



## WOOD FIBRE OF *FICUS EXASPERATA* (VAHL) AS ALTERNATIVE FOR PULP AND PAPER MAKING IN NIGERIA

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**ABSTRACT:** This study was undertaken to evaluate the fiber characteristics of *Ficus exasperata* Vahl and its potential as a raw material for pulp and paper making. Trees were felled, crosscut and discs of about 20cm were cut from the base (10%), mid-stem (50%) and stem-top (90%) along the merchantable height and 2x2x2 wood samples were collected at the corewood, innerwood and outerwood. The fibre characteristics measured were; fibre length, fibre diameter and lumen width in accordance with ASTM D1413-48 of 1983 and ASTM D 1413-61 (2007) while the derived morphology were cellwall thickness, slenderness ratio, flexibility, runkel ratio, coefficient of rigidity F-factor and muhlsteph ratio. The result shows that average fibre length was found to be 1.07mm, fibre diameter 25.10µm, lumen width 14.05µm and cellwall thickness 5.0µm, while average values of, runkel ratio, slenderness ratio, elasticity ratio and muhlsteph ratio were 0.79, 50.57, 63.33 and 57.39 respectively. Based on the fibre morphology, *F. exasperata* is said to have the required fibres characteristics suitable for pulp and paper production.

**Keywords:** *Ficus exasperata*, fibre length, cell-wall thickness, runkel ratio, slenderness ratio and muhlsteph ratio.

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### 1. INTRODUCTION

The significance of paper and paper products in this contemporary world and with increase in the level of literacy cannot be over-emphasized. Paper has assumed a position of almost incredible importance in both developed and developing countries like Nigeria (Onilude, 2011). Paper was first made from non-woody plants and presently, the use of non-wood pulp is included in the grades of paper such as printing and writing papers, liner boards, newsprint and specialty paper (Hurter, 2001). But today, more than 95% of

paper is made from wood, while the remainder consists of fibrous materials, such as rice chaff, flax and rags.

Pulp and paper industry is one of the largest and highest demand sectors in the world of industrial production. The paper products are used not only for writing and printing, but also for other purposes like card board, wrapping. Though wood is a major lignocellulose material for production of paper due to its desirable characteristics, rapid growth of population and industrialization have resulted in huge shortage of this forest resource. Therefore, much attention has been

drawn for the discovery of other fast growing and lesser use wood species as alternative raw material for pulp and paper making. However, the choice of *F. exasperata* came about because it is a fast-growing tree species and focus has been on its utilization just for medicinal purpose. Hence, the need to evaluate the fibre morphology of *F. exasperata* as raw material in order to give recommendation on its utilization for pulp and paper making instead of mounting pressure on the well-known species such as *Gmelina arborea* and *Eucalyptus* species.

## 2. MATERIALS AND METHOD

Three mature trees of *F. exasperata* were selected from Forestry Research Institute of Nigeria Arboretum which is located along latitude 7°23'34"N to 7°23'36"N and longitude 3°51'36"E to 3°51'36"E. The logs were cross-cut into billets at base, middle and top of the stems. Discs were obtained from each billet and partitioned into corewood, middlewood and outerwood for determination of Fibre Length (FL), Fibre Diameter, Lumen Width, Cell wall Thickness, Slenderness Ratio, Elasticity Ratio, Runkel Ratio, Coefficient of Rigidity, F-Factor and Muhlsteph Ratio using standard methods. Data were subjected to statistical analysis in a Randomized Complete Design using Analysis of variance (ANOVA). However, follow-up test was carried out using Least Significant Difference test (LSD) at 0.05% level of probability.

### 2.1 Maceration

#### 2.1.1 Fibre measurement

The fibre measurements were conducted at Anatomy Laboratory in Forestry Research Institute of Nigeria, Ibadan in accordance with ASTM D1413-49. 1983 and ASTM D1413-61. 2007. Four samples each were collected from corewood, innerwood and outerwood at various points namely base (10%), mid-stem (50%) and stem-top (90%) along the merchantable height and prepared into slivers of 3mm x10mm. Maceration of the slivers was carried out using acetic acid and hydrogen peroxide (1:1) ASTM D1413-61. 2007 and placed in an oven for 2hours at a temperature of 100°C after which the resultant solution was agitated in order to separate it into individual fibres. The macerated fibers were randomly selected and dropped on a standard slide by means of a medicine dropper rubber bulb using a procedure adopted by Dutt *et al.*, 2005. All the characteristics namely, fibre length, fibre diameter, lumen width and cell wall thickness were viewed using a stage micrometer mounted on a Zeiss light microscope

under 40x. From each of the samples macerated, twenty-five (25) fibres were measured without staining.

#### 2.1.2 Derived morphology

Six derived morphological indices of the fibre were calculated from the measured fibre dimensions based on method adopted by (Saika, *et al.*, 1997; Ogbonnaya *et al.*, 1997; Ververis *et al.*, 2004; Oluwadare and Sotannde, 2006 and Tutus *et al.*, 2010).

These include:

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

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

$$\text{Flexibility power} = \frac{\text{Lumen width}}{\text{Fibre diameter}} \times \frac{100}{1} \dots (3)$$

$$\text{Runkel ratio} = \frac{2 \times \text{cell wall thickness}}{\text{lumen width}} \dots (4)$$

$$\begin{aligned} \text{Coefficient of rigidity} \\ = \frac{\text{Cell wall thickness}}{\text{Fibre diameter}} \times \frac{100}{1} \dots (5) \end{aligned}$$

$$\text{F - Factor} = \frac{\text{Fibre length}}{\text{Cell - wall thickness}} \dots (6)$$

$$\begin{aligned} \text{Muhlsteph ratio} \\ = \frac{\text{Fibre width}^2 - \text{lumen width}^2}{\text{Fibre width}^2} \times \frac{100}{1} \dots (7) \end{aligned}$$

## 3 RESULTS AND DISCUSSION

### 3.1 Fibre Morphology

The fibres of *F. exasperata* are narrow; most of the fibres are tapered in shape while others are bifurcated with lignified wall and provide support to the tree. The morphological characteristics of fibres like length and width are important parameter to estimate the pulp quality. In addition, cell wall thickness and lumen size also influenced the rigidity and strength property of paper.

#### 3.1.1 Fibre length (mm)

The result in Table 1 shows that along the stem height, the fibre length increased from 1.03±0.13 mm at the base to 1.11±0.59 mm at the stem-top and also increased from 0.96 mm in the core-wood to 1.19±0.10

in the outer-wood. Fibre length averaged  $1.07 \pm 0.28$  mm in the wood of *F. exasperata*. Analysis of variance (ANOVA) in Table 2 shows that radial position ( $P=0.011$ ) had significant influence on the fibre length of *F. exasperata* wood ( $p < 0.05$ ).

Fibre length is regarded as an important index of paper quality and very important characteristics in papermaking. Fibres from the wood of *Ficus exasperata* could be classified as medium fibre with an average fibre length of 1.07 mm. The values agree with the values range obtained by Adeniyi *et al.* (2013). They also fall within the range 0.75-1.75m for *Gmelina arborea* reported by Rogue and Fo 2007 and 0.99-1.33mm as recorded by Ogunkunle (2010) for 12 *Ficus* species. According Izekor and Fuwape, (2011) fibre length ranging from 1.65 to 2.33mm was recorded for *Tectona grandis*. As part of the requirement for suitable fibre for pulp and paper making, long fibre is said to be

desirable for good network. However, fibre length in this study proves to be of importance because is greater than 1mm (Migneault *et al.*, 2008). Average fibre length in hardwoods recorded 1mm and in coniferous wood about in 3mm (Anon, 1951; Cutter, 1971 and PPRI 2011). Also, fibre length obtained in this study is of acceptable range for hardwoods species for papermaking. Since fibre length is critical in selecting any species for the production of high-quality pulp for papermaking, it is expected that this wood species will provide pulp with good strength properties. Variation in sampling height and radial position were observed to have varying degrees of influence on the fibre length. The observed trend according to Oluwadare and Sotannde (2006) could be of practical importance since such variation may represent variation in fibre length distribution within the tree which may reflect a better way of sampling different sections of the wood.

Table 1: Mean of Fibre Morphology along the Sampling Height and Radial Portion

Morphology	Wood portion	Core	Inner	Outer	Mean
Fibre Length(mm)	Base	$0.95 \pm 0.06^*$	$1.06 \pm 0.17$	$1.09 \pm 0.11$	$1.03 \pm 0.13$
	Mid-stem	$1.05 \pm 0.09$	$1.06 \pm 0.12$	$1.11 \pm 0.14$	$1.07 \pm 0.12$
	Stem-top	$0.87 \pm 0.05$	$1.07 \pm 0.10$	$1.38 \pm 0.98$	$1.12 \pm 0.59$
Fibre Diameter( $\mu$ m)	Base	$19.77 \pm 0.08$	$24.27 \pm 16.90$	$25.14 \pm 18.92$	$23.06 \pm 14.43$
	Mid-stem	$33.19 \pm 24.61$	$24.79 \pm 16.14$	$21.88 \pm 0.61$	$26.62 \pm 17.54$
	Stem-top	$27.52 \pm 21.35$	$20.56 \pm 0.14$	$23.59 \pm 0.88$	$23.89 \pm 13.29$
Lumen width( $\mu$ m)	Base	$13.83 \pm 0.15$	$13.77 \pm 0.26$	$13.62 \pm 0.28$	$13.74 \pm 0.23$
	Mid-stem	$13.93 \pm 0.20$	$13.66 \pm 0.29$	$13.83 \pm 0.24$	$13.80 \pm 0.24$
	Stem-top	$12.18 \pm 0.11$	$13.74 \pm 0.15$	$13.62 \pm 0.24$	$13.18 \pm 0.19$
Cell-wall thickness ( $\mu$ m)	Base	$2.97 \pm 0.07$	$5.25 \pm 0.78$	$5.76 \pm 8.68$	$4.66 \pm 0.67$
	Mid-stem	$9.63 \pm 1.14$	$5.57 \pm 0.81$	$4.03 \pm 0.31$	$6.41 \pm 0.83$
	Stem-top	$7.67 \pm 1.06$	$3.41 \pm 0.88$	$4.98 \pm 0.37$	$5.35 \pm 0.65$

\*Means  $\pm$  Standard error of mean of 25 replicate fibres.

