Histological Characterisation of Saplings of Three Lesser-Used Hardwood Species as Indices of their Suitability for Papermaking

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Abstract

This study focused on the histological description of saplings of three hardwoods species: Hildegardia barteri, Bombax glabra, and Bombax buonopozense in order to assess their suitability for papermaking. The selected anatomical features (fibres, vessels, parenchyma and ray cells) were studied in order to identify the cells dimension, arrangement and distribution. Wood basic density (WBD) was determined using immersion method while fibre characteristics were determined using standard procedures of IAWA method. Mean WBD obtained were 360 kg/m^3 (base), 330±42.42 kg/m^3, (middle) and 155 ±21.21kg/m^3 (top) for H. barteri; 390±183.85 kg/m^3 (base) 405 ±106.06kg/m^3 (middle) 345±77.78 kg/m^3 (top) for B. glabra and 220 kg/m^3 (base) 355± 35.36 kg/m^3 (middle) 340±70.71 kg/m^3 (top) for B. buonopozense; mean MTD of vessels ranged from 109.57-117.0µm, 84.114-96.0µm, and 94.714-104.0µm axially, for H. barteri, B. glabra and B. buonopozense respectively. The lowest value of Runkel ratio ± standard deviation (0.30±0.055 and 0.40±0.079) for H. barteri and B. glabra were observed at stem base respectively; however for B. Buonopozense, it was 0.23±0.03 at stem top. The variations between species may be dependent on their genetic make-up while within species may be dependent on the micro-climatic factors of the site of growth. Photomicrographs presented in this study showed that micro-structural arrangement of cells slightly varies among the species. The results for the selected lesser-used species, revealed promising properties for papermaking.

Keywords: Lesser used species, morphological characteristics, saplings, wood density.

Introduction

There is increasing emphasis on the contributions of pulp and paper industry to the green economy (Ince *et al.,* 2011) and the demand for wood, pulp and paper products is rising with increasing world population (Jimenez *et al.,* 2005). It is expected that the demand for pulp and paper will increase from 300 Mmt to over 490 Mmt in the year 2020 (O'Brien, 2006). Paper recycling is an option but the number of times this is conducted often lead to forfeiting the strength and quality of paper produced (Richtel and Galbraith, 2008 and Khantayanuwong *et al.,* 2006). Yet, there are huge tropical forest trees that have not been explored because of lack of information on their properties which will provide first-hand information on their potential utilisation and this is related to their different anatomical structures and fibre properties (Ogle and Nhantumbo, 2006).

Ali *et al*.(2008) reported the need to explore the potential of lesser known or lesser-used timber species in order to minimize pressure on the most sought species, and to contribute to increased productivity. Therefore, information on properties of unexploited *hardwood species will increase* their potential use while reducing over reliance on few species known for paper making.

A general belief from early research reported that the effect of fiber properties on paper with desirable strength could only be made from long fiber wood species especially that of softwoods. However, subsequent studies have shown that fiber length possibly is not the overriding factor in producing paper with acceptable strength (Akachuku, 1980). Wood-fiber characteristics that have often been associated with paper strength in particular, paper made from hardwoods are slenderness ratio (the length to diameter ratio), and Runkel ratio (twice the cell wall thickness/lumen diameter (2w/l)). The Runkel ratio is a microscopic extension of the wood density in that wall thickness and lumen width are the basic factors used in their determination. It provides the relationship between anatomical structures and paper making properties. Some anatomical attributes commonly used to predict the papermaking properties are fibre wall thickness, porosity pattern (cell arrangement), fibre length, lumen width, Runkel ratio, felting power and coefficient flexibility (Horn,1978; Pekka, 2015).

Besides, they equally influence printability, sheet bulk, opacity and surface smoothness (Fiserova and Gigac, 2010). Therefore, this study examined the anatomical features, fibre characteristics and wood density of *Hildegardia barteri, Bombax glabra,* and *Bombax buonopozense* and their suitablability for pulp and paper making.

Materials and Methods

Five year-old saplings of *Hildegardia barterii, Bombax glabra* and *Bombax. buonopozense* were sown as mixed species in the nursery of Department of Forest Resources Management, University of Ibadan. Two saplings from each tree species were randomly chosen from the pool of all the mixed species. Diameter at breast height and total height of the selected saplings were measured for the three species. Wood samples from the base, middle and top of the stem were collected based on the total height of each sampled tree as well as from the first –formed branches of each tree selected .

Determination of Basic wood density and Moisture content

The basic density was calculated using the hydrostatic or immersion method described by Ofori and Brentuo, (2010):

$$Basic\ density = \frac{Oven\ dry\ mass}{Volume\ of\ water\ displaced\ by\ swollen\ wood\ sample} \quad (1)$$

The moisture content of the wood samples at the green state was determined using the formula of Siau (1984):

$$Moisture\ content = \frac{M_g - M_{od}}{M_{od}} \times 100 \quad (2)$$

Where, M_g is the green mass of the wood, M_{od} is its oven dry mass

Morphological characteristics

Measurement of fibre dimensions and derived values

The fibre characteristics were determined by preparing the wood material into tangential slivers of 1.0 mm thickness from the wood samples. The slivers were delignified and macerated according to method of Franklin (1945) and Zhai *et al.,* (2013). Drops of the resultant suspension were placed on slides and viewed under a microscope. Twenty-five cells were measured for each sample. The following fibre characteristics were measured: fibre length (L), fibre diameter (D), lumen width (d) and double cell wall thickness (w) to discuss the potentials of these wood species for pulp and paper purposes. To characterise the fibres, morphological indices were derived as: Runkel ratio (2w/d), Felting power (L/D) and coefficient of flexibility (d/D) and ratio of fibre length to cell wall thickness (L/T) (Horn and Setterholm, 1990) was measured and one half of the double wall thickness was reported as cell wall thickness for the species of the cells as used by Ishiguri *et al.* (2012).

Microscopic observation and wood property measurements

Wood block samples of size 10 mm^3 were treated in preparation for sectioning in order to observe the anatomical properties. Treatment was done by boiling the wood blocks in water until they get softened. Sectioning of the wood was done with the use of a glass knife and Leitz sliding microtome for anatomical examination of transverse, radial and tangential sections of the wood samples and they were viewed under a microscope.

Afterwards, permanent slides of these sections of each position of the species were prepared using safranine O stain, 50% and 95% ethanol as stain extractor, clove oil, xylene for dehydration and differentiation process and Canada balsam as the adhesive. The features of these species were compared with the wood anatomy of some species described by IAWA (1989) and Gasson *et al.* (2011).

The experiment was laid in a 3 x 4 factorial in a randomized complete block design with three replicates. Data collected were analysed using Analysis of Variance (ANOVA) and significant means were separated using Duncan's multiple range test at 5% probability.

Results

The mean basic density along axial position of *H. barteri, B. glabra* and *B. buonopozense* ranged between 155 - 360 kg/m^3, 345 - 405 kg/m^3 and 220 - 335 kg/m^3 respectively; while the mean basic density at the branches are 490 kg/m^3, 445 kg/m^3 and 380 kg/m^3 respectively. Results obtained for the moisture content along the axial position of *H. barteri, B. glabra* and *B. buonopozense* ranged between 185 - 340%, 157 - 201% and 210 - 370% respectively while the mean values obtained for their branches were 200%, 129.15% and 180% respectively (Table 1).

Table 1: Summary of mean values of wood basic density and moisture content of samples

				AXIAL POSITIONS		
Parameters	Species	Total height (cm)	DBH (cm)	Positions	Mean	±SE
Density (kg/m^3)	*H. barteri*	310.7	2.64	SB	360	±28.12
				SM	330	±16.46
				ST	155	±13.62
				BR	490	±41.92
	B. glabra	303	2.455	SB	390	±14.92
				SM	405	±48.74
				ST	345	±41.03
				BR	445	±40.13
	B. buonopozense	307	2.415	SB	220	±61.46
				SM	355	±46.72
				ST	340	±29.89
				BR	380	±21.39
Moisture content (%)	*H. barteri*			SB	185	±24.03
				SM	205	±14.75
				ST	565	±111.35
				BR	200	±23.09
	B. glabra			SB	193	±34.67
				SM	157	±60.34
				ST	201	±27.13
				BR	129.15	±44.09
	B. buonopozense			SB	370	±44.22
				SM	220	±24.49
				ST	210	±25.55
				BR	180	±11.95

