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EVALUATION OF PULP AND PAPER MAKING POTENTIALS OF *FICUS EXASPERATA* Vahl IN MAKURDI, NIGERIA

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ABSTRACT

The study evaluated the fