the outerwood had 1.86 ± 0.14 mm^2. At the top, it increased from innerwood towards the middlewood and then decreased towards the outerwood. Where the innerwood had an average value of 2.15 ± 0.13 mm^2, the middlewood 2.58 ± 0.14 mm^2, and the outerwood had 2.0 ± 0.11 mm^2 as shown in Table 5.

Table 6 presented the analysis of variance where it showed the significant differences among the Vessel frequency of the sampled trees and along the sampling height but not significant in the radial direction. The interaction between the sampling height and radial direction also showed significant differences. The follow-up test at a probability level of 5% further showed the level of significant differences.

PHOTO MICROGRAPHIC DESCRIPTION OF THE *BLIGHIA SAPIDA* WOOD.

Vessels were diffuse mostly solitary, pore pairs and radial multiple of three were present, axial parenchyma cells were scanty and in radial bands of uniseriate. Rays were mostly uniseriate, biseriate rays were also present, ray cells were procumbent, intervascular pits were small, perforations were simple, and fibres were bordered at the radial section.

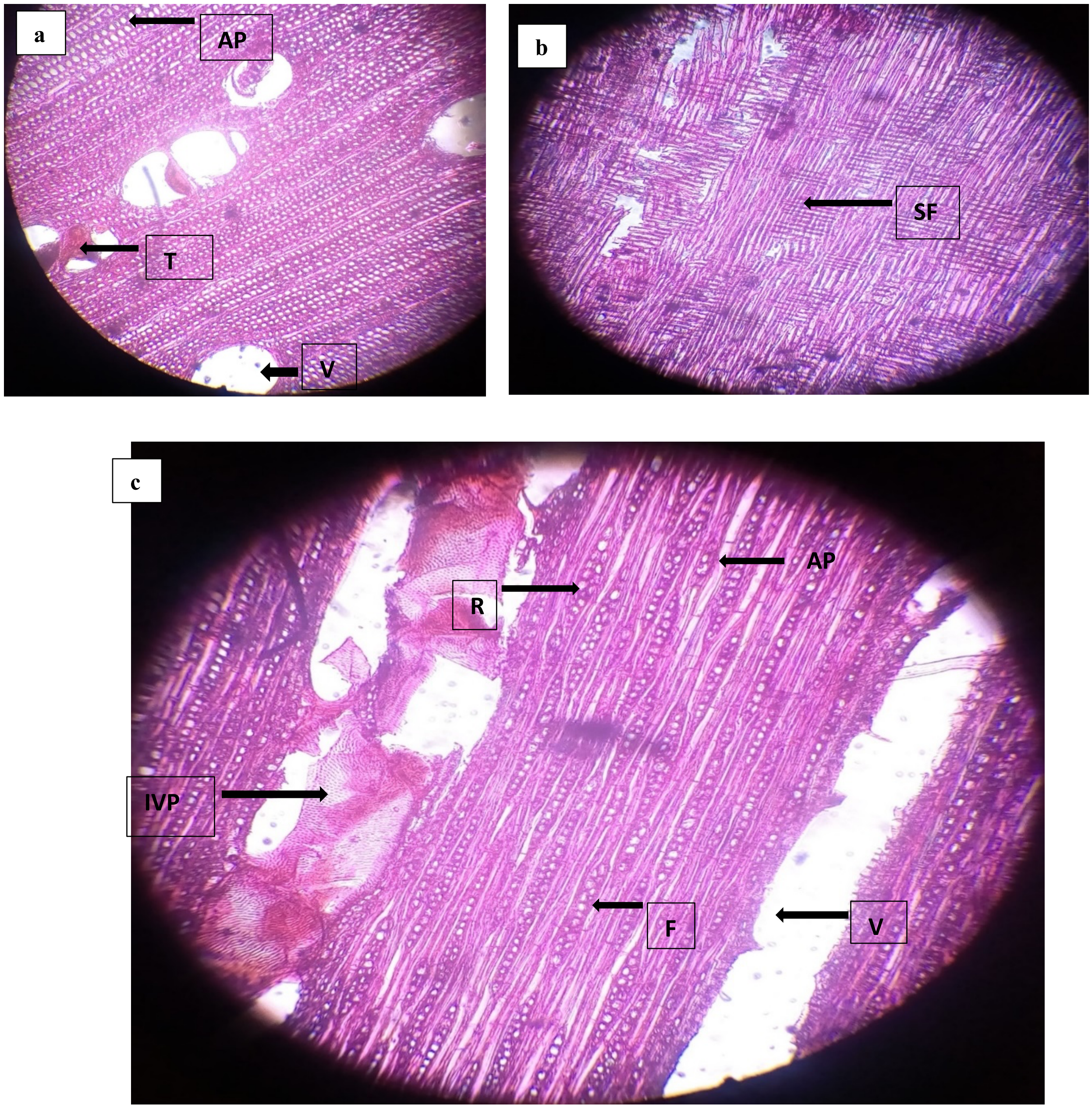

Fig. 1.
Micrographic description of sections of Blighia sapida wood Anatomy
a - transverse section; b - radial section; c - tangential section

AP = Axial Parenchyma; R = Ray; F = Fibre; IVP = Intervessel Pitting; V = Vessel; T = Tylosis; SF = Storied and Septate Fibre

DISCUSSIONS

FIBRE LENGTH

The mean value of fibre length of *Blighia sapida* wood was 1.13 mm, having a range value of (1.08 - 1.15 mm) which is lower than 1196 – 1274 µm observed in Ghana by Quartey (2015). This could be a result of factors such as site growth, climatic condition, age of the trees studied, and the portion along the bole from which samples were collected (Areo *et al.* 2020). Also, Ajala and Ogunsanwo (2011) reported the documentation of Panshin and deZeeuw (1980) that the extent of wood maturity played a significant role in the magnitude and pattern of wood property variability. A site with favourable growth conditions such as a large amount of rainfall and moderate temperature with good porosity and drainage ability enhances rapid production of wood by the vascular cambium, which produces more of long fibres resulting from the juvenile wood produced from the process. The more the age of a tree, the more the matured wood in it and the more the short length fibres of wood, as juvenile wood is more of long fibres than mature wood.

The fibre length of 1.13mm was higher than 0.65mm reported for *Leucaena leucocephala* by Oluwadare (2007), and 1.07mm reported for *Ficus exasperata* by Anguruwa (2018). However, it is less than 1.34 mm obtained by Riki and Oluwadare (2020), less than 1.29 mm for *Gmelina arborea* as reported by Roger *et al*., (2007); 1.28 mm, and the range of 0.99 mm to 1.24 mm for *Gmelina arborea* and *Ficus spp*, by Ogunkunle (2010); lower than 1.76 in *Aningeria robusta* by Ajala and Noah (2019); 1.40 mm in *Ricinodedron Heudelotii* by Ogunleye *et al.,* (2017); 1.38mm in *Gerdenia ternifolia* reported by Noah *et al*. (2015), 1.52mm reported for *Artocarpus altilis* by Areo and Omole (2020) and 1. 48mm in *Vitex doniana* reported by Ogunjobi *et al.,* (2014) in Nigeria. Hindi *et al*., (2010) also reported that *Leucaena leucocephala*, *Azadirachta indica,* and *Simmondsia chinens* had a fibre length of 1.13mm which is the same as the fibre length observed for *Blighia sapida* wood fibre, 1.04mm and 0.50 mm respectively, which are lower than the length observed for *Blighia sapida*.

However, the length of fibre greatly affects the strength of the pulp and the paper made from it (Kaila and Aittamaa, 2006; Oyelere *et al*., 2019). Therefore, paper made from *Blighia sapida* is expected to show higher quality than from the woods of *Leucaena leucocephala*, *Azadirachta indica, Ficus exasperate,* and *Simmondsia chinens* with shorter fibres. According to (Oluwadare and sotannde, 2007) higher fibre length results in greater resistance of the paper to tearing and is necessary for producing strong and durable paper. However, *Blighia sapida* has a short fibre length, since the mean fibre length was lower than 1.60mm as fibre below 1.60 mm is classified as short while those above 1.60 mm are said to be long as reported by Ogunjobi *et al.,* (2014). Therefore, it is not suitable for quality paper production. However, it may be used in combination with long length fibres to produce some specialty papers such as art papers that require strength as a major requirement, most especially the surface strength. Hardwood produces short fibres, which are known to be dense and deliver strength to paper. In view of that, *Blighia sapida* short wood fibre will conform well in combination with long length fibres to produce specialty papers that require strength.