SB-Stem base, SM-Stem middle, ST-Stem top and BR-Branch

The mean fibre length along the axial position of *H. barteri, B. glabra* and *B. buonopozense* ranged between 1.2-1.8 mm, 1.3- 1.7mm and 0.97- 1.4 mm respectively; Mean fibre diameter ranged between 15.9 – 19.4µm, 17.3 – 22.0 µm and 22.3– 23.6µm; lumen width ranged between 11.6– 14.9 µm, 12.0 – 15.7 µm and 17.9 – 18.4 µm; Cell wall thickness ranged between 2.2 – 2.3 µm, 2.6 – 3.1 µm and 2.1 – 2.6 µm (Table 2) for *H. barteri, B. glabra* and *B. buonopozense* respectively.

The mean Runkel ratio ranged between 0.3 – 0.4, 0.4 – 0.4 and 0.2– 0.3; values of coefficient flexibility ratio ranges between 72.4 – 76.9%, 69.5 – 71.7% and 77.9 – 81.1% and the values of felting power ranged between 79.6 – 101.7, 78.7 – 83.2 and 45.5 – 63.4 for *H. barteri, B. glabra* and *B. buonopozense* respectively (Table 3).

Table 2: Fibre and morphological characteristics of *Hildegardia barteri, Bombax glabra and Bombax buonoponzense*

Morphological indices	Species	Axial position of samples		
		Position	Mean	±SE
Fibre length (mm)	*B. buonoponzense*	SB	1.4	±0.01
		SM	1.2	±0.01
		ST	1.0	±0.02
		BR	1.1	±0.02
	B. glabra	SB	1.7	±0.06
		SM	1.4	±0.01
		ST	1.3	±0.04
		BR	1.3	±0.0
	H. barteri	SB	1.7	±0.05
		SM	1.8	±0.21
		ST	1.2	±0.06
		BR	1.4	±0.01
Fibre diameter (µm)	*B. buonoponzense*	SB	23.0	±3.05
		SM	23.6	±0.29
		ST	22.3	±0.87
		BR	19.1	±2.31
	B. glabra	SB	22.0	±1.33
		SM	18.8	±0.77
		ST	17.3	±0.07
		BR	17.5	±0.26
	H. barteri	SB	19.4	±0.26
		SM	18.8	±2.23
		ST	16.0	±1.78
		BR	16.8	±1.06

SB-Stem base, SM-Stem middle, ST-Stem top and BR-Branch

Table 2 Cont'd: Fibre and morphological characteristics of *Hildegardia barteri, Bombax glabra and Bombax buonoponzense*

Morphological indices	Species	Axial position of samples		
		Position	Mean	±SE
Lumen width (µm)	*B. buonoponzense*	SB	17.9	±1.86
		SM	18.4	±1.39
		ST	18.1	±1.02
		BR	15.2	±2.30
	B. glabra	SB	15.7	±0.31
		SM	13.3	±0.31
		ST	12.0	±0.46
		BR	12.5	±1.13
	H. barteri	SB	14.9	±0.65
		SM	14.2	±2.30
		ST	11.6	±1.48
		BR	12.8	±1.07
Cell wall (µm)	*B. buonoponzense*	SB	2.6	±0.59
		SM	2.6	±0.55
		ST	2.1	±0.07
		BR	2.0	±0.01
	B. glabra	SB	3.1	±0.50
		SM	2.7	±0.22
		ST	2.6	±0.19
		BR	2.5	±0.43
	H. barteri	SB	2.2	±0.19
		SM	2.3	±0.03
		ST	2.2	±0.14
		BR	2.0	±0.01

SB-Stem base, SM-Stem middle, ST-Stem top and BR-Branch

Table 3: Derived morphological indices of *Hildegardia barteri, Bombax glabra and Bombax buonoponzense*

Derived morphological indices	Species	Position	Mean	±SE
Runkel ratio	*B. buonoponzense*	SB	0.3	±0.03
		SM	0.3	±0.08
		ST	0.2	±0.02
		BR	0.3	±0.03
	B. glabra	SB	0.4	±0.05
		SM	0.4	±0.02
		ST	0.4	±0.04
		BR	0.4	±0.10
	H. barteri	SB	0.3	±0.03
		SM	0.3	±0.05
		ST	0.4	±0.02
		BR	0.3	±0.02
Coefficient flexibility	*B. buonoponzense*	SB	78.1	±2.29
		SM	77.9	±4.94
		ST	81.1	±1.40
		BR	79.0	±2.46
	B. glabra	SB	71.7	±2.87
		SM	71.1	±1.22
		ST	69.5	±2.36
		BR	71.6	±5.37
	H. barteri	SB	76.9	±2.30
		SM	75.5	±3.27
		ST	72.4	±1.24
		BR	76.2	±1.58
Felting power	*B. buonoponzense*	SB	63.4	±8.74
		SM	52.3	±0.49
		ST	45.5	±3.33
		BR	64.6	±9.32
	B. glabra	SB	83.1	±3.33
		SM	78.9	±1.28
		ST	78.7	±2.81
		BR	75.6	±0.35
	H. barteri	SB	91.9	±0.37
		SM	101.7	±22.74
		ST	79.6	±4.46
		BR	83.2	±5.08

SB-Stem base, SM-Stem middle, ST-Stem top and BR-Branch

Wood anatomical descriptions

The observed features in *Bombax buonopozense* show that the MTD of the vessels from stem base to top) ranges from 94.714-104.0 µm, with simple perforation, exclusively solitary, diffuse and have obovate/angular shape (Plates 1c,1f and1i). The ray cells are multiseriate (2 cell wide above), heterogenous type II & III, there is presence of sheath cell which are immature parenchyma cells (Plates 1b, 1e and 1h). Axial parenchyma cells are present, but predominantly apotracheal diffuse in aggregates, vasicentric, parenchyma cells are more than fibre cells. The fibre cells are thin-walled and have straight grain (Plates 1b, 1e and 1h).

