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Wood Quality Studies in Plantation-Grown Sterculia (*Sterculia setigera* Del.) in the Guinea Savanna, Nigeria

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Abstract: Wood quality studies were carried out on the plantation material to ascertain its suitability for papermaking. Physical parameters, ring width and fibre morphology were studied in axial and radial directions in five trees. Mean pith diameter ranged from 5.00-6.60 mm and increased significantly ($p<0.05$) from base to top. Bark thickness, bark and bast fibre proportion were 5.50-7.40, 24.96-31.59 and 10.06-12.69%. Bark thickness and bast fibre proportion significantly decreased from base upward while bark proportion increased. Grain orientation increased from base to the middle of the stem and later decreased to the top. Significant between-tree variation was observed for ring width with a range of 4.9 mm in tree 5 to 6.2 mm in tree 2; however, no consistent pattern along the stem axis was observed. Radially, it increased from pith to ring 5, then a leveling-off before a decrease towards the bark. Fibre length, lumen width and cell wall thickness varied significantly along the stem axis with a range of 2.46-2.64 mm, 19.50-21.15 µm and 2.83-3.16 µm. All the derived indices showed the species to be suitable for writing and printing papers. There was homogeneity in the overall distribution of the measured indices within the trees. The dependence of the derived values on fibre dimensions was evidence in the significant correlation between them. Based on the fibre biometry of the species, it will be beneficial and worthwhile to consider plantation establishment of this species on large-scale for papermaking in Nigeria.

Key words: Physical properties, fibre morphology, coefficient of uniformity, variation pattern, *Sterculia setigera*

INTRODUCTION

The first paper mill in Nigeria, the Nigerian Paper Mill (NPM) Jebba was established in 1969. Wood raw materials were from admixture of 16 hardwood species that furnish the short fibre pulp. However, the long fibre pulp requirement of the mill (33,000 metric tonnes) cannot be met locally. Prior to the closure of the mill in 1992, over $20 million was spent on importation of long fibre pulp in Nigeria (FAO, 1991, 1993, 1996). Consumption of long fibre pulp decreased from 23,510 MT in 1985 to 2,750 MT in 1991 (Osadare, 2001). Similarly, at the Nigerian Newsprint Manufacturing Company (NNMC) volume of pulp production decreased from 21,792 MT in 1991 to 13,300 MT in 1992 prior to closure in 1993 (Bureau for Public Enterprise, 2006; Central Bank of Nigeria, 1990). In Nigeria the production of papers and paperboards in 2005 was put at approximately 27,000 MT (Central Bank of Nigeria, 2005).

To meet with the increasing demand for paper and paper products, NPM through the qnality control unit identified an indigenous species, *Sterculia setigera* Del. to have produced superior paper

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quality compared to other 15 hardwood species. The species is one of the agro forestry trees in the savanna; its usefulness for this purpose is doubtful (Bakhoum *et al*., 2001). The species is naturally distributed from the southern guinea savanna to Sudan savanna. The wood is soft, fibrous and porous with diamond shaped network of fibres. The first trial plantation of five hectares was established in 1988 and another 15 ha in 1989. So far, wood quality studies are yet to be carried out on this plantation material, this is necessary for efficient fiber management and utilization. As a first step towards utilization of any raw materials, it is important that its wood quality parameters be examined especially if it is for papermaking (Osadare and Udohitinah, 1993), since the morphological characteristics of wood present considerable challenges in the quality and quantity of pulp produced (Amidon, 1981). The overall influence these properties have on paper properties cannot be over-emphasized (Panshin and De Zeeuw, 1980; Plumptre, 1984; Schmidt and Smith, 1961; Sri and Wilfredo, 1995; Twinmasi, 1996). It is imperative that the wood quality parameters of this promising native pulpwood species be examined as such information will be useful in future tree improvement programmes and plantation management of this species for the desired purpose. This study investigates some wood quality parameters of *Sterculia setigera* Del. via their pattern of variations in the radial and axial directions. The uniformity of the measured parameters within the tree was also discussed.

