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Assessing the suitability of *Ficus sur* and *Cola gigantea* as raw material for pulp and paper production in Ghana

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ABSTRACT

The efficient utilization of the Lesser Used timber species is of utmost importance in the sustainable management of tropical forest in Ghana. Cola gigantea and Ficus sur are two lesser utilized timber species which are available in the forest estate of Ghana. Pulp and paper production is one of the essential wood industries contributing immensely to the world economies in pulp and paper producing countries. These species could be used as material for pulp and paper if the properties are established. In this study the anatomical properties of Cola gigantea and Ficus sur were determined to ascertain their suitability for pulp and paper production. Five naturally-grown matured trees each of Cola gigantea and Ficus sur were selected from Pra-Anum Forest Reserve in the moist semi-deciduous (–South-east type) forest zone of Ghana. Results indicated that, the ground tissue (vessels: parenchyma: fibres) proportions for the species were 8%:43%: 49% and 9%: 47%:44% for C. gigantea and F. sur respectively. The mean fibre length, lumen diameter and double wall thickness for the species were 2.0mm, 14.8µm, 9.9µm and 1.5mm, 23.9µm 7.5µm for C. gigantea and F. sur respectively. Ficus sur can be used to produce sheets with higher tensile strength, burst index and fold endurance whilst Cola gigantea can be used for sheets with high tear index. Therefore, both Ficus sur and Cola gigantea can be used as a suitable raw material for pulp and paper production in Ghana if their pulping characteristics proved suitable.

Key words: Fibre morphology, Cola gigantea, Ficus sur

INTRODUCTION

The Pulp and Paper strategy Final Report [12] stated that, growth in Latin American pulp production has been strong over the past decade as a result of the maturing and expanding plantation resources in that region. It further stated that the growth is supported by strong demand from China and Europe since China alone imports 22 per cent of the world's total supply of pulp. Short plantation harvest periods provide Latin America with a competitive advantage. There have been several efforts to generate information on the appropriate pulping techniques as well as appropriate wood and non wood species for this industry in Ghana. Darkwa [1] discussed the problems associated with the utilization of mixed tropical hardwood species and concluded that it was possible to produce pulp and paper from mixed tropical hardwood. Sekyere [14, 15] worked on the utilization of some tropical hardwoods and bamboo as raw material for pulp and paper production in Ghana. He concluded that *Bambusa vulgaris*, *Musanga cecropiodes* , *Gmelina arborea* and *Eucalyptus deglupta* grown in Ghana are suitable species for pulp and paper production. Although Ghana has not been able to develop vibrant pulp and paper industry, it has the potential to produce wood pulp for export from the vase fast growing species found in the natural forest. This will help increase the foreign exchange and revenue generated from the forest as well as creating employment for the teaming unemployed youth in the country. Ghana' natural forest is stocked with about 2300 different plant species, 730 of these species are trees, 420 of these trees species are widely distributed and 240 of these tree species grows to attain timber sizes [3]. He further stated that about 126 species out of these 240 timber species occurs in sufficient volumes to be considered as a raw material base for timber industry. The potential for the utilization of Ghana's hardwoods from natural forests for pulp and paper-making is high. The high level of diversity and distribution is as results of the suitable climatic and edaphic conditions prevailing in this country.

There is therefore the need to intensify the search from among these numerous species, those that are fast growing, easy to establish in plantations and has suitable anatomical characteristics for pulp and paper production. *Ficus sur* and *Cola gigantea* are some of the fast growing timber species found in Ghana's natural forest and can easily be propagated either by seeds, stem cuttings or by both methods. This study focused on their anatomical properties, one of the important factors for selecting plant species as a raw material for pulp and paper production. Inagaki *et al* [4] stated that cell wall thickness and fiber length are used to evaluate the suitability of a wood for a particular application and the final paper products.

Ficus sur belongs to the family moraceae and widely distributed throughout tropical Africa from Cape Verde east to Somalia, and south to Angola and South Africa. It also occurs in Yemen. *Ficus sur* occurs from sea-level to 2500m altitude, on riverbanks and in riverine forest, but also in upland forest, woodland and wooded grassland in Ghana. The tree prefers full sun and grows on a wide range of soil type and can tolerate partial shade. This species can be propagated by seed and stem cutting. The heartwood is white to yellow and not clearly demarcated from the sapwood. The grain is fairly straight or interlocked with moderately coarse to coarse texture. The wood is slightly sticky when freshly sawn due to the latex. The wood is porous and lightweight with basic density between 300—650Kg/m^3[10,11] .

Cola gigantea belongs to Sterculiaceae family and very common in the dry semi- deciduous ecological zone of Ghana. The tree can grow to about 50m high and 5m in girth with 90cm as the prescribed minimum felling diameter [10]. Oteng-Amoako [10]; Owusu *et al* [11] classified the wood as non-durable and medium density wood. The tree prefers full sun and grows on a wide range of soil type and can tolerate partial shade. It can be propagated by seeds and performs well under plantation establishment.

The main objective of this study was to assess the suitability of *Cola gigantea and Ficus sur* for pulp and paper production in Ghana.

MATERIALS AND METHODS

Five matured trees each of *Cola gigantea* and *Ficus sur* were selected from Pra-Anum Forest Reserve in the moist semi-deciduous (–South-east type) forest zone of Ghana which lies between 6^0 12'-6^{0}19'N and 1^{0}9'-1^{0}17W. The average diameters of the trees at 1.3 meter above ground (dbh) were 63.8cm and 48.4cm for *Cola gigantea* and *Ficus sur* respectively. The mean clear bole length between where the first branch begins and the terminal point of buttresses of each species were 1797cm and 1140cm for *Cola gigantea* and *Ficus sur* respectively. The samples were taken from butt (10%), middle (50%) and top (90%) height positions along the clear boles. The outer sample was taken close to the bark (sapwood) and the inner sample near the pit (heartwood) in the radial direction.

Maceration

Samples of dimension 2mm x 2mm x 30mm from the top, middle and bottom in axial position; and from sapwood and heartwood were prepared. The samples were kept in separate vial containing 60ml solution of 6% hydrogen peroxide and 97% acetic acid. The specimens were incubated at 60 ^{0}C for seven (7) days to obtain complete macerations. The macerates were rinsed with water and mounted temporarily in diluted glycerol for measurements of cell dimensions.

Microscopic observations and measurements

All the anatomical observation and measurements were done under light microscope (Fisher Scientific Micromaster premier equipped with computer software for live imagine captioning). Anatomical measurements were done using the eyepiece scale of 100 divisions and 10x objective lens. The number of vessels per square millimeter was determined by counting the number of vessels using scale grid eyepiece with the field area of 1.4963mm^2. An average of five (5) counts per section was converted to correspond to an area of 1mm^2.

Vessels, parenchyma and fibres proportions were determined from each sample using 10x objective lens and 10x eyepiece with a dot grid scale of 20 points. The dot scale was placed five times at different areas on the slide and at each placement; the number of points covering any tissue was counted and expressed as a percentage of the total number of points.The tangential diameter of vessel lumina was determined by measuring the diameter of sixty (60) vessels for each species. Fibre length, lumen width and the double wall thickness were measured on 210 complete and straight fibres per species. Excel 2007 analysis tool pack and Statistical Package for Social Sciences (SPSS) version 15 package were used to perform the Analysis of Variance (ANOVA), Least Significant Difference (LSD) post-hoc-test to determine the variation in the quantitative anatomical features.

RESULTS AND DISCUSSION

Tissue proportion variation in *Cola gigantea* and *Ficus sur*

From Table 1, the proportion of vessel was 8% in both sapwood and heartwood of *C. gigantea*. Parenchyma proportion was 44% in sapwood and 42% in heartwood. The fibre proportion varied from 48% in sapwood to 50% in heartwood of *Cola gigantea* and the tangential vessel diameter varied from 180µm in sapwood to 188µm in heartwood (Table 2). From the same Table 1, the mean vessel proportion was 9% in both sapwood and heartwood of *F. sur*. Parenchyma proportion varied from 49% in sapwood to 44% in heartwood. Fibre proportion was 42% in sapwood and 47% in heartwood of *Ficus sur* and vessel diameter was 216µm for *Ficus sur* sapwood and 236µm for its heartwood (Table 2). The wider vessel diameters in heartwood of both species were expected. Both species are fast-growing light demander species hence grows rapidly in the juvenile stages with larger cell lumen and thin cell walls but the growth rate relatively slows down as the plant age. Therefore the plant produces cells with relatively thicker cell wall and smaller cell lumen. This may account for relatively smaller vessel diameter in sapwood as compared with that of the heartwood of both species. The mean percentage tissues proportion varied slightly between *Cola gigantea* and *Ficus sur*. The vessel proportion varied from 8% in *Cola gigantea* to 9% in *Ficus sur*. Proportion of parenchyma varied from 43% in *C. gigantea* to 47% in *F. sur* and fibre proportion was 49% in *Cola gigantea* and 44% in *Ficus sur*. From Table 2, the vessel frequency was 4.0/mm^2 for both *C. gigantea* and *Ficus sur*. Inter-vessel pit sizes were 3.0µm for *C. gigantea* and 8.0 µm for *Ficus sur*. The tangential vessel diameter varied from 184 µm in *C. gigantea* to 225µm in *Ficus sur*. Ray parenchyma height varied from 1224 µm in *C. gigantea* to 729µm in *Ficus sur* and the ray width was 139 µm in *C. gigantea* and 121µm in *Ficus* sur. Ramirez *et al* [13] stated that vessels and fibres are essential in assessing the suitability of wood species for pulp and paper production. They further stated that *Eucalyptus globules*, a suitable pulp and paper raw material has around 4-6 vessels / mm^2. Although high percentage of vessels facilitate penetration of pulping liquour into the wood, sheet surface quality is lowered since vessel elements may pick out from sheet surface during printing process, leaving ink-free spots on the printed page [7]. The average tissue proportions of these species coupled with low vessel frequency (4 vessels/ mm^2) make them suitable species for pulp and paper production.

Table 1 Percentage ground tissues proportion (%) in *Cola gigantea* and *Ficus sur*

Tissues	Vessel		Parenchyma		Fibres	
	Mean ± α	Range	Mean ± α	Range	Mean ± α	Range
Cola gigantea						
Sapwood	8 ± 3	5 – 10	44 ± 8	30 – 55	48 ± 6	40 – 60
Heartwood	8 ± 3	5 – 15	42 ± 11	20 – 65	50 ± 11	30 – 70
Whole tree	8 ± 3	5 – 15	43 ± 9	20 – 65	49 ± 9	30 – 70
Ficus sur						
Sapwood	9 ± 5	5 – 20	49 ± 10	30 – 65	42 ± 8	30 – 55
Heartwood	9 ± 4	5 – 15	44 ± 7	30 – 55	47 ± 8	35 – 65
Whole tree	9 ± 4	5 – 20	47 ± 9	30 – 65	44 ± 8	30 – 65

α = standard deviation

Fibre morphological variation in *Cola gigantea* and *Ficus sur*

From Table 3, the mean fibre length was 2.1mm for sapwood and 1.9mm for heartwood of *Cola gigantea*; fibre diameter varied from 24.2 µm in sapwood to 25.1 µm in heartwood; fibre lumen diameter was 13.9 µm for sapwood and 15.6 µm for heartwood; and the double cell wall thickness was 10.3 µm for sapwood and 9.5 µm for heartwood of *Cola gigantea*. These fibre morphological parameters of *Cola gigantea* also varied along the bole from butt to top. All the parameter studied on *Cola gigantea* except fibre lumen diameter seems to increase from the top to the butt. The fibre lumen diameter of *Cola gigantea* however, increased from top to middle and decreased towards the butt. Tables 4.1.3 and 4.1.5 indicated that the *Cola gigantea* sapwood had significantly longer fibres than its heartwoods at $P< 0 .01$. The lumen diameter of *C. gigantea* heartwood was significantly wider than that of its sapwood at $P<0.01$. Although the mean value of wall thickness of *C. gigantea* sapwood was higher than that of its heartwood, there was no statistical difference between them at $P<0.05$(Tables 4.1.3 and 4.1.5). For *Cola gigantea* from Table 4.1.5, except the double cell wall thickness across and fibre lumen diameter along the bole, all the other fibre morphological parameters studies varied significantly across and along the bole at $P\leq0.01$. Generally, fibre lumen diameter of *C. gigantea* decreased from heartwood to the sapwood at any particular height (Table 3) and showed an increase from base to the middle and decreased to the top (Table 3). From Table 4, the mean fibre length varied from1.7mm in sapwood to 1.4mm in heartwood for *Ficus sur*; fibre diameter varied from 31.7 µm in sapwood to 30.9 µm in heartwood; fibre lumen diameter was 23.9 µm for sapwood and 23.8 µm for heartwood; and double cell wall thickness was 7.8 µm for sapwood and 7.1 µm for heartwood of *Ficus sur*. The fibre diameter and the fibre lumen diameter of *Ficus sur* increased from top to the middle and decreased towards the butt. Fibre length and double cell wall thickness of *Ficus sur* seems to increase from the top to the butt. Table 5 showed that the *Ficus sur* sapwood had significantly longer fibres than its heartwoods at $P< 0 .01$ but there was no significant difference between the lumen diameter of *Ficus sur* sapwood and its heartwood at $P<0.05$. *F. sur* sapwood was significantly thicker than that of its heartwood at $P<0.05$ (Table 5). For *F. sur* however on the same Table 5, except the lumen diameter across the bole, all the other fibre morphological parameters studies varied significantly across and along the bole at $P\leq0.05$. The general decrease in fibre length from the base to the top and its corresponding increase from the heartwood to the sapwood sections observed in this study has been reported in other species by Jorge *et al* [6]; Izekor and Fuwape [5] when they studied *Eucalyptus globules* and *Tectona grandis* respectively. This trend according to these authors is due to increase in length in cambial initials with cambial age. The differences in fibre length associated with increase in height is mainly due to the differences in the juvenile and mature wood proportion in the tree, since the proportion of juvenile wood increases with an increase in height [17]. Fibre length and wall thickness of *C. gigantea* were significantly longer and thicker than those in *F. sur* but the fibre diameter and lumen diameter of *F. sur* was significantly wider than those of *C. gigantea* at $P<0.01$ (Tables 5).