Table 2: Significance (p-values) of Fibre Morphology along the Sampling Height and Radial position of *F. exasperata*

Sources	Df	FL(mm)	FD( $\mu$ m)	LW( $\mu$ m)	CW( $\mu$ m)
Tree (T)	2	0.008	<0.001	<0.001	0.004
Sampling height (SH)	2	0.643	0.528	0.171	0.543
Radial position (RP)	2	0.011	0.478	0.458	0.377
T x SH	4	0.451	0.982	0.119	0.934
T x RP	4	0.131	0.216	0.052	0.166
SH x RP	4	0.164	0.266	0.180	0.203
T x SH x RP	8	0.455	0.100	0.308	0.106
Error	81				
Total	107				

p-values  $> 0.05$  are not significant. FL = Fibre length, FD = Fibre diameter, LW= Lumen width, CW = Cell-wall thickness.

**Table 3:** Variation in Sampling Heights and Radial position on the Fibre Dimensions of *F. exasperata*

Variables	FL(mm)	FD ( $\mu\text{m}$ )	LW( $\mu\text{m}$ )	CW( $\mu\text{m}$ )
<b>Sampling Height</b>				
Base	1.03 $\pm$ 0.13 <sup>*a</sup>	23.06 $\pm$ 14.43 <sup>a</sup>	13.74 $\pm$ 2.42 <sup>a</sup>	4.66 $\pm$ 6.69 <sup>a</sup>
Middle	1.07 $\pm$ 0.12 <sup>a</sup>	26.62 $\pm$ 17.54 <sup>a</sup>	13.81 $\pm$ 2.42 <sup>a</sup>	6.4 $\pm$ 8.38 <sup>a</sup>
Top	1.11 $\pm$ 0.59 <sup>a</sup>	23.89 $\pm$ 13.29 <sup>a</sup>	13.81 $\pm$ 1.86 <sup>a</sup>	5.35 $\pm$ 6.57 <sup>a</sup>
<b>Radial position</b>				
Corewood	0.96 $\pm$ 0.10 <sup>b</sup>	26.83 $\pm$ 19.10 <sup>a</sup>	13.32 $\pm$ 1.77 <sup>a</sup>	6.76 $\pm$ 9.11 <sup>a</sup>
Middlewood	1.06 $\pm$ 0.13 <sup>ab</sup>	23.21 $\pm$ 13.27 <sup>a</sup>	13.73 $\pm$ 2.33 <sup>a</sup>	4.74 $\pm$ 6.39 <sup>a</sup>
Outerwood	1.19 $\pm$ 0.57 <sup>a</sup>	23.54 $\pm$ 12.26 <sup>a</sup>	13.69 $\pm$ 2.46 <sup>a</sup>	4.92 $\pm$ 5.64 <sup>a</sup>
Average	<b>1.07<math>\pm</math>0.28</b>	<b>24.52<math>\pm</math>15.19</b>	<b>14.05<math>\pm</math>0.22</b>	<b>5.47<math>\pm</math>7.23</b>

FL = Fibre length, FD = Fibre diameter, LW= Lumen width, CW = Cell-wall thickness. \*Means $\pm$  Standard error of mean of 4 replicate samples. Values with the same alphabet in each column are not significantly different at  $\alpha = 0.05$  using Least Significant Difference test.

### 3.1.2 Fibre diameter ( $\mu\text{m}$ )

Along the sampling height, the diameter of the fibre did not exhibit a specific pattern of variation. It increased from 23.06 $\pm$ 14.43 at the base to 26.62 $\pm$ 17.54 at the mid-stem and decreased 23.89 $\pm$ 13.29 toward the stem-top. Also decrease was observed from 26.83 $\pm$ 19.10 at the core-wood to 23.21 $\pm$ 13.27 at the inner-wood and then increased marginally 23.54 $\pm$ 12.26 toward the outer-wood. On average, Fibre Diameter is 24.52 $\pm$ 15.19 (Table 1).

Fibre diameter of *F. exasperata* increased from the base to the middle and then decreased towards the top along the sampling height while decrease was observed from corewood to middle wood and top. This observation might probably be due to the varying proportion of lumen and cell-wall thickness within the tree. However, in this study, the average fibre diameter obtained is 25.81 $\mu\text{m}$ , this falls within the range 18.5-27.5 $\mu\text{m}$  for *Gmelina arborea* recorded by Rogue and Fo (2007). On the other side, fibre diameter was higher than 14.0-16.0 $\mu\text{m}$  as reported by Pulp and Paper Resources Information PPRI 2011 for Eucalyptus, 20 and 16  $\mu\text{m}$  for Betula and Eucalyptus reported by Asikainen (2015). In paper production, the importance of fibre diameter is usually based on its relationship with fibre length. This is called slenderness ratio or felting rate. The ratio of fibre length to diameter obtained in this study is moderate (less than 70  $\mu\text{m}$ ). This is because, strength properties of the papers have been found to be positively correlated with the slenderness ratio Tutus *et al.*, 2010. Based on the results, it shows that *F. exasperata* is suitable for pulp and paper production.

### 3.1.3 Lumen width ( $\mu\text{m}$ )

The result presented in Table 1 shows that lumen width of the fibre showed no particular trend of variation along the sampling height, but increased with 23.06 $\pm$ 14.43  $\mu\text{m}$  from the base to 26.62 $\pm$ 17.54  $\mu\text{m}$  at the mid-stem and then decreased 23.89 $\pm$ 13.29 at the stem-top. Same with radial position, there was slight increase from the core-wood 13.74 $\pm$ 2.42  $\mu\text{m}$  to the outer-wood 13.81 $\pm$ 1.86  $\mu\text{m}$ . The average lumen width of *F. exasperata* is 14.05 $\pm$ 0.22  $\mu\text{m}$ .