MATERIALS AND METHODS

Raw Materials

Wood materials for the study were collected in November 2004 from the first generation trial plot of *Sterculia setigera* established in 1989. The plantation is located at Oke-Awon, Jebba on latitude 9° 08′ N and longitude 04°49′ E at an altitude of 400 m. Mean annual rainfall is between 1000 to 1250 mm (Afolayan, 1982) with mean temperature of 29.4°C. The soil is hydromorphic with or without iron pan (Akoun, 2001). The plantation is located in the Southern Guinea Savanna where the species has its natural distribution.

Sample Preparation

Ten trees were selected and their total height, diameter at breast height, crown diameter, merchantable height, crown depth, diameter at butt, middle and top measured. Five of the ten trees with straight bole were randomly selected using destructive sampling method to study pith diameter, bark thickness, bark proportion, bast fibre proportion and grain orientation along the stem height. From each tree, a disc of 5 cm thick were cut at 0.38, 1.3, 2.63, 4.13, 5.63 and 7.13 m along stem height to study axial variation in selected properties. The results obtained were pooled together to determine how these properties varied along the stem axis.

Determination of the Physical Properties

Ring width was determined as described by Osadare (2001). In this method ring width was measured in the four cardiual positions on the transverse surface of the disc using a double biconcave lens super imposed over a calibrated transparent ruler. Width was from the first formed earlywood to the last formed latewood bands of each growth ring. Mean from the four points was used for each growth ring.

Bark thickness and bark proportion was computed using Wang *et al*. (1984) method as described in the equation below:

$$BP = \wedge [\frac{(DOB)^2}{2} (TD) - \frac{(DIB)^2}{2} (TD)] \times 100 \qquad (1)$$

Where:

BP = Bark proportion
DO = Diameter over bark
DIB = Diameter inside bark
TD = Average disc thickness and $\Lambda = 3.142$

Proportion of bast fibre from air-dried sample was calculated using the relationship below:

$$\text{Bast fibre (\%)} = (\text{Wf}/\text{Wb} + \text{Wf}) \times 100 \tag{2}$$

Where:

Wf = Weight of bast fibre
Wb = Weight of bark without bast fibre

The methods of Schmidt and Smith (1961) and Saikia *et al*. (1997) was modified and used to determine grain orientation. It is assumed that fibre lie in a perpendicular position along the stem. The fibre perpendicularity was inscribed using the tip of a divider, any deviation from this position was considered as grain orientation denoted or measured as 0° using a protractor.

Fibre Dimensions and Derived Value

The five trees with straight boles selected from the 10 trees were used to study axial and radial variation in ring width, fibre dimensions and derived values. For fibre dimensions determination, small slivers were obtained from each annual growth ring from the disc obtained at the different sampling heights as described earlier. The slivers were placed in an equal volume (1:1) of 30% hydrogen peroxide and 10% glacial acetic acid, boiled until soft and bleached white (Franklin, 1945). The slivers were then washed, placed in 30 mL-test tubes with 20 mL-distilled water and shaken vigorously to separate the fibre bundles into individual fibre. The macerated fibre suspension was carefully aligned on a slide using a rubber teat. The resulting image on Rheichert visopan microscope screen was measured for fibre length, diameter, lumen width and cell wall thickness. From these, the derived values for slenderness ratio as fibre length/fibre diameter, flexibility coefficient as (fibre lumen diameter/fibre diameter)×100 and Runkel ratio as (2×fibre cell wall thickness)/lumen diameter were calculated.

Coefficient of Uniformity

Trees taper in their form especially in diameter from base to top. Moreover, different sections along stem height are of different physiological ages. Also, properties of wood have been found to vary from pith outwards and from base to top (Akachuku, 1980, 1984). The more uniform the wood is irrespective of its position within the tree the better is its value in utilization. To assess how uniform the properties measured were distributed within the wood in the radial and axial directions, coefficient of uniformity was computed as used by Oluwadare and Sotannde (2006). If mean deviation from 100% is greater than 10%, the wood may be considered to vary widely in the property so considered. This uniformity is expressed as:

$$\text{CRU} = \frac{\text{Mean of outer value rings (9-13)}}{\text{Mean of inner rings (1-5)}} \times 100 \tag{3}$$

$$\text{CAU} = \frac{\text{Mean of base value (SH 0.38 m, 1.13 m, 1.3 m)}}{\text{Mean of top value (SH 4.13 m, 5.63 m, 7.13 m)}} \times 100 \tag{4}$$

Where:

CRU = Coefficient of radial uniformity
CAU = Coefficient of axial uniformity
SH = Sampling height

Positive sign (+) shows mean deviation above 100% while negative sign (-) means deviation below 100%. The ratio of radial coefficient of uniformity to axial coefficient of uniformity was used to assess the overall uniformity of these properties in the trees.

Statistical Analysis

Two-way analysis of variance was used to determine the significance of variation ($p<0.05$) in the radial and axial directions for the properties measured in the five trees. Treatments considered were trees, radial variation (rings) and axial variation (sampling heights). Since the radial variation shows no significant variation for ring width and fibre morphology, ANOVA was computed only for variation in the axial direction. Nevertheless, the overall variation pattern in the radial direction in these properties was presented for the importance of the parameters. Correlation analysis was used to determine the relative linear association between ring width and fibre properties using the mean value for each tree.

RESULTS AND DISCUSSION

Physical Properties

In Table 1, pith diameter had a mean range of 5.00-6.60 mm with standard error of 0.68-0.93. The pith found in *S. setigera* is whitish and fluffy parenchymatous material. In papermaking process, there is need to get rid of this material as it could interfere with inter-fibre bonding properties thus making paper to have weak spots. Pith consumes huge amounts of pulping and bleaching chemicals, reduces drainage rate during washing, dewatering and papermaking (Byrd, 2007).

The thickness of the bark is small with mean range of 5.50-7.40 mm (Table 1); this perhaps explain the proportion of the bark with a minimum value of 10.10% and maximum value of 48.95%. Being a savanna species, it was expected that the bark values could be higher as an adaptive feature of the species to cope with fire and water stress.

Table 1: Physical properties of the wood of *Sterculia setigera*

	Tree No.					
Wood properties	1	2	3	4	5	Grand mean
Pith diameter (mm)						
Mean	6.00	5.00	6.60	5.10	6.30	5.80
Standard error	0.79	0.93	0.84	0.74	0.68	
Bark thickness (mm)						
Mean	5.50	5.60	7.20	7.40	6.80	6.50
Standard error	0.66	0.77	1.17	0.99	1.01	
Bark proportion (%)						
Mean	24.96	29.37	0.59	26.72	25.03	27.43
Standard error	4.39	5.22	3.52	2.64	2.79	
Bast fibre proportion (%)						
Mean	10.79	11.93	10.06	12.69	11.34	11.36
Standard error	1.73	1.93	1.94	1.45	1.87	
Grain orientation (%)						
Mean	8.79	8.86	9.64	10.29	8.64	9.20
Standard error	0.96	0.69	0.60	1.10	0.87	

The mean proportion of bast fibre was between 10.06-12.69% (Table 1). This is important in that bast fibre as found in many non-wood fibre sources is additional source of fibre. Depending on the quality of the bast fibre, it could furnish additional fibre material in addition to the woody portion; this needs further investigation.

The grain orientation had mean range of 8.64-10.29° (Table 1). The standard error shows that degree of variation was not much (0.60-1.10) however, the mean fibre orientation in this species (9.20°) is greater than 7° standard for most softwood from the point view of strength. Nevertheless, for papermaking, this may not be a serious problem once the fibre is not twisted and not composed of reaction wood.

Axial Variation in the Physical Properties

The extrinsic growth index (diameter over bark) showed the species to be slow growing. Diameter decreased from base to top (Table 2). The taper characteristic is similar to that of *Pinus caribaea* grown in similar site in Nigeria (Osadare, 2001).

In Table 2, pith diameter progressively and significantly ($p<0.05$) increased from base (2.90 mm) to top (7.90 mm) (Table 3). This shows that more mature wood at the base had lower proportion of

Table 2: Physical properties of the wood along sampling heights

	Position of disc along sampling heights (m)						
Wood properties	0.38	1.13	1.3	2.63	4.30	5.63	7.13
Pith diameter (mm)	2.90	3.90	5.20	5.70	6.80	7.60	7.90
Bark thickness (mm)	9.80	7.80	7.20	6.50	5.60	4.70	3.40
Bark proportion (%)	18.94	20.55	19.92	21.83	25.95	34.96	49.23
Bast fibre proportion (%)	15.11	13.78	13.54	11.21	9.57	8.11	5.99
Grain orientation (θ°)	10.30	10.50	10.90	11.40	9.80	7.60	6.00
Diameter over-bark (cm)	22.15	-	13.91	-	10.84	-	4.93

- = Not measured

Table 3: Analysis of variance for the physical parameters (axial direction)

Wood properties	df	MSS	F-value	Significance level
Pith diameter				
Trees	4	5.9365	13.9552	*
Sampling heights	6	34.9806	82.2314	*
Residual	24	0.4254		
Total	34			
Bark thickness				
Trees	4	2.8705	5.1709	*
Sampling heights	6	45.0025	81.0678	*
Residual	24	0.5551		
Total	34			
Bark proportion				
Trees	4	58.2782	2.4260	*
Sampling heights	6	904.2436	37.6422	*
Residual	24	24.0221		
Total	34			
Bast fibre proportion				
Trees	4	4.9904	0.5428	ns
Sampling heights	6	110.9745	12.0695	*
Residual	24	9.1946		
Total	34			
Grain orientation				
Trees	4	4.5492	1.2932	ns
Sampling heights	6	24.7809	7.0446	*
Residual	24	3.5177		
Total	34			

*: Significant at $p<0.05$, ns = Not significant

pith and the juvenile wood at top, greater proportion. The implication of this is that there may be need to select minimum top diameter for logs in order to keep to minimum the proportion of pith in order not to interfere with paper quality.

Bark thickness and bast fibre proportion decreased from 9.8 mm and 15.1% at base to 3.4 mm to 5.99% at top, respectively (Table 2). This is not unexpected as diameter of the tree greatly decreased from base to top (Table 2) thus the tapering of the species equally affects these properties. However, for bark proportion, it increased significantly ($p<0.05$) from base to top (Table 2, 3). It means the volume of wood at the top will equally decrease corroborating the need to have minimum top diameter for this native pulpwood species. A top diameter inside bark of 7-10 cm has been suggested by (Ek, 1982) for pulpwood species.

Grain angle increased from 10.3° at base to 11.4° at the middle portion along the tree length and significantly decreased to 6.00 at top (Table 2, 3). This seems to follow a pattern of transition from juvenile wood to mature wood from crown wood region downward. Grain angle is usually higher in juvenile wood than in mature wood (Osadare, 2001). If fibre is twisted, it may cause difficulty during chipping causing blunting of chipper blades.

Ring Width and Fibre Characteristics

Mean ring width was between 4.9-6.2 mm (Table 4). This depict slow growth rate compared with similar hardwood species like *Gmelina arborea.* This is further corroborated by the growth parameters in Table 2. This may not be too advantageous since pulpwood species must grow at faster rate to meet demand supply. However, with tree improvement programmes, this can be improved upon. Another importance of faster growth rate includes higher volume of wood, higher pulp yield, breaking length, stretch, tear and double folds. These were found to be higher in fast growing trees than in slow growing trees (Palmer and Gibbs, 1973).

In Table 4, the mean ranged of 2.46-2.64 mm was obtained for fibre length. This differs significantly between the trees (Table 6). The mean value of 2.56 mm is far above the values obtained for most tropical hardwoods (Osadare and Udohitinah, 1993; Osadare, 1996; Ogbonnaya *et al*., 1997; Oluwadare, 1998; Poku *et al*., 2001). A mean value of 2.41 mm was reported for naturally grown trees of this species (Ogunwusi, 1997). Fibre diameter and lumen width ranged from 23.73- 29.28 µm m and 18.16- 22.12 µm, respectively. This is similar to values obtained by Ogunsanwo and Onilude (2000) for *Triplochiton scleroxylon* and for some non-wood materials for papermaking by Ogbounaya *et al*. (1992) and Pahkala (2001). Diameter and lumen width are has been described to be vital to paper strength especially during beating operations (Panshin and De Zeeuw, 1980).

Table 4: Ring width and fibre morphology of *Sterculia setigera* wood

	Tree No.					
Wood properties	1	2	3	4	5	Grand mean
Ring width (mm)						
Mean	5.60	6.20	6.00	5.50	4.90	5.60
Standard error	0.22	0.33	0.49	0.27	0.28	
Fibre length (mm)						
Mean	2.64	2.55	2.59	2.57	2.46	2.56
Standard error	0.02	0.03	0.04	0.08	0.04	
Fibre diameter (µm)						
Mean	26.71	26.45	25.62	26.38	26.44	26.32
Standard error	0.14	0.53	0.59	0.21	0.29	
Fibre lumen width (µm)						
Mean	21.15	20.57	19.50	20.34	20.34	20.38
Standard error	0.11	0.40	0.47	0.32	0.15	
Cell wall thickness (µm)						
Mean	2.83	2.87	3.16	2.92	2.93	2.94
Standard error	0.33	0.05	0.07	0.04	0.06	

Cell wall thickness had a mean value of 2.94 µm and significantly differs from tree to tree (Table 4, 6). This shows the cell wall to be thin and could enhance paper qualities. Cell wall thickness is vital to pulp yield, fibre flexibility, coarseness and ease of collapsibility during refining of pulp. Thick walled fibre tends to produce paper with high bulkiness and porosity (Panshin and De Zeeuw, 1980; Schmidt and Smith, 1961).

Axial Variation in Ring Width and Fibre Morphology

Ring width and fibre morphology variation in the axial direction are shown in Table 5. Ring width did not show a distinct pattern of variation as it significantly varied sinusoidally (Table 6). This may be due to the tapering of the tree however the importance of ring width variation has been shown to be important for the lowest sample heights (Degron and Nepveu, 1996), thus ring width variation may not be too significant at the top as found in *Quercus petraea.*

Fibre length significantly ($p<0.05$) decreased from 2.64 mm at the base to 2.36 mm at top (Table 5, 6). According to (Dinwoodie, 1965), for most pulp wood species fibre length is an important index for the suitability of any material for papermaking, since it affect tear strength (Byrd *et al*., 1965; Lobosky and Ifju, 1981). The pattern observed is similar to that of Ogunwusi (1997) on naturally

Table 5: Ring width and fibre morphology along sampling heights

	Position of disc along sampling heights (m)						
Wood properties	0.38	1.13	1.3	2.63	4.30	5.63	7.13
Ring width (mm)	5.30	6.70	6.20	5.10	5.40	4.90	5.30
Fibre length (mm)	2.64	2.62	2.61	2.62	2.53	2.56	2.36
Fibre diameter (µm)	26.51	25.93	25.33	25.58	26.39	27.67	26.96
Fibre lumen width (µm)	20.65	20.01	19.64	20.13	20.69	21.33	20.50
Cell wall thickness (µm)	2.93	2.96	2.85	2.73	2.85	3.17	3.23
Slenderness, L/D	100.00	101.00	103.00	102.00	96.00	93.00	88.00
Coefficient of flexibility (d/D)	78.00	77.00	78.00	79.00	78.00	77.00	76.00
Runkel ratio (2cw/d)	0.28	0.30	0.29	0.27	0.28	0.30	0.31

Table 6: Analysis of variance for ring width and fibre dimensions (axial direction)

Wood properties	df	MSS	F-value	Significance level
Ring width				
Trees	4	2.1608	3.0202	*
Sampling heights	6	3.0486	4.2614	*
Residual	24	0.7154		
Total	34			
Fibre length				
Trees	4	0.0311	4.5072	*
Sampling heights	6	0.0467	6.7681	*
Residual	24	0.0069		
Total	34			
Fibre diameter				
Trees	4	1.1767	2.3534	ns
Sampling heights	6	3.3878	6.7756	*
Residual	24	0.5000		
Total	34			
Lumen width				
Trees	4	2.4726	4.5806	*
Sampling heights	6	1.5152	2.8070	*
Residual	24	0.5398		
Total	34			
Cell wall thickness				
Trees	4	0.1118	5.5622	*
Sampling heights	6	0.0132	0.6567	ns
Residual	24	0.0201		
Total	34			

*: Significant at $p<0.05$, ns: Not significant

grown material from this site. Therefore, papers made from Sterculia are expected to have increased mechanical strength and thus be suitable for writing, printing, wrapping and packaging purposes (Neto *et al.*, 1996).

Fibre diameter and lumen width tends to significantly increase from base to the top intersparsely. This is similar to observation of Ogunsanwo and Onilude (2000), on *Triplochiton scleroxylon* and on *Swietenia macrophylla* by Seth and Page (1988). Fibre diameter and lumen width may not impact serious negative problem on paper quality unless when they are considered as derived values in relation to slenderness and flexibility of individual fibre.

Cell wall thickness had significant increase from the middle portion to the top after initial decrease at the lower portion (Table 5). This pattern do not follow observed trend in most hardwood species (Panshin and De Zeeuw, 1980), but similar to observed trend in *Cynara cardunculm* and *Calamus* sp. (Bhat *et al.*, 1993; Quilho *et al.*, 2004). However, the trend may be disadvantageous as thick walled fibres will not collapse readily during refining thereby affecting mechanical strength of paper (Chittenden and Palmer, 1990; Twinmasi, 1996; Ogbonnaya *et al.*, 1997; Ververis *et al.*, 2004). On the overall effect, it is considered that the fibre is fairly thin walled compared to Eucalyptus and Pines species (Hicks and Clark, 2001; Osadare, 2001).

The derived values variation in the longitudinal axis followed the pattern of the fibre dimension that determines it. Slenderness is associated with fibre length while Runkel ratio is closely associated with cell wall thickness (Table 5). Flexibility coefficient of the fibre shows that the fibre from this species will collapse into a ribbon and will entangle easily thereby increasing inter-fibre bonding. This is necessary for the development of good strength properties.

Radial Variation in Ring Width and Fibre Dimensions

In Table 7, significant ($p<0.05$) increase was observed for ring width from pith to ring 5 and later decreased systematically toward the bark. The common trends in most wood whether hardwood or softwood has been gradual decrease from pith to bark (Panshin and De Zeeuw, 1980; Osadare, 2001). Ring width in conjunction with percentage latewood affect pulp yield and strength properties of paper. This provide avenue for tree improvement which will require that the distribution of ring width in Sterculia be monitored over time in order to assess its overall influence on paper quality.

Table 7: Pith to bark variation in ring width and fibre morphology

	Ring number from pith to bark												
Wood properties	1	2	3	4	5	6	7	8	9	10	11	12	13
Ring width (mm)	4.80	5.30	5.80	5.90	6.30	5.90	6.10	6.10	6.10	5.90	5.80	5.80	4.00
Fibre length (mm)	2.36	2.51	2.59	2.61	2.58	2.67	2.69	2.66	2.63	2.74	2.85	2.70	2.67
Fibre diameter (µm)	26.25	26.23	26.45	26.19	26.31	26.01	25.83	25.91	25.68	26.98	25.24	25.66	25.26
Fibre lumen width (µm)	20.19	19.99	20.52	20.37	20.56	20.61	20.35	20.04	19.99	20.88	19.63	20.03	19.70
Cell wall thickness (µm)	3.03	3.12	2.97	2.91	2.88	2.70	2.74	2.94	2.85	3.05	2.81	2.82	2.78
Slenderness, L/D	89.00	96.00	98.00	100.00	98.00	103.00	104.00	103.00	102.00	102.00	113.00	105.00	106.00
Coefficient of flexibility (d/D)	77.00	76.00	78.00	78.00	78.00	79.00	79.00	77.00	78.00	77.00	78.00	78.00	78.00
Runkel ratio (2cw/d)	0.30	0.31	0.29	0.29	0.28	0.26	0.27	0.29	0.29	0.29	0.29	0.28	0.28

The fibre dimensions and their derived indices in radial direction are shown in Table 7. Fibre length increase from pith to ring number 11 (2.36-2.85 mm) and decreased in the last two rings nearest the bark (2.70-2.67 mm). Fibre length may be expected to contribute to hand-sheet bulk, since longer fibres do not pack together as closely (Hicks and Clark, 2001). Nevertheless, the length of the fibres may not necessarily cause flocculation, as minimum length is required for good inter-bonding. The observed trend may be due to rate of growth as depicted by ring width in association with enviroumental factors and genetic makeup of the species.

Both fibre diameter and lumen width did not show a distinct pattern of pith to bark variation (Table 7). However, cell wall thickness tends to decrease from pith to bark though in an inconsistent pattern. These properties jointly influenced the derived indices that are of superior values to most hardwoods and some softwood. The fibres are still highly flexible with a good Runkel ratio and high slendemess ratio. This shows that the wood could produce pulp of good quality of high strength value.

Uniformity of the Properties in the Stem

The coefficients of uniformity indices in radial and axial direction are shown in Table 8. Fibre length and slenderness ratio showed higher values of 107.43 and 110.0% with percentage deviation values of +7.43 and +10.0% in the radial direction (Table 8). This means that these properties do not show minimum inter-ring uniformity in the distribution of fibre length and slenderness within the tree. However, other properties were uniformly distributed within the stem since percentage deviation range between -1.38 in fibre lumen to 1.0% in coefficient of flexibility (Table 8). The importance of uniformity of fibre properties in papermaking raw materials has been emphasized by Oluwadare and Sotannde (2006). The better the fibre is uniformly distributed within the fibrous raw material, the greater the homogeneity of the product that could be produced thereof.

In the axial direction similar trend was observed except that fibre length show better uniformity (+5.64%) than in radial direction. This is advantageous in that top logs can be used since the quality of the fibres at the top does not differ greatly compared to those at the base. Ring width was not distributed uniformly (+16.7%), this translate to differing growth pattern as exerted by the enviroument, crown wood formation and genetic makeup of the species. Using the ratio of RCU: ACU to assess the overall uniformity of these indices; mean deviation was between -0.48 for Runkel ratio to +2.25% in fibre lumen width. This implies that the wood of Sterculia showed moderate within-tree variation and thus could produce more uniformed wood that will enhance greater proportion of wood utilization; this is important especially when whole wood utilization is envisaged in order to have higher pulp yield.

Table 8: Coefficient of uniformity indices in radial and axial direction for the wood properties

Wood properties	ACU* (%)	RCU** (%)	RCU : ACU
Pith diameter	185.8 (+85.8)	NA	NA
Bark thickness	181.0 (+81.0)	NA	NA
Bark proportion	53.9 (-46.1)	NA	NA
Bast fibre proportion	183.5 (+83.5)	NA	NA
Grain orientation	135.5 (+35.5)	NA	NA
Ring width	116.7 (+16.7)	98.20 (-1.80)	84.10 (-15.9)
Fibre length	105.64 (+5.64)	107.43 (+7.43)	101.69 (+1.69)
Fibre diameter	95.99 (-4.01)	98.01 (-1.99)	102.10 (+2. 10)
Fibre lumen width	96.45 (-3.55)	98.62 (-1.38)	102.25 (+2.25)
Cell wall thickness	94.49 (-5.51)	95.96 (-4.04)	101.56 (+1.56)
Slendemess	11 0.0 (+10.0)	110.00 (+10.0)	100.00(0)
Coefficient of flexibility	101.0 (+1.00)	101.00 (+1.00)	100.00(0)
Runkel ratio	97.75 (-2.25)	97.28 (-2.72)	99.52 (-0.48)