Table 2. Vessel and ray morphology of *Cola gigantea and Ficus sur*

	Cola gigantea		***Ficus sur***	
Anatomical features	Mean ± α	Range	Mean ± α	Range
Vessels				
Frequency (mm^{-2})	4.0 ± 0.3	3.0 – 5.0	4.0 ± 0.2	3.0 – 5.0
Pit size (µm)	3.0 ± 0.4	2.9 - 3.4	8.0 ± 0.7	3.8 - 10.1
Tangential vessel diameter (µm)				
Sapwood	180 ± 30	125 – 238	216 ± 25	163 – 263
Heartwood	188 ± 25	150 – 238	236 ± 35	163 – 300
Whole tree	184 ± 28	125 – 238	225 ± 31	163 – 300
Rays height (µm)				
Sapwood	1320 ± 400	563 – 2800	793 ± 178	500 – 1375
Heartwood	1078 ± 321	563 – 1873	665 ± 128	400 – 1063
Whole tree	1224 ± 453	563 – 2800	729 ± 167	400 – 1375
Ray width (µm)				
Sapwood	140 ± 31	75 – 225	126±21	88 – 163
Heartwood	139 ± 20	88 – 188	117 ± 32	50 – 163
Whole tree	139 ± 31	75 – 225	121 ± 27	50 – 163

α = standard deviation

Izekor and Fuwape [5] stated that fibre morphological characters differs between species and even within species due to inherent physiological and genetical variations which account for the between species wood properties They further stated that silvicultural, environmental and edaphic conditions may modify fibre morphology of the same wood species growing under different ecological and climatic zones. Therefore variations between the fibre morphological parameters of *Cola gigantea* and *Ficus sur* may be due to differences in their genetic and physiological properties. *Ficus sur* has thinner and wider fibres as compared with *Cola gigantea* (Table 3 and 4). According to Niskanen [9], thinner and wider fibres collapse more easily and are more flexible and conformable. They tend to form more inter- and intra-fibre bonds. Thin-walled fibres therefore yield a higher relative bonded area (RBA) and less porosity in the paper sheet. This results in a higher sheet density and tensile strength, due to the higher bonding degree. Conformable and flexible thin-walled fibres will also improve surface smoothness. Seth and Page [16] and Niskanen [9] stated that in a well-bonded sheet the tear and tensile strength depend less on fibre length. Niskanen [9] explained that, when forming paper from pulp, longer fibres start flocking at a lower fibre concentration than shorter fibres do. Under equal conditions, shorter fibres, therefore, yield a more uniform paper with better formation than longer fibres. Therefore, *F. sur* can be used to produce sheets with smooth surface, higher sheet density and tensile strength than *Cola gigantea*.

Table 3 Summary descriptive analysis of fiber length (FL, mm), double wall thickness (DWT, µm), Fiber lumen diameter (FLD, µm) and fiber diameter (FD, µm) variation along and across the stem of *Ficus sur*

	Sections	Top (90%)	Middle (50%)	Butt (10%)	Total
		Mean ±α (n)	Mean ± α (n)	Mean ± α (n)	Mean ± α (n)
Fibre length **(mm)**	Sapwood	1.3± 0.13 (35)	1.7±0.27(35)	2.0±0.16 (35)	1.7^{a}±0.34 (105)
	Heartwood	1.6±0.15 (35)	1.1±0.11(35)	1.7±0.15 (35)	1.4^{b}±0.30 (105)
	Total	1.4^{m}±0.19 (70)	1.4^{m}±0.38(70)	1.8^{n}±0.23 (70)	1.5±0.34 (210)
Fibre diameter **(µm)**	Sapwood	33.8±4.9 (35)	34.5±3.9(35)	26.9±3.1 (35)	31.7^{c}±5.3 (105)
	Heartwood	31.1±3.8 (35)	32.7±3.9(35)	29.1±3.0 (35)	30.9^{c}±3.9 (105)
	Total	32.4^{d}±4.6 (70)	33.6^{d}±4.0(70)	28.0^{e}±3.2 (70)	31.3±4.6 (210)
FLD **(µm)**	Sapwood	26.5±4.7 (35)	25.8±3.9(35)	19.5±3.3 (35)	23.9^{j}±5.1 (105)
	Heartwood	22.2±3.9 (35)	27.6±4.1(35)	21.6±3.2 (35)	23.8^{j}±4.6 (105)
	Total	24.3^{f}±4.8 (70)	26.7^{h}±4.1(70)	20.6^{g}± 3.4(70)	23.9±4.8 (210)
DWT **(µm)**	Sapwood	7.3±1.4 (35)	8.6±2.0 (35)	7.4±1.9 (35)	7.8±1.9 (105)
	Heartwood	8.9±2.1 (35)	5.1±1.1 (35)	7.4±2.5 (35)	7.1±2.5 (105)
	Total	8.1^{u}±1.9 (70)	6.7^{v}±2.4 (70)	7.4^{vu}±2.2 (70)	7.5±2.2 (210)

Means with the same letters are not significant ($P<0.05$)

Table 4 Summary descriptive analysis of fiber length (FL, mm), double wall thickness (DWT, µm), Fiber lumen diameter (FLD, µm) and fiber diameter (FD, µm) variation along and across the stem of *Cola*

		Top (90%)	Middle (50%)	Butt (10%)	Total
	Sections	Mean ± α (n)	Mean ± α (n)	Mean ± α (n)	Mean ± α (n)
Fibre length **(mm)**	Sapwood	1.7±0.14 (35)	2.3±0.28 (35)	2.4±0.26 (35)	2.1^{n}±0.39(105)
	Heartwood	1.8±0.18 (35)	1.9 ±0.18 (35)	1.9±0.26 (35)	1.9^{m}±0.21 (105)
	Total	1.8^{a}±0.17 (70)	2.1^{b}±0.29 (70)	2.1^{b}±0.37 (70)	2.0±0.33 (210)
Fibre diameter **(µm)**	Sapwood	22.6±2.8 (35)	24.7±3.9 (35)	25.3±3.4 (35)	24.2^{s} ±3.5(105)
	Heartwood	24.7±2.4 (35)	24.8±3.1 (35)	26.1±4.0 (35)	25.1^{t} ±3.3(105)
	Total	23.5^{c}±2.8 (70)	24.8^{d}±3.5(70)	25.7^{d}±3.7(70)	24.7±3.4 (210)
FLD **(µm)**	Sapwood	13.9±2.9 (35)	14.7± 2.9 (35)	13.2±3.1 (35)	13.9^{u}±3.0(105)
	Heartwood	14.6±3.2 (35)	16.4±2.9 (35)	15.9±3.8 (35)	15.6^{u}±3.4(105)
	Total	14.3^{e}±3.0(70)	15.5^{f}±3.0(70)	14.6^{ef}±3.7(70)	14.8±3.3 (210)
DWT **(µm)**	Sapwood	9.8±2.0 (35)	10.0±2.8 (35)	12.0±3.0 (35)	10.3^{w}±3.0(105)
	Heartwood	8.7±2.3 (35)	8.5±1.8 (35)	10.3±3.1 (35)	9.5^{w}±2.5(105)
	Total	9.3^{g}±2.8(70)	9.2^{g}±2.5(70)	11.1^{h}±3.1(70)	9.9±2.8 (210)

Means with the same letters are not significant ($P<0.05$)

Comparison of fibre dimensions and derived values of *C. gigantea* and *F. sur* with other Ghanaian timber species suitable for pulp and paper production

Table 6 shows the fibre dimensions and derived values for *Cola gigantea*, *Ficus sur*, *Musanga cecropiodes*, *Gmelina arborea* , *Eucalyptus deglupta* and *Bambusa vulgaris*. The fibres of both the *Cola gigantea* and *Ficus sur* were longer than those of the suitable commercially available timber species found in Ghana. Sekyere [15] asserted that the suitability of a material for pulp and paper is largely determined by its runkel ratio and said that the lower the ratio, the better the material for paper production. Based upon the runkel ratio, both *Cola gigantea* and *Ficus sur* will be better raw material for production of pulp and paper with higher strength properties than *Bambusa vulgaris* and *Eucalyptus deglupta*. The double fold endurance, tensile strength and burst factor seems to be positive correlation with the flexibility ratio and that the higher the flexibility ratio, the higher these properties will be [2, 15]. Therefore based upon the flexibility ratio, *Ficus sur* will produce sheets with higher tensile strength, burst and fold endurance than all the other materials except *Eucalyptus deglupta*. *Cola gigantea* will have the least of these properties compared with other materials (Table 6). Apart from *Bambusa vulgaris*, *Cola gigantea* will have the highest tear index because of its higher slenderness ratio.

Table 5 Analysis of variance (ANOVA) of the fibre morphological parameters in *Cola gigantea* and *Ficus sur*

Species	Sections	Sources of variation	F-value	F-crit	df
Cola gigantea	Radial (sapwood & heartwood)	Fibre length	32.75**	6.76	1, 208
		Fibre lumen diameter	14.05**	6.76	1, 208
		Double wall thickness	3.48^{ns}	3.89	1, 208
	Axial (butt, middle, top)	Fibre length	34.29**	4.71	2, 207
		Fibre lumen diameter	2.77^{ns}	3.04	2, 207
		Double wall thickness	10.84**	4.71	2, 207
F. sur	Radial (sapwood & heartwood)	Fibre length	29.16**	6.76	1, 208
		Fibre lumen diameter	0.04^{ns}	3.89	1, 208
		Double wall thickness	4.51*	3.89	1, 208
	Axial (butt, middle, top)	Fibre length	56.65**	4.71	2, 207
		Fibre lumen diameter	39.24**	4.71	2, 207
		Double wall thickness	5.40**	4.71	2, 207
	Whole *C. gigantea & Ficus sur*	Fibre length	174.78**	6.70	1, 418
		Fibre lumen diameter	500.21**	6.70	1, 418
		Double wall thickness	94.81**	6.70	1, 418

*** = Significant at P< 0.01, * = significant at P<0.05, ns = not significant at P<0.05*

Table 6 Fiber dimensions and derived values of *Cola gigantea* and *Ficus sur* compared with some of the cellulosic materials in Ghana found to be suitable for pulp and paper production

Species	*Cola gigantea*	*Ficus sur*	*B. vulgaris*	*Musanga cecropiodes*	*Gmelina arborea*	*Eucalyptus deglupta*
Fiber length L (mm)	1.99	1.55	2.65	1.25	1.00	0.99
Fibre diameter, D (µm)	24.70	31.30	14.60	25.11	28.80	17.48
Fibre wall thickness, W (µm)	4.95	3.75	4.95	3.00	2.80	2.55
Fibre lumen diameter, l (µm)	14.80	23.9	9.65	18.88	20.31	12.20
Slenderness ratio L/D	80.57	49.52	182.00	49.80	38.80	56.60
Runkel ratio 2W/l	0.72	0.33	1.03	0.32	0.27	0.84
Flexibility ratio (l/D) x 100	59.92	76.36	66.10	75.20	78.70	69.80

Sources of data: Sekyere (1994 and 1997)

CONCLUSION

From the fibre dimensions, vessels frequency and the derived values, both *Cola gigantea* and *Ficus sur* will be better raw material for production of pulp and paper with higher strength properties than *Bambusa vulgaris* and *Eucalyptus deglupta*. *Ficus sur* can be used to produce sheets with higher tensile strength, burst and fold endurance than all the other raw materials except *Eucalyptus deglupta* whilst *Cola gigantea* will have the least of these properties compared with other materials. *Cola gigantea* can use to produce sheets with highest tear index because of its higher slenderness ratio. Therefore, both *Ficus sur* and *Cola gigantea* can be used as a suitable raw material for pulp and paper production in Ghana.

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