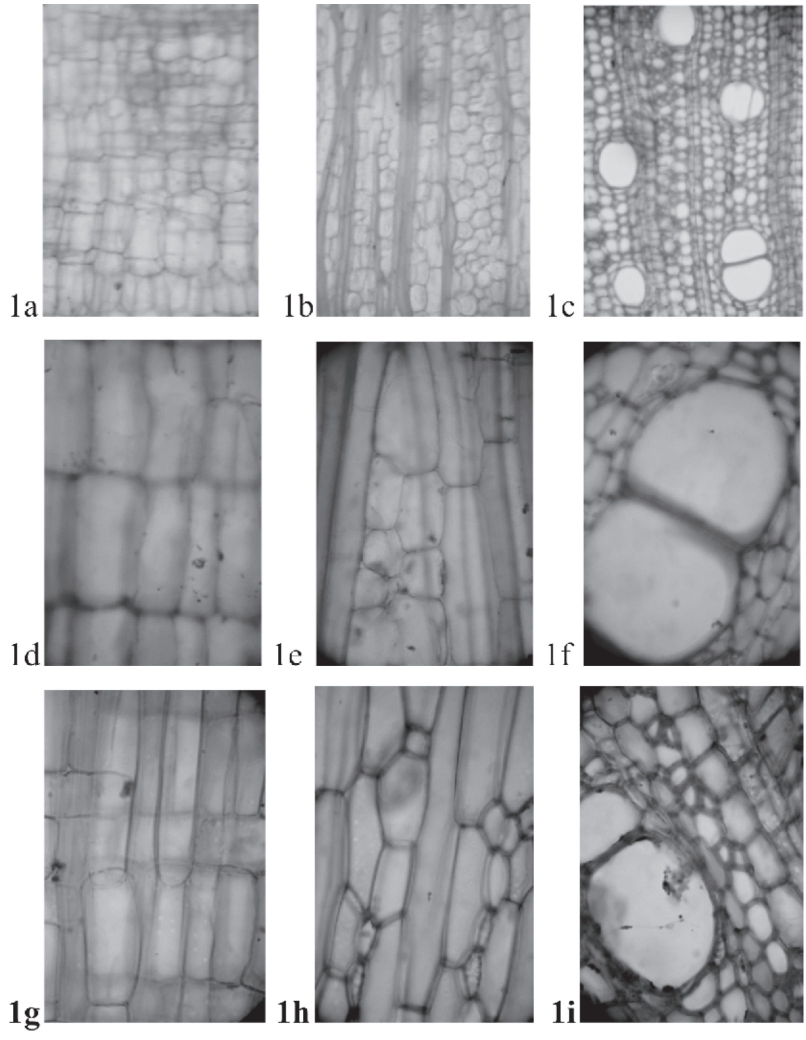

Plate1: Sections of *Bombax buonopozense* at stem at base, middle and top positions (x40)
R.L.S (1a) T.L.S (1b) and T.S (1c) of base position; R.L.S (1d) T.L.S (1e) and T.S (1f) of middle position; R.L.S (1g) T.L.S (1h) and T.S (1i) of top position.

For *Bombax glabra,* Mean Tangential Diameter (MTD) of vessels ranges from 84.114-96.0 ųm, Solitary, simple perforation, Diffuse, Round/obovate in shape (Plates 2c, 2f and 2i). The ray cells are Multiseriate (two cell wide and above), heterogenous type III, sheath cell present (2b, 2d and 2h). Axial parenchyma present, predominantly apotracheal in diffuse aggregates, vasicentric (Plates 2b, 2e and 2h). The fibre cells are also thin-walled and have straight to interlocked grains.

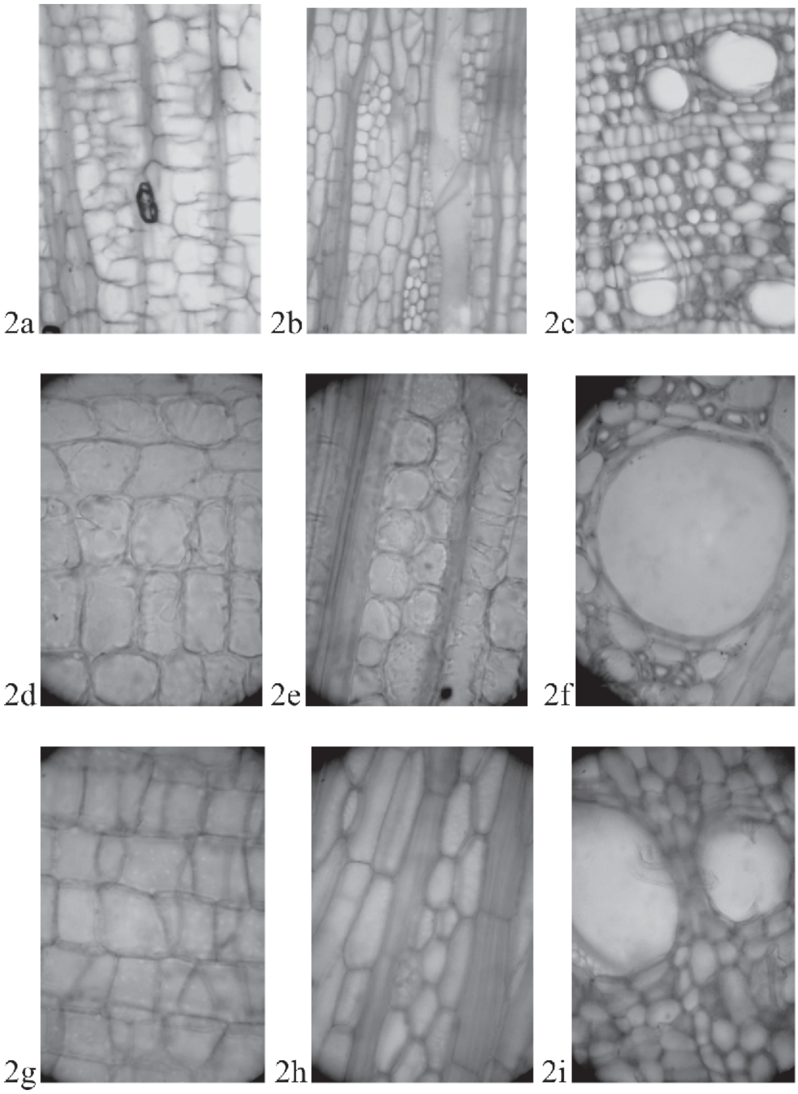

Plate 2: Sections of *Bombax glabra* at stem at base, middle and top positions (x40)
R.L.S (2a) T.L.S (2b) and T.S (2c) of base position; R.L.S (2d) T.L.S (2e) and T.S (2f) of middle position; R.L.S (2g) T.L.S (2h) and T.S (2i) of top position.

The observed features in *Hildegardia barteri* show that: Vessels are exclusively solitary, have a round shape/angular, the MTD ranged from 109.57-117.0 um, simple perforation, diffuse in aggregates (Plates 3c, 3f and 3h). The ray cells are multiseriate (four cell wide and above), heterogenous type III and sheath cells (immature parenchyma cells) are present (Plates 3b and 3e). The parenchyma cells are predominantly paratracheal (vasicentric), axial parenchyma present, Apotracheal in diffuse aggregate is also present. There are more of parenchyma cells than fibre cells. Fibre cells are thin-walled and the grains are interlocked to wavy; fibres are banded together (Plates 3b and3e). The Tangential Longitudinal Section (TLS) could not be obtained due to the fact that wood sample from top was too fragile for sectioning.

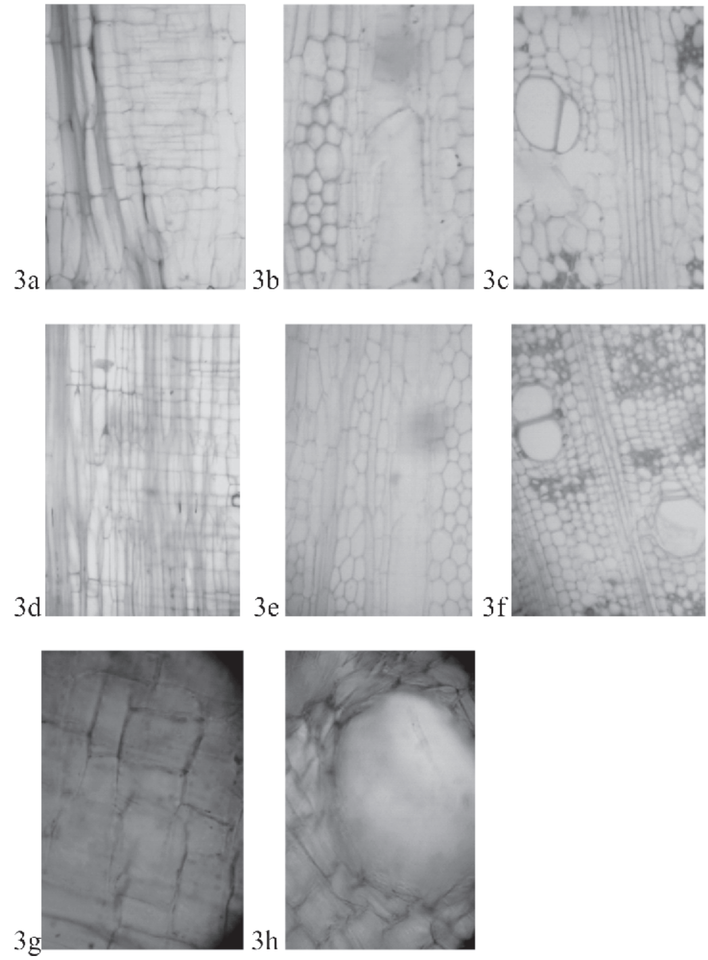

Plate 3: Sections of *Hildegardia barteri* at stem at base, middle and top positions (x40) R.L.S (3a) T.L.S (3b) and T.S (3c) of base position; R.L.S (3d) T.L.S (3e) and T.S (3f) of middle position; R.L.S (3g) and T.S (3h) of top position.