The observed variation in the length of the fibre length along the vertical axis of the wood shows that fibre length slightly increased towards the middle and then decreased towards the top. And according to Zobel and Buijtenen (1989) who reported that the variations in fibre length characterized by an increase in the distance are mostly due to differences in the ratio of immature and mature wood in the tree, as the ratio of immature wood results in an increased fibre length. This is a pattern reported in the study of Tavares *et al.,* (2011) on *Acacia nilotica* as it slightly increased towards the middle and then decreased towards the top with a variation of 1.12 mm in the base, 1.16 mm in the middle, and 0.986 mm in the top of the tree. This trend is also in agreement with the report of Ogunjobi *et al*., (2014) who reported an irregular pattern of variation along the axial length of the wood and it slightly derailed from the trend observed by Riki and Oluwadare (2020) and Areo and Omole (2020) who reported a decrease from the base to the top as the trend observed in *Blighia sapida* increased from the base to the middle and then decreased to the top.

Radially, it also follows an irregular pattern by slightly decreasing from innerwood towards the middlewood and then increasing to the outerwood. This pattern of variation is not in agreement with ogunjobi *et al.,* (2014), Tavares *et al*., (2011), Ogunleye *et al*., (2017), and Riki and Oluwadare (2020) who reported an increase from the innerwood to the outerwood. The inconsistency variation pattern may have been a result of defects in the wood as a result of the tree age. Matured trees in the forest with hollows, due to a lack of appropriate silvicultural practices, tend to have heart rot which is a result of the fungal attack and this will greatly have a negative impact on the structural integrity of the wood thereby bringing about the inconsistent pattern of variation in wood. And according to Green *et al.,* (1999) who opined that the pattern of variation may have been due to the fact that wood is a natural material, therefore it is subject to many changing influences.

FIBRE DIAMETER

The mean fibre diameter of *Blighia sapida* wood was 23.25 μm which is almost the same as 23.57 μm observed by Ogunkunle (2010) for *Gmelina arborea* in Nigeria. It is higher than 21.9 observed by Ogunjobi *et al.,* (2014) for *Vitex doniana* which is lower than 29.47 μm observed by Ajala and Noah (2019) for *Aningeria robusta*, 35.09 μm observed by Areo and Omole (2020) for *Artocarpus altilis*. It is also lower than 36.09 and 34.25 μm reported for *Rhizophora racemosa* and *Rhizophora harrisonii*, respectively (Emerhi, 2012), and 39.42 μm observed by Riki and Oluwadare (2020) for *Delonix regia*.

An inconsistent pattern was observed axially as it decreased from the base to the middle and then increased to the top. This is in line with the report of Ajala and Noah (2019). The observed changes in fibre diameter along the sampling height may have been as a result of the increasing wood cell wall thickness during the tree aging process and due to the physiological and molecular changes that occur in the vascular cambium (Riki and Oluwadare, 2020). The observed higher diameter at the top portion than the lower portion may have also resulted from the larger fibre lumen width at the top than the lower portion of the tree.

An inconsistent pattern was also observed radially as it increased towards the middlewood and then decreased towards the outerwood. This is in accordance with the report of Riki and Oluwadare (2020). It slightly derailed from the trend observed by Ajala and Noah (2019) and Adejoba and Onilude (2012), as it increased slightly to the middlewood and follows the trend by decreasing to the outerwood.

However, the decrease in the diameter at the lower portion may have been due to the age of the tree which may have resulted from wood cell wall thickness, the physiological as well as the molecular changes that transpired in the vascular cambium during the tree aging process (Plomion *et al*., 2001). In comparison with tropical hardwood species, it falls within the range of 18.69 – 28.93 reported by Riki and Oluwadare (2020) which is found to be suitable for quality pulp and paper production. However, other indices of *Blighia sapida* wood fibre such as the short fibre length and the high Runkel ratio greater than 1, indicated that it is not suitable for quality paper production but could be used in combination with other long length wood fibres in production of specialty papers such as art papers to render strength.

LUMEN WIDTH

The mean lumen width of *Blighia sapida* wood was 11.68 μm which is lower than 12.7 μm reported by Ogunjobi *et al*., (2014) for *Vitex doniana*, 16.18 μm reported by Ajala and Noah (2019) for Aningeria robusta, 22.95 μm by Areo and Omole (2020) for *Artocarpus altilis*, 18.92 μm and 17.55 μm in *Rhizophora racemosa Rhizophora harrisonii* respectively reported by Emerhi (2012) and 26.83 μm observed by Riki and Oluwadare (2019) for Delonix regia. However, in the axial direction, it increased from the base to the top. This trend agrees with the report of Ajala and Noah (2019), Riki and Oluwadare (2020), Areo and Omole (2020). It did not conform to the results of Adejoba and Onilude (2012) who reported a decrease from the base upward.

Radially, it decreased from innerwood to outerwood. This trend is in agreement with the report of Oluwadare and Sotannde (2007), Ogunjobi *et al*., (2014), Ajala and Noah (2019), Riki, Noah (2020), Areo and Omole (2020), and *Majekobaje et al.* (2022). It did not conform to Adejoba and Onilude (2012) who reported an increase from innerwood to outerwood on *Ficus mucoso*.

Fibre lumen width affects the beating ability of the pulp, the narrower the lumen width, the more difficult the pulp beating will be as a result of lower penetration of liquid into the empty portion of the fibre (Areo and Omole 2020). The lumen width of *Blighia sapida* favourably compared with the species prominent in pulp and paper production. The density which predicts the strength property of wood is also affected and determined by the size of the lumen. The more the lumen width, the lower the density, and the lower the lumen width, the more the density of the wood. This is made evident in the report of Olayanu *et al*., (2022) who reported a decrease in density from the base to the top of *Blighia sapida* wood with the base having the mean density of 806.55±9.98 kg/m^3, the middle 685.70±12.44 kg/m^3, and 637.08±10.97 kg/m^3 as the mean density of the top. Jacobsen *et al.,* (2007) and Hugo *et al*., (2009) stated that variation in wood density is mainly driven by variation in fibre lumen diameter which is directly related to cell size and to the cell wall thickness.

CELL WALL THICKNESS

The mean cell wall thickness of *Blighia sapida* wood fibre was 5.78 μm which is higher than 4.6 μm reported for *Ricinodendron heudelotii* by Ogunleye *et al.,* (2017), 4.9 μm by Ogunjobi *et al.,* (2014) and

2.90 µm by Oluwadare and Sotannde (2007) for *Leucaena leucocephala*. It is within the range of 5.0 – 10.0 µm reported for Pine, which is a well-known species for its long fibre pulp useful in quality paper production by PPRI (2011). However, it is lower than 6.11 µm for *Artocarpus altilis* reported by Areo and Omole (2020), 6.61 µm reported by Ajala and Noah (2019) for *Aningeria robusta*, 6.49 µm reported by Riki and Oluwadare (2020) for *Delonix regia*, 8.58 µm for *Rhizophora racemosa* and 9.45 µm for *Rhizophora harrisonii* reported by Emerhi (2012), 7.89 µm for 20 years old Teak by Izekor and Fuwape (2011).

Axially, the fibre cell wall thickness decreased from the base to the top of the tree. The trend is in agreement with the report of Ogunsanwo (2000), Oluwadare and Sotannde (2007) Izekor and Fuwape (2011), Adejoba and Onilude (2012) on *Ficus mucoso,* and Noah *et al.,* (2015) on *Gerdenia ternifolia*, Ogunjobi *et al.,* (2014), Ogunleye *et al.,* (2017) and Areo and Omole (2020).

Radially, the fibre cell wall thickness increased from the pith to the bark. The trend is in agreement with the report of Tavares (2011), Ogunjobi *et al.,* (2014), Riki and Oluwadare (2020) and Areo and Omole (2020). The decrease in cell wall thickness from the base to the top and increase from the pith to the bark is validated by the report of Olayanu *et al*., (2022) who reported a decrease axially in density from the base to the top of *Blighia sapida* wood with the base having the mean density of 806.55±9.98 kg/m^3, the middle 685.70±12.44 kg/m^3, and 637.08±10.97 kg/m^3 as the mean density of the top. Radially, 640.54±14.58 kg/m^3 is the mean density for the innerwood, the middlewood is 718.56±12.96 kg/m^3, and the outerwood with a mean density of 770.24±12.10 kg/m^3.

The thicker cell walls of this species may have been a setback in the production of quality paper, but its cell wall comparison with Pines confirmed the suitability of *Blighia sapida* wood as raw material for pulp and paper industries if other morphological indices meet up with the requirements for the production of paper. The thicker the cell wall, the harder it becomes to defiberise the fibres during pulping and the more the quantity of chemical liquor needed for pulping. A thin wall thickness is most suitable for pulping. More so, the wood species compared favourably with other hardwood economic species for its high cell wall thickness, which makes it a suitable wood material for construction works that require strength. Jacobsen *et al.,* (2007) and Hugo *et al.,* (2009) stated that variation in wood density is mainly driven by variation in fibre lumen diameter which is directly related to cell size and to the cell wall thickness. Earlywood tends to be of the larger lumen, with larger fibre width and thin wall thickness which will lower the density and eventually reduce the strength property of the wood while latewood tends to be of narrow fibre diameter and narrow lumen, of thick wall fibres which increases the wood density and eventually increases the strength property of the wood. The wood at the top portion of the tree is more earlywood than latewood and the lower portion of the tree is more latewood than earlywood. This is made evident by the report of Olayanu *et al*., (2022) who reported a decrease axially in density from the base to the top of *Blighia sapida* wood.

Thick-walled fibres have the ability to transmit more stress than thin-walled fibres, though renders the permeability, treatability, and adhesive absorption difficult as the small lumens, the thick walls, and the narrow pit openings between fibres, hamper the flow of adhesive into the wood, which resulted into shallow penetration and renders it inadequate according to Adeniyi *et al.,* (2013).

SLENDERNESS RATIO

The mean slenderness ratio of *Blighia sapida* wood fibre was 49.9 which is higher than, 36.03 reported by Riki and Oluwadare (2020) for *Delonix regia*, 44.79 reported for *Artocarpus altilis* by Areo and Omole (2020), 42 observed for *Leucaena leucocephala* by Oluwadare and Sotannde (2007), 47 reported for *Gerdenia ternifolia* by Noah *et al*. (2015), 35.85 reported by Ogunleye *et al*., (2017) for *Ricinodendron heudelotii*. However, it is lower than the 55.06 reported for *Aningeria robusta* by Ajala and Noah (2019).

The slenderness ratio for *Blighia sapida* increased from the base towards the middle and then decreased towards the top. This trend was also observed by Areo and Omole (2020) but not in line with the report of Riki and Oluwadare (2020), who reported that slenderness decreased from the base to the top and increased from innerwood to outerwood.

The slenderness ratio, which is also known as the felting power, explains the value obtained from the ratio of fibre length to that of the fibre diameter. However, the slenderness ratio observed in this study for *Blighia sapida* wood was low which will result in the production of weaker paper as low slenderness reduces the tearing resistance of paper. According to Veveris *et al*., (2004) who stated that if the slenderness ratio of fibrous material is less than 70, then the fibrous material is assumed not to be valuable for quality pulp and paper production. The slenderness ratio was low owing to the short thick fibre of the wood. Ogbonnaya *et al*., (1997) opined that a low slenderness ratio results in reduced tearing resistance, which is partly as a result of the short thick fibres that do not give good surface contact and inter fibre bonding.

FLEXIBILITY RATIO

The flexibility ratio of *Blighia sapida* wood fibre was 50.63%, which is higher than the 24%, 16%, and 12% reported by Ezeibekwe *et al.,* (2009) for *Dactyladenia bacteri, Dialum guineense,* and *Anthonota macrophylia* respectively. It is lower than 55.05% reported by Ogunjobi *et al.,* (2014) for *Vitex doniana*, 63.33% reported for *Ficus exasperata* by Anguruwa (2018), 63.59% obtained for *Artocarpus altilis* by Areo and Omole (2020), 68.45% reported for *Delonix regia* by Riki and Oluwadare (2020), 63-79% for Ficus species by Ogunkunle (2010) and 79% reported for *Gmelina arborea* by Ogunkunle and Oladele (2008).

According to Amidon (1981) who described flexibility is an important attribute to the development of burst and tensile strength, the development of the paper properties that affect printing, and also determines the degree of fibre bonding in a paper sheet. It shows the ratio of fibre lumen width to its diameter. Bektals *et al*., (1999), classified flexibility ratio into the four following groups;

The first is the High Elastic Fibres which is a category of wood fibres with a flexibility ratio higher than 75%. According to the report, the density of such wood is low, having a thin cell wall and wider lumen, with a value of less than 450 kg/m^3. The fibres of such wood could be easily collapsed and flattened to produce good surface area contact, leading to good inter-fibre bonding.

The second is the Elastic Fibres, a category of wood fibres with a flexibility ratio of between 50-75%. As reported, the density is of medium construction category with cell-wall and lumen of equal dimension. The fibres partially collapsed and give a relative contact and fibre bonding.

The third is the Rigid Fibres: This constitutes woods with fibre flexibility of between 30-50%. The fibres are of thicker walls, with a density of medium to high which are barely flattened and have poor surface contact and inter-fibre bonding. And the fourth is the High Rigid Fibres which comprises wood with less than a 30% flexibility ratio. This shows the general attribute of over matured trees with the very thick cell wall and narrow lumen width fibres. Papers resulting from it produce a very poor surface contact and fibre-to- fibre bonding.

As a result of the values that favourably compared with economic species useful for quality paper production, *Blighia sapida,* a lesser-used species (LUS) may have been suitable for paper production as it fell within the range of elastic fibres of 50-75%, but since other morphological features such as the runkel ratio is reported to be higher than 1 and the fibre length is also short, it is not a suitable fibrous material for quality paper production but could be employed in the production of specialty papers such as art papers, most especially when used in combination with other long length fibres.

RUNKEL RATIO

The mean value of *Blighia sapida* wood fibre runkel ratio was 1.10 which is higher than 0.55 reported by Riki and Oluwadare (2020) for *Delonix regia*, 0.59 for *Leucaena leucocephala* by Oluwadare and Sotannde (2007), 0.26 and 0.68 reported for *Gmelina arborea* and Ficus species by Ogunkunle (2010), 0.76% in *Aningeria robusta* by Ajala and Noah (2019), 0.88 for *Gerdenia ternifolia* by Noah *et al*., (2015), and 0.95 and 0.97 for *Rhizophora racemosa* and *Rhizophora harrisonii* respectively by Emerhi (2012).

Ademiluyi and Okeke (1977) classified fibre value according to the runkel ratio and submitted that as the Runkel ratio increases, the paper quality produced from it also decreases, with the Runkel ratio less than one being the best and those greater than one of poorer quality.

Fibres with a higher Runkel ratio are less flexible, rigid, and form bulkier paper of low bonded areas than fibres with a lower runkel ratio (Veveris *et al*., 2004). Therefore, the mean runkel ratio recorded in this study was slightly higher than 1 which makes it not suitable for quality paper production but could be used for the production of specialty papers that requires higher strength properties.

RIGIDITY COEFFICIENT

The mean of *Blighia sapida* wood fibre rigidity coefficient was 24.68 which is higher than 18 reported for *Artocarpus altilis* by Areo and Omole (2020), 19 reported for *Leucaena leucocephala* by Oluwadare and Sotannde (2007) and 18.84 reported for *Ficus exasperata* by Anguruwa (2018). It is almost the same with 23.1 reported for *Eucalyptus camaldulensis* by Hus *et al*., (1995), and 25.9 reported for *Fagus orientalis* by Akgul and Tozluogu (2009), and lower than 37 reported by Tank (1971) for *Fagus orientalis*.

The rigidity coefficient is an important factor that controls the flexibility and coarseness of the wood fibre. The rigidity coefficient is 100 times the proportion of cell wall thickness to the fibre diameter and the lower the rigidity coefficient of wood fibre, the more it positively impacts the breaking and tear strengths (Bektaş *et al*., 1999). As reported by Dutt and Tyagi (2011) that low rigidity coefficient fibres produce a great degree of conformability within the paper sheet, which results in the production of a sheet of lower bulk that produces paper of good physical strength properties, high brightness, and low porousity, which makes it appropriate for various utilization purposes such as wrapping, packaging, printing, and writing.

The rigidity coefficient falls within the acceptable range of other wood species which makes it suitable for paper production if other morphological criteria for quality paper production are met by the fibre. But since other morphological features of *Blighia sapida* wood fibre such as the Runkel ratio were higher than 1 and the fibre length was also short, it is not a suitable fibrous material for quality paper production but other fibrous utilization purposes could be explored.

F-FACTOR

The F-factor 219.57 of *Blighia sapida* wood fibre falls within values recorded for other hardwood species such as 240.6, 140.40, 235.9, and 206.8 for Pine nigra, *Fagus orientalis*, *Populus euramericana,* and *Populus tremula*, respectively, according to Akgul and Tozluogu (2009). 236.33 reported by Riki and Oluwadare (2020) for *Delonix regia* and 250.73 reported by Areo and Omole (2020) for *Artocarpus altilis*. This is in agreement with the trend observed by Areo and Omole (2020) who reported an inconsistent decrease from innerwood to middlewood and then an increase towards the outerwood. It disagrees with the trend observed by Riki and Oluwadare (2020) who reported an increase from innerwood to outerwood.

Akgul and Tozluogu (2009) found that a greater F-factor (flexibility) is calculated by dividing the length of the fibre by the thickness of the wall. F-factor (flexibility) helps in revealing how flexible the paper that will be produced from such fibre will be (Mertoglu-emas, 2019). 229 was reported for sapwood and 236 was reported for heartwood of white poplar wood by Mertoglu-emas (2019) which is in the same range as 219.57 observed in this study.

The form-factor obtained for *Blighia sapida* wood species was higher than that of *Fagus orienntalis* and as reported by Akgul and Tozluoglu (2009) who opined that the papers obtained from that type of fibres present high flexibility thereby making it suitable for quality paper production. The value obtained was the same with white poplar wood reported by Mertoglu-emas (2019) who also further submitted that such F-factor values could be used as the intermediate paper for corrugated board and newspaper, due to low bleaching expenses required as a result of its light color, in blends with other long fibres for office papers. It can therefore be concluded that *Blighia sapida* wood fibre form factor shows that it cannot be used in the production of quality paper but could be employed in producing intermediate papers such as corrugated boards and art papers.

MUHLSTEPH RATIO

Muhlsteph Ratio of *Blighia sapida* wood was 72.85 which is higher than 47.28 for Pine nigra wood (Agul and Tozluogu 2009), 52 for *Shorea mujongensis* (Listya and Supartini 2011), 46.17 reported for Acacia hybrid, 45.85 reported for *Acacia margium* and 55 reported for *Acacia auriculiformis* (Yahaya *et al*., 2010), 58.86 reported for *Artocarpus altilis* by Areo and Omole (2020), 57.39 for *Ficus exasperata* by Anguruwa (2018) and 61.2 for *Pinus brutia* by Bektas *et al.* (1999). It is lower than the 76.68 reported for *Fagus orientalis* by Agul and Tozluogu (2009).

Areo and Omole (2020) reported that when a lower value is obtained from wood fibres, it depicts that such fibre has a thin cell wall, and thin wall fibres could be easily crushed while producing paper, which positively affects the density of paper produced and tear resistance properties. Therefore, the use of thin wall fibres is more preferable in the paper industry. The value obtained for *Blighia sapida* wood species, was a bit higher which may not be suitable for quality paper production except being used for production of intermediate papers.

VESSEL LENGTH

The mean vessel length of *Blighia sapida* wood was 222.57 μm. This is lower than the report of Okoegwale *et al*., (2020) on *Blighia sapida* and *Lecaniodiscus capanoides* of the same family (Sapindaceae) wood vessel length, who reported 316.0 μm for rainforest *Blighia sapida* wood and 285.16 μm for derived savannah *Blighia sapida* wood while 301.60 μm and 268.74 μm were recorded for *Lecaniodiscus capanoides* in the rainforest and derived savanna respectively in Edo state. The disparity in the result may have been a result of soil factors, tree age, and climatic factors.

Metcalfe and Chalk (1950) and IAWA (1989) classified vessels into three categories; Long length vessels >800 μm, Medium length vessels 350-800 μm, and Short length vessels <350 μm. The result of the study falls within the category of short-length vessels which is an indication that the wood will be denser, thereby having considerable mechanical strength and will not also require the use of fillers for the production of good quality paper of smooth surface.

Along the bole of the tree, vessel length increased from the base to the top. This pattern of variation is not in agreement with the report of Anguruwa and Oluwadare (2019) and Areo (2021) who reported a reduction in vessel length from the base to the middle and an increase to the top of the tree. The increase at the top portion may have been a result of more sapwood proportion than heartwood and the reduction in the density of the wood at the top as it was reported by Olayanu *et. al*., (2022) that *Blighia sapida* sapwood proportion increased from the base to the top while density decrease from the base to the top. The sapwood is expected to have more vessel sizes due to its conducting function in wood. The increase at the top portion may have also resulted to the reduction of the density at the upper portion of the wood as it was reported by Thomas *et al*., (2004) that the size of the vessel or the diameter reduces with higher wood density.

Across the bole, vessel length decreased from innerwood to outerwood. This pattern of variation is not in agreement with the report of Anguruwa and Oluwadare (2019) and Areo (2021) who reported an increase from innerwood to outerwood. This may have been a result of the submission of Carlquist (1988) who stated that examination of the various diameter of cells and vessel elements in the radial direction, reveals an increase in vessel size fluctuates greatly, which may have resulted from a growth factor. It may have also been as a result of the submission of Thomas *et al*., (2004) that the size of the vessel or the diameter reduces with a higher wood density as it was reported by Olayanu *et.al*., (2022) that the density of *Blighia sapida* wood increase from the innerwood to outerwood.

VESSEL DIAMETER

The mean vessel diameter of *Blighia sapida* wood was 149.31 µm. The samples for this study were collected from the derived savannah region and it compared favourably with the report of Okoegwale *et al*. (2020) on *Blighia sapida* wood who reported 148.24 µm for derived savanna *Blighia sapida* wood and 172.30 µm for rainforest *Blighia sapida* wood.

As reported by Adeniyi *et al*. (2013) *Triplochiton scleroxylon, Gmelina arborea, Terminalia ivorensis, Milicia excelsa, Tectona grandis, Nauclea diderrichii, Ricinodendron heudeolotii, Lophira alata, Afzelia africana* and *Milicia excelsa* have vessel diameter over 200 µm and those of *Ceiba petandra* (387.75 µm), *Ricinodendron heudeolotii* and *Bombax bounopozense* (318.56 µm) are well over 300 µm which have the implication of having large pores that made them to be light and of coarse texture as the pores lower their density. While the pore sizes of *Nesogordomia papaverifera* (less than 100 µm), *Mansonia altissima* (127.72 µm) and *Diospyros mespiliformis* (119.04 µm) are small to medium size. According to the classification of IAWA (1989) ≤50 µm are very small vessels, 50-100 µm are small vessels, 100-200 µm are medium vessels and ≥200 µm are large vessels. IAWA (1989) further opined that the mean diameters of 100-200 µm are more common in trees. The average vessel diameter of the wood species of this study falls within the category of medium vessels and it shows that it is compared favourably with other economic species and can be used for medium to heavy construction works. More so, species with large pores such as *Bombax bounopozense* and *Ceiba pentandra* may not be good for producing quality papers as they will require fillers to have smooth surfaces and they are usually easily attacked by beetles as they usually have their eggs laid in the pores after feeding on the sapwood starchy contents (Adeniyi *et al*., 2013).

Along the tree height, the lower value of vessel diameter at the base is justified by the high density recorded for wood at the base of the tree. The narrower the vessel, the more the density of wood, which eventually impacts the strength property of wood.

Radially, vessel diameter increased slightly from the innerwood to the middlewood and then decreased slightly towards the outerwood. This may have been as a result of the submission of Carlquist (1988) who stated that examination of the various diameter of cells and vessel elements in the radial direction, reveals increase in vessel size fluctuates greatly, which may have resulted from growth factor.

VESSEL FREQUENCY

The mean vessel frequency of *Blighia sapida* wood was 2.04 mm^2 which is lower than 2.46 mm^2 reported by Areo (2021) for *Artocarpus altilis*, 3.59 mm^2 reported by Anguruwa (2018) for *Ficus exasperata*, 3.60 mm^2 reported for *Ficus thornningii* and 5.20 mm^2 were reported for *Gmelina arborea* by Ogunkunle and oladele (2008). The low frequency may have been a result of the wood density which was a bit high.

When the vessel frequency is high, it impacts negatively on wood density. The larger the pores, the lesser the frequency of vessels and the more the fibre that impacts the strength of the wood. The frequency of vessels observed was low, an implication that the wood will be of high density that will impact high strength property when used. According to Thomas *et al*., (2004) the size of the vessel or the diameter reduces with higher wood density and Calquist (1988) and Martinez-cabrera (2011) reported that increasing vessel frequency or vessel density will result in a reduction in vessel diameter.

CONCLUSION

The research into the anatomical properties of *Blighia sapida* wood has been able to reveal the inherent anatomical characterization of the wood species. The thicker cell walls of the species showed that the use of the wood species might be a setback to the production of quality paper, but the suitability of the wood species fibre for pulp and paper industries is made evident through the comparison of the cell wall thickness with Pines if other morphological indices meet up with the requirements for the production of paper. However, the mean Runkel ratio, one of the major determinants of the suitability of fibrous material for paper production, recorded for *Blighia sapida* wood was higher than 1 and the fibre length recorded was also shorter than required which makes it not suitable for quality paper production but other utilization purposes could be explored. Also, the thicker cell wall of the wood species compared favourably with other economic tree species confirmed the suitability of the wood species for various construction and structural works. The low vessel frequency and average vessel diameter of the wood species showed that the wood is of high density and will greatly impact the strength properties of the wood owing to the strong correlation between the wood density and strength. It can therefore be recommended that the wood species could be used for medium to heavy construction works. Since the values recorded for fibre morphological indices of the wood species have validated that it cannot be used for quality paper production, hence, it could be recommended for use in the production of intermediate papers that require strength through its mixture with other long length fibres for the production of papers such as corrugated paper boards, art papers and so on. Also, it could be recommended that research should be carried out on the young wood of the wood species to confirm its suitability for quality paper production as juvenile wood has been proven to be of long fibre length and thinner wall thickness which are major requirements of fibrous materials for paper production.

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