Variations in sampling height and radial position of the species were observed not to have influence on the lumen size of the fibre. While the lumen size obtained in the *F. exasperata* decreased from base to the top along the sampling height, it showed slight increase from core wood to outer wood along the radial position. Lumen width affects the beating ability of pulp because the narrower the lumen width, the poorer will be the beating of pulp because of the penetration of liquids into empty spaces of the fibres (Dutt *et al.*, 2005). The average lumen width 14.1  $\mu\text{m}$  is slightly higher than the result recorded by Adeniyi *et al.* (2013). However, it was also recorded by Rogue and Fo (2007) that lumen width of 15.9  $\mu\text{m}$  was obtained for *Tectona grandis*. Papers made from wood of *F. exasperata* is expected to exhibit good contact between fibres and consequently good strength characteristics suitable for writing, printing, wrapping and packaging purposes.

### 3.2 Derived Fibre Morphology

#### 3.2.1 Cell-wall thickness ( $\mu\text{m}$ )

The fibres along the stem height, the wall thickness increased from  $4.66\pm 6.69 \mu\text{m}$  at the base to  $6.4\pm 8.38 \mu\text{m}$  at the mid-stem and then decreased to  $5.35\pm 6.57 \mu\text{m}$  toward the stem-top. But along the radial position, the wall thickness decreased from  $6.76\pm 9.11 \mu\text{m}$  at the core-wood to  $4.74\pm 6.39$  and  $4.92\pm 5.64 \mu\text{m}$  toward the inner and outer-wood respectively. Average cell-wall thickness of *F. exasperata* is  $5.47\pm 7.23 \mu\text{m}$ . Cell wall thickness of a fibre affects the rigidity and strength of a paper. Variations in sampling height and radial position

of the species were observed to have no significant influence on the cell-wall thickness of the fibre. The fibres in *F. exasperata* has large lumen and thin wall. Paper manufactured from thick-walled fibres will be bulky with coarse surface texture, and containing a large amount of void volume (Agnihotri *et al.*, 2010). The values in this study was a bit higher than  $1.94\text{--}4.99\mu\text{m}$  reported by Ogunkunle (2010) for *Ficus* species. The cell-wall thickness of *F. exasperata* happens to be within the range of  $5\text{--}10\mu\text{m}$  recorded by PPRI (2011). Large fibres with thin walls give a positive effect as they tend to form non-porous tightly bonded paper sheet that is easily collapse and flexible (Syed *et al.*, 2016).

Table 4: Mean values of Derived Fibre Morphology along the Sampling Height and Radial Portion

Property	Wood portion	Core	Inner	Outer	Mean
Slenderness ratio					
	Base	47.97±2.90*	50.59±12.93	51.81±13.02	50.12±10.54
	Mid-stem	45.24±22.87	49.19±12.30	52.69±9.40	49.04±15.79
	Stem-top	46.86±13.05	52.12±5.03	64.69±5.83	52.56±31.67
Elasticity Ratio					
	Base	69.99±7.34	65.35±16.64	62.99±16.06	66.11±13.92
	Mid-stem	59.73±24.47	63.21±17.53	65.54±12.93	61.83±18.75
	Stem-top	57.85±20.44	66.99±6.96	61.29±13.81	62.05±14.74
Runkel ratio					
	Base	0.44±0.16	0.72±0.87	0.78±0.96	0.65±0.73
	Mid-stem	1.24±1.26	0.85±1.15	0.61±0.50	0.90±1.05
	Stem-top	1.25±1.63	0.51±0.16	0.73±0.49	0.83±1.03
Coeff of rigidity					
	Base	15.00±3.67	17.33±8.32	18.51±8.93	16.95±6.96
	Mid-stem	21.64±12.28	18.39±8.76	17.23±6.46	19.09±9.38
	Stem-top	21.07±10.07	16.54±3.48	19.36±6.90	18.97±7.37
F-Factor					
	Base	334.96±69.65	378.59±240.01	338.43±155.26	350.66±166.19
	Mid-stem	465.53±625.24	341.39±188.95	349.62±136.91	385.48±378.52
	Stem-top	243.78±117.29	331.69±86.43	421.32±465.21	332.26±283.01
Muhlsteph ratio					
	Base	50.52±9.99	54.56±18.59	57.96±17.25	54.41±15.59
	Mid-stem	62.33±27.32	57.23±19.03	55.51±14.77	58.36±20.63
	Stem-top	62.81±18.22	54.67±9.08	60.69±15.84	59.39±14.88

\*Means± Standard error of mean of 25 replicate fibres.

Table 5: Significance (p-values) of Derived Fibre Morphology along the Sampling Height and Radial position of *F. exasperata*

Sources	Df	SL	ER (%)	RR	CR (%)	FF	MR (%)
Tree (T)	2	0.014*	<0.001	0.008	<0.001	<0.001	<0.001
Sampling height (SH)	2	0.744	0.322	0.452	0.322	0.634	0.267
Radial position (RP)	2	0.048	0.519	0.300	0.519	0.915	0.607
T x SH	4	0.512	0.410	0.627	0.410	0.597	0.295
T x RP	42	0.241	0.067	0.092	0.067	0.123	0.044
SH x RP	4	0.484	0.217	0.186	0.217	0.260	0.324
T x SH x RP	8	0.137	0.040	0.111	0.040	0.001	0.014
Error	81						
Total	107						

\*p-values > 0.05 are not significant. S= Slenderness, ER = Elasticity Ratio, RR= Runkel ratio, CR= Coefficient of rigidity, FF= F-Factor, MR= Muhlsteph's ratio.

**Table 6.** Variation in Sampling Heights and Radial position on the Derived Fibre Morphology of *F. exasperata*

Sources	SL	ER (%)	RR	CR (%)	FF	MR (%)
<b>Sampling Height</b>						
Base	50.12 <sup>*a</sup>	66.11 <sup>a</sup>	0.65 <sup>a</sup>	16.95 <sup>a</sup>	350.66 <sup>a</sup>	54.41 <sup>a</sup>
	±10.5	±13.92	±0.72	±6.96	±166.19	±15.59
Middle	49.04 <sup>a</sup>	61.83 <sup>a</sup>	0.90 <sup>a</sup>	19.09 <sup>a</sup>	385.48 <sup>a</sup>	58.36 <sup>a</sup>
	±15.79	±18.75	±1.05	±9.38	±378.5	±20.63
Top	52.56 <sup>a</sup>	62.05 <sup>a</sup>	0.83 <sup>a</sup>	18.98 <sup>a</sup>	332.26 <sup>a</sup>	59.39 <sup>a</sup>
	±31.67	±14.74	±1.03	±7.37	±283.01	±14.88
<b>Radial Position</b>						
Corewood	44.69 <sup>a</sup>	61.52 <sup>a</sup>	0.98 <sup>a</sup>	19.24 <sup>a</sup>	348.09 <sup>a</sup>	58.55 <sup>a</sup>
	±15.14	±19.23	±1.25	±9.61	±370.44	±20.09
Middlewood	50.63 <sup>ab</sup>	65.19 <sup>a</sup>	0.69 <sup>a</sup>	17.41 <sup>a</sup>	350.52 <sup>a</sup>	55.55 <sup>a</sup>
	±10.46	±14.19	±0.83	±7.09	±179.17	±15.81
Average	50.57	63.33	0.80	18.84	356.13	57.39
	±21.17	±15.92	±0.94	±7.95	±287.39	±17.20

S= Slenderness, ER = Elasticity Ratio, RR= Runkel ratio, CR= Coefficient of rigidity, FF= F-Factor, MR= Muhlstaph's ratio.\*Means± Standard error of mean of 4 replicate samples. Values with the same alphabet in each column are not significantly different at  $\alpha = 0.05$  using Least Significant Difference test.

### 3.2.2 Slenderness ratio

Along the sampling height, SR of the fibres decreased from 50.12±10.54 at the base to 49.04±15.79 at the mid-stem and then increased afterwards with 52.56±31.67 at the stem-top while increase was observed along the radial position from 44.69±15.14 at the core-wood to 56.40±30.99 at the outer-wood (Table 4). The average SR was observed to be 50.57±21.17. Variation along the radial position (at P=0.048) had significant effect on the Slenderness Ratio (SR) of the fibres in the wood of *F. exasperata* (Table 5). Least Significant Difference Test conducted shows that the slenderness of the fibre at the corewood differ from the fibre at the outerwood (Table 6).

According to Akgul, and Tozluoglu, (2009), one of the criterions that control suitability of wood material to paper production is slenderness ratio. In this study, sampling height had no significant influence on the slenderness ratio of the fibres of *F. exasperata*. This implied that growth of the plant had no influence in the slenderness of its fibre. The medium length and thin-walled fibres in *F. exasperata* have a very good slenderness ratio averaged 50.58, this value is lower than those obtained for eucalyptus species (Oluwadare and Sotannde, 2006 and Veenin *et al.*, 2005). The value obtained in this study is higher than 42 obtained in *Eucalyptus camaldulensis* (Manahil and Abdelazim, 2015). According to Sharma *et al.* (2013) and Xu *et al.* (2006), slenderness ratio of greater than 33 is best suitable for pulp and paper making. However, the fibres

in this study exceeded the satisfactory slenderness ratios of 33. A high SR in fibre will produce higher rate of tear resistance in a paper (Akpakpan *et al.*, 2012).

### 3.2.3 Elasticity Ratio (%):

Elasticity Ratio of the fibres in *F. exasperata* was not consistent along both the sampling height and radial position. Elasticity Ratio of the fibre along the sampling height gave the highest value of 66.11±13.92% at the base and lowest 61.83±18.75% at the mid-stem while Elasticity Ratio was highest with 65.19±14.19 at the inner-wood and least 61.52±19.23% at the core-wood along the radial position (Table 4). On average, Flexibility of the fibre of *F. exasperata* is 63.33±15.92.

Elasticity Ratio is the ratio of lumen width to fibre diameter expressed in percentage. In this study, the fibres in the wood of *F. exasperata* had an average elasticity Ratio of 63.33% which is close to 62% obtained in *Eucalyptus camaldulensis* (Manahil and Abdelazim, 2015) and 59% obtained in *Leucaena leucocephala* (Oluwadare and Sotannde, 2007). Based on elasticity Ratio, Bekta *et al.* (1999) and Hemmasi *et al.* (2011), classified fibres into four groups: (1) High elastic fibres; having elasticity coefficient >75, (2) Elastic fibres; having elasticity ratio between 50 and 75, (3) Rigid fibres; having elasticity ratio between 30 and 50 (4) highly rigid fibres having elasticity ratio <30. The rigid fibres are usually used more on fibre plate, rigid cardboard and cardboard production (Akgul and Tozluoglu, 2009). According to this classification, the average flexibility ratio of the fibres in *F. exasperata*

falls on Elastic fibres. Therefore, the fibres in the *F. exasperata* will readily collapse during paper making process, giving larger surface contact area for bonding and consequently produced paper with good strength characteristics (Singh *et al.*, 2011).

### 3.2.3 Runkel ratio

The RR of the fibres was not consistent but increased from  $0.65 \pm 0.72$  at the base to  $0.90 \pm 1.05$  at the mid-stem and then decreased slightly to  $0.83 \pm 1.03$  towards the stem-top of the sampling height. In radial position, it decreased from core-wood to inner-wood and then increased toward the outer-wood (Table 4). Average RR value of the fibre is  $0.80 \pm 0.94$ . The Runkel Ratio (RR) of the fibres shows that both variation in sampling height ( $P=0.452$ ) and radial position ( $P=0.300$ ) had no significant effect on the RR of *F. exasperata* (Table 5). The mean separation shows no significant difference at all level (Table 6).

Fibres of this wood species have average Runkel ratios of 0.80. Eroglu, 1998 has classified the most suitable Runkel's ratio as  $<1$  where the cell is thin as the fibres are more flexible and form paper with large bonding. Ververis *et al.* (2004) opined that Runkel ratio  $\geq 1$  is not preferable for pulp and paper making but the higher value can be improved by using a suitable screening technique which cost more. According to Wahab *et al.* (2006), fibres with higher Runkel ratio are stiffer, less flexible, and form bulkier paper of lower bonded areas than fibres with lower Runkel ratio. The average value in this study is less than 0.85 obtained in *Anogeissus leiocarpus* (Ogunjobi *et al.*, 2014), but higher than Runkel ratio of 0.65 obtained in *Eucalyptus camaldulensis* (Manahil and Abdelazim, 2015).

### 3.2.4 Coefficient of rigidity (%)

Coefficient of rigidity along the sampling height was highest  $19.09 \pm 9.38\%$  at the mid-stem followed by  $18.98 \pm 7.37\%$  obtained at stem-top of the sampling height and  $16.95 \pm 6.96\%$  obtained at base (Table 4) In radial position, the least coefficient of rigidity was recorded  $17.41 \pm 7.09$  at the inner-wood. The average Coefficient of rigidity was observed to be  $18.84 \pm 7.96$ .

In this study, the high variation observed in the coefficient of rigidity was measured along the sampling height and radial position. On the average, rigidity coefficient of the fibres in *F. exasperata* was 18.84% and makes it suitable as raw material for pulp and papermaking. According to Dutt and Tyagi (2011), fibres with low rigidity coefficient give higher degree of conformability within the sheet, which result in sheet of

lower bulk or higher density. The implication of this is that paper from such fibres will have good physical strength properties with high brightness and low porosity and could be said to be appropriate for printing, writing, packaging and wrapping purposes.

### 3.2.5 F-Factor (Flexibility of Fibre)

Along the sampling height, F-Factor increased and then decreased from  $350.66 \pm 166.19$  at base to  $385.48 \pm 378.50$  at the mid-stem and  $332.26 \pm 283.01$  at the stem-top (Table 4). In radial plane, increase was observed from  $348.09 \pm 370.44$  in core-wood to  $369.79 \pm 287 \pm 88$  in outer-wood. Average F-factor of *F. exasperata* fibre is  $356.13 \pm 287.39$ .

F-Factor was obtained by dividing fiber length into wall thickness. In this study, *F. exasperata* shows bigger F-factor averaged 356.13; this was obtained by dividing fibre length to cell-wall thickness. It is an indication that flexibility of papers obtained from this *F. exasperata* could be recommended for paper making. The F-Factor result of other hardwood species recorded 240.6, 140.4, 235.9 and 206.8 for *Pinus nigra*, *Fagus orientalis*, *Populus euramericana* and *Populus tremula* respectively according to Akgul and Tozluoglu (2009). While studies on softwood species gave average F-factor of 606.66 and 410.34 for *Pinus brutia* and *Cedrus libani* respectively (As *et al.*, 2002).

### 3.2.6 Muhlsteph's ratio

Sampling height, MR increased from  $54.41 \pm 15.59\%$  at the base to  $59.39 \pm 14.88$  at the stem-top while along the radial plane, MR decreased from  $58.55 \pm 20.09$  at the core-wood to  $55.55 \pm 15.15$  at the inner-wood and then increased  $58.05 \pm 15.67$  toward the outer-wood (Table 4). The Muhlsteph's ratio of *F. exasperata* fibre average  $57.39 \pm 17.20$ .

Muhlsteph's proportion indicated as dividing cell-wall by cross-section area gave the influence of cell-wall on the paper's physical properties. Therefore, thin wall fibres are easily crushed on paper production, so this greatly affect both resistance properties and paper density positively (Casey, 1961). The average Muhlsteph's ratio in this study is 57.39% and this is slightly higher than 52 obtained for *Shorea mujongensis* by Listya and Supartini (2011). According to the criteria of fibre quality by Casey, 1961, Muhlsteph's ratio of *F. exasperata* falls into the quality class II. Akgul and Tozluoglu (2009) recorded Muhlsteph's value for juvenile *Fagus orientalis* and *Pinus nigra* wood is 76.68 and 47.28 respectively. Muhlsteph's ratio result compared with other studies shows that 61.2 was

obtained for *Pinus brutia* (Bekta *et al.*, 1999). Also, 46.17 for Acacia hybrid, 45.85 for *A. mangium* and 55 for *A. auriculiformis* (Yahaya *et al.*, 2010). When lower value is obtained from wood fibres, it shows that it consists of thinner cell wall fibres. This is due to the fact that the use of thin wall fibres is more preferable in paper industry of which *F. exasperata* prove to be one (Akgul and Tozluoglu, 2009).

#### 4. CONCLUSION

Based on the results of the study, the following conclusions are made.

1. Fibre morphology of *F. exasperata* was not significantly affected by sampling height and radial position.
2. Wood species characteristics happen to be similar to fibres from other hardwoods fibre, softwoods fibres and some non-wood fibres. Bulk of the fibres had their lengths, Elasticity Ratio and Runkel ratios between 1.00 and 1.30 mm, 64.55 and 84.5% and, 0.39 and 0.89, respectively.
3. The difference in the properties among the tree stands, along the sampling height and radial position was little. This is an indication that wood chips from (Top, Middle and Base) can be mix during pulping and storage.
4. Since large volume of the wood is required to achieve full digester capacity due to low density and bulkiness, efficient bailing system must be developed in order to densify the wood for efficient handling.

#### REFERENCES

- ASTM (American Society for Testing and Materials) D1413-49. (1983). Standard Test Method of Testing Small Scale Clear Specimens of Timber.
- ASTM (American Society for Testing and Materials) D1413-61. (2007.) Preparation of Decayed Wood for Microscopical Examination.
- Adeniyi, I. M, Adejoba, O. R, Alao, O. T, Noah, A. S. and Salaudeen, G. T. (2013). Comparative Analysis of Some Ficus species. *Research in plant Sciences*. 1(2): 15-19.
- Agnihotri, S., Dutt, D. and Tyagi, C. H. (2010). Complete Characterization of Bagasse of Early Species of *Saccharum officinerum*-Co 89003 for Pulp and Paper Making, *BioResources*, 5(2): 1197-1214.
- Akgul, M. and Tozluoglu, A. (2009). "Some Chemical and Morphological Properties of Juvenile Woods from Beech *Fagus orientalis* L. and Pine *Pinus nigra* A. plantation" *Trends in Applied Science Research*, 4(2): 116.
- Akpakpan, A. E., Akpabio, U. D. and Obot, I. B (2012). "Evaluation of Physicochemical Properties and Soda Pulping of *Nypa fruticans* Frond and Petiole," *Elixir Applied Chemistry* 45: 7664-7668.
- Anon, A. (1951). The Dictionary of Paper. American Paper and Pulp Association. Inter-Science Inc., New York. 405 pp.
- As, N., Koc, H., Dogu, D., Atik, C., Aksu, B. and Erdinler, S. (2002). The Chemical, Mechanical, Physical and Anatomical Properties of Economically Important Wood in Turkey, IU Istanbul, *Journal of Forestry*. pp. 70-88.
- Asikainen, S. (2015). Applicability of Fractionation of Softwood and Hardwood Kraft Pulp and Utilisation of the Fractions. *VTT Science* 73 p14-26.
- ASTM (American Society for Testing and Materials) D1413-49. (1983). Standard Test Method of Testing Small Scale Clear Specimens of Timber.
- ASTM (American Society for Testing and Materials) D1413-61. (2007). Preparation of Decayed Wood for Microscopical Examination.
- Bektas, I., Tutus, A. and Eroglu, H. (1999). A Study of the Suitability of Calabrian Pine (*Pinus brutiaten*) for Pulp and Paper Manufacture. *Turkey Journal of Agriculture*, 23: 776-784.
- Casey, J. P. 1961. Pulp and Papermaking, Second Edition, Pub. Wiley-Interscience New York. 2: 3.
- Cutter, E. G., (1971). Plant Anatomy: Experiment and Interpretation. Part 2 - Organs. Edward Arnold Publishers Ltd., London, 343 pp.
- Dutt, D., Upadhyaya, J. S., Malik, R. S. and Tyagi, C. H. (2005). Studies on the pulp and paper-making characteristics of some Indian non-woody fibrous raw materials. *Cellulose Chemistry and Technology*. 39 (1-2): 115-128.
- Dutt, D. and Tyagi, C. H. (2011). Comparison of various *Eucalyptus Species* and Their Morphological, Chemical, Pulp and Paper Making Characteristics. *Indian Journal of Chemical. Technology*, 18:145-151.
- Eroglu, H. (1998). Fiberboard industry, Karadeniz Technical University. Publication No: 304, Trabzon, p. 30.
- Hemmasi, A. H., Samariha, A., Tabei, A., Nemati, M. and Khakifirooz, A. (2011). "Study of Morphological and Chemical Composition of Fibres from Iranian Sugarcane Bagasse," *Ameriacn-Eurasian. Journal of Agriculture and Environmental Sciences*, 11(4): 478-481.
- Hurter, R.W. (2001). Non-wood Plant Fibre Uses in Paper Making Short Course notes Extracted from "Agricultural Residues" *Tappi*, (2001), Ottawa Ontario Canada.
- Izekor, D. N. and Fuwape, J. A. 2011. Variations in the Anatomical Characteristics of Plantation Grown