*RCU: Radial coefficient of uniformity, **ACU: Axial coefficient of uniformity, NA: Not applicable, +: Values in parentheses shows deviation from 100%, + sign: Above, - sign: below

Table 9: Correlation coefficient matrix for ring width and fibre morphology

Wood properties	Ring width (mm)	Fibre length (mm)	Fibre diameter (µm)	Lumen width (µm)	Cell wall thickness (µm)	Slenderness	Coeff. of flexibility (%)	Runkel ratio
Ring width (mm)	1.00	.						
Fibre length (mm)	ns	1.00	.					
Fibre diameter(m	ns	ns	1.00	.				
Lumen width (mm)	ns	ns	0.96*	1.00	.			
thickness (mm)	ns	ns	-0.99**	-0.95*	1.00	.		
Slenderness	0.66	0.77	0.64	-0.39	0.60	1.00	.	
Coeff. of flexibility (%)	ns	ns	0.92*	0.95*	-0.90*	ns	1.00	.
Runkel ratio	ns	ns	-0.98**	-0.99**	0.99**	ns	-0.94*	1.00

*Correlation is significant at the 0.05 probability level, **Correlation is significant at the 0.01 probability level, ns: Not significant

Correlation Between Ring Width and Fibre Morphology

The simple correlation coefficients which elucidate the extent of linear relationships among ring width and fibre dimensions and their derived values are shown in Table 9. Ring width had low and insignificant relationship with all the selected properties. However, fibre diameter was significantly ($p<0.05$ and $p<0.01$) correlated with lumen width ($r = 0.96$), cell wall thickness ($r = -0.99$), coefficient of flexibility ($r = 0.92$) and Runkel ratio ($r = -0.98$). Similarly lumen width had significant relationship with coefficient of flexibility ($r = 0.95$) and Runkel ratio ($r = -0.99$), while cell wall thickness had significant relationship with coefficient of flexibility ($r = -0.90$) and Runkel ratio ($r = 0.99$). Coefficient of flexibility was correlated with Runkel ratio ($r = -0.94$) (Table 9). These relationships show the dependence of the derived values on the fibre morphology. Therefore, the flexibility of the fibre is a function of the degree of cell wall thickness, lumen width and fibre diameter which affects pulp yield as well as response of the fibre to refining operations. It may be possible to use the fibre biometry in predicting the derived morphology.

CONCLUSIONS

The wood of *Sterculia setigera* contains pith and bast fibre. The pith may not be too detrimental to paper quality especially as the tree ages while the bast fibre may be additioual source of fibre for papermaking.

Some trends were observed in the axial direction; grain orientation and ring width tend to increase towards the middle before decreasing to the top. Fibre length and cell wall thickness decreased from the base to the top.

Across the growth radii, ring width increased from pith towards the fifth ring, then a constant level and a progressive decrease to the bark. Fibre length as well as cell wall thickness increase across the radii was not consistent. The derived values were high for slenderness and flexibility while Runkel ratio was of minimum value.

The distribution of the various parameters within the tree showed high uniformity along the two axes. Fibre diameter, lumen width and cell wall thickness had high and significant correlation with one another and derived morphological features.

Based on these findings, Sterculia wood compares favourably with some softwood and had better values than most hardwood species for papermaking. The fibre biometry indicates potential suitability of the species for good quality writing and printing paper. It is necessary to pursue the plantation establishment of this species vigorously as this will help to step down the total dependence of the paper mills on imported fibre with its prohibitive cost.

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