Discussion

Along the axial direction, the mean Basic Wood Density (BWD) of *B.glabra* was the highest while that of *H.barteri* was the least. Each tree species has its own characteristic wood density as regards to cell types and distribution of the cells within the wood. This affirms that density variation between species is basically due to differences in anatomical structure (Tsoumis, 1992). Observations made from the study reveals that *H.barteri* which has the least BWD has the largest vessel diameter but not with the highest moisture content (MC). The mean basic wood density is found to be one of the major technical properties of wood because its determination is well correlated to structural, chemical and other physical properties of wood like strength, stiffness and performance in use. For pulp and paper manufacture, wood basic density ranging from 400-600 kg/m^3 is preferred (Downes *et al*., 1997). Only the mean density for the branch of *H.barteri* and *B. glabra* fall within this range while that of *B. buonopozense* closely follows. The mean BWD of other positions are lower to the range aforementioned. The low density of the species is attributed to the fact that they are immature wood. Since low density woods are found to be more suitable for pulp and paper products than for construction purposes (Saranpaa, 1994). Thus, basic wood density as an index of wood quality gives a good general indication of properties and different end-use purposes

The anatomical features observed for *B. buonopozense* correlate with the findings of Gasson *et al.* (2011) on some anatomical features of *Prunus africana* such as the mean tangential diameter of vessels ranging between 50-100 µm or 100-200 µm, simple perforation plate, rays with different cells mixed throughout (type III) and the presence of sheath cells. The mean fibre length of the sapling of *B. buonopozense* (1.18mm) correlates with the findings of Adeniyi *et al*. (2009) on the matured wood of the species which was 2.33mm.

For *B. glabra,* the observed anatomical features correlate with the findings of Gasson *et al.* (2011) on some anatomical features of *Balmea stormae* such as the mean tangential diameter of vessels ranging between 50-100 µm, simple perforation plate, fibres with thin cell wall and diffuse porosity. The lowest mean value of runkel ratio was observed at the stem base of *B. Glabra* Higher runkel ratio above one produces stiffer fibre, bulkier paper of lower bonded area (Walia, 2013). The variation in the mean BWD of the saplings of *Bombax glabra* along the axial direction increases in a non-uniform pattern.

The observed anatomical features of *H. barteri* (correlate with the findings of Gasson *et al.* (2011) on some anatomical features of *Dalbergia nigra* such as the diffuse porosity, simple perforation plate, mean tangential diameter vessel of 100-200µm, apotracheal axial parenchyma diffuse in aggregates and the presence of paratracheal axial parenchyma vasicentric. The lowest mean value of runkel ratio was observed at the stem base of *H. barteri.* The mean basic wood density of the sapling of *Hildegardia barteri* along the axial direction decreases from the stem base to the stem top. The fibre length of the species at their stem base and stem middle of the species are not significantly different from each other but both are significantly different from the stem top and branches. The stem base was observed to have the highest fibre length. The result indicates that fibre length at the stem base and middle were more matured than the fibre length at the tops and branches. Fibre length in hardwood pulps is said to have a significant effect on sheet properties such as the tearing and bursting strength (Horn, 1990). A high percentage of parenchyma cells can reduce paper strength (Horn and Setterholm, 1990). Thus, juvenile wood of these species may not be too suitable for paper-making. However, a balance must be struck to have ideal wood for paper-making. Other anatomical features like lumen size and cell wall thickness affect the rigidity and strength properties of the papers made from the fibres. At the axial direction, values of runkel ratio of the species at the four positions are not significantly different from each other. The most important and primary observation in order to find suitability of any wood for paper making is the runkel ratio (Nasir, 2006) and runkel ratio for favourable pulp properties is usually obtained when value is below 1.

In general, the vessel elements are not too variable among the three species. Fichtler and Worbes (2012) opined that high variation of vessel diameter exists within families and thus has relationship with tree morphology. Though trees within malvaceae have larger vessels compared to other families.

Conclusion

The effects of fibre characteristics and morphology on paper properties are applicable to any type of fibre regardless of the source and so the products made from fibres of different species will often vary markedly due to the morphological differences among the wood species. Pulp strength properties are usually favourable when Runkel ratio is below one. Higher ratio above one produces stiffer fibre, bulkier paper of lower bonded area. Likewise, many properties of wood are related directly to its anatomical structures. The structure of the selected lesser-known wood species revealed promising properties for paper-making end-use. The variation that occurred along the axial direction may be attributed to genotypic differences and micro-climate since the species are grown under similar conditions in the nursery.

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