- Tectona grandis* Wood in Edo State, Nigeria. *Archives of Applied Science Research*, 3(1): 83-90.
- Listya, M. D. and Supartini, (2011). Anatomical Properties of *Shorea mufongpense* Species of Dipterocarpus from Kalimanta. *Journal of Forestry Research* 8(2): 91-100.
- Manahil, F. E. and Abdelazim, T. A. (2015). Effect of Growth Rate on Fibre Characteristics of *Eucalyptus camaldulensis* Wood of Coppice Origin Grown in White Nile State, Sudan. *Journal of Natural Resources and Environment*, STU. 3.1(3): 14-23.
- Migneault, S., Koubaa, A., Erchiqui, F., Chaala, A., Englund, K., Krause, C, and Wolcott, M. (2008). Properties of Extruded Wood-Fibre/HDPE Composites. *Journal of Applied Polymer Science*, 110: 1085-1092.
- Ogbonnaya, C. I., Roay-Macauley, H., Nwalozie, M. C. and Annerose, D. J. M. (1997). Physical and Histochemical Properties of Kenaf (*Hibiscus cannabinus* L.) Grown Under Water Deficit on a Sandy Soil. *Industrial Crops Production*, 7: 9-18.
- Ogunjobi, K. M., Adetogun, A. C and Shofidiya, S. A. (2014). Investigation of Pulping Potentials of Waste from Conversion of *Anogeissus leiocarpus*. *Journal of polymer and Textile Engineering*. 1(2): 26-30.
- Ogunkunle, A. T.J. (2010). A Quantitative Modeling Of Pulp and Paper Making Suitability of Nigerian Hardwood Species. *Advances in Natural and Applied Sciences*, 4(1): 14-21
- Oluwadare, A. O. and Sotande O. A. (2006). Variation of the Fibre Dimensions in The Stalks of Miraculous Berry (*Thaumatococcus danielli Benth*). *Production Agricultural Technology (PAT)*, 2(1): 85-90.
- Oluwadare, A. O. and Sotande, O. A. (2007). The Relationship Between Fibre Characteristics and Pulp-Sheet Properties of *Leucaena leucocephala* (lam.) *De Wit*. *Middle-East Journal of Science Resources*, 2(2): 63-68.
- Onilude, M.A. (2011) Pulp and Paper Industry: A Neglected Goldmine in Nigeria. Inaugural Lecture 2010/2011, University of Ibadan, Nigeria. PPRI (Pulp and Paper Resources and Information) 2011.
- Rogue, R.M and Fo, T. M. 2007. Wood density and fibre dimensions of *Gmelina arborea* in fast growth trees in Costa Rica: relation to the growth rate. *Sistemasy Recursos Forestales* 16 (3): 267-276.
- Saika, S. N., Goswami, T. and Ali, F. 1997. Evaluation of Pulp and Paper Making Characteristics of Certain Fast-Growing Plants. *Wood Science and Technology*, 31: 467-475.
- Sharma, M., Sharma, C. L. and Kumar, Y. B. 2013. "Evaluation of Fibre Characterizations in Some Weed of Arunachal Pradesh, India for Pulp and Paper Making," *Research Journal of Agriculture and Forestry Science*, 1(3): 15-21.
- Singh, S., Dutt, D. and Tyagi, C. H. 2011. Complete characterization of Wheat Straw (*Triticum aestivum* PBW-343 L. Emend. Fiori and Paol.) -A renewable Source of Fibre for Pulp and Paper Making. *BioResources*, 6(1): 154-177.
- Syed, N. N. F., Zakaria, M. H. and Bujang J. S. 2016. Fibre Characteristics and Paper Making Sea Grass using Hand-Beaten and Blended Pulp. *Journal of Bioresources* 11(2): 5358-5380.
- Tutus, A., Comlekcioglu, N., Karaman, S. and Alma, M. H. 2010. Chemical Composition and Fibre Properties of *Crambe orientalis* and *C. Tataria*. *International Journal of Agriculture and Biology*, 12(12): 1814-9596.
- Veenin, T., Fujita, M., Nobuchi, T. and Siripatanadilok, S. 2005. Radial Variations of Anatomical Characteristics and Specific Gravity in *Eucalyptus camaldulensis* Clones. *IAWA Journal* 26: 353-361.
- Ververis, C., Georghiou, K., Christodoulakis, N. and Santas, R. 2004. Fibre Dimensions, Lignin and Cellulose Content of Various Plant Materials and Their Suitability for Paper Production. *Industrial Crops and Products*, 19:245-254. DOI:10.1016/J.INDCROP.2003.10.006.
- Wahab, R., Mustafa, M. T., Rahman, S., Salam, M. A., Sulaiman, O., Sudin, M., and Rasat, M. S. M. 2006. "Relationship Between Physical, Anatomical and Strength Properties Of 3-Year-Old Cultivated Tropical Bamboo *Gigantochloa scortechinui*," *Journal of Agricultural and Biological Science*, 7(10): 782-791.
- Xu, F., Zhang, F.C., Sun, R. C. and Lu, Q. 2006. Anatomy, Ultrastructure and Lignin Distribution in Cell Wall of *Caragana korshinskii*. *Industrial Crops and Products*, 24: 186-193.
- Yahaya, R., Sugiyama, J., Silsia, D. and Gril, J. 2010. Some Anatomical Features of an Acacia Hybrid, *A. mangium* and *A. auriculiformis* Grown in Indonesia with Regard to Pulp Yield and Paper Strength. *Journal of tropical Forest Science* 22(3): 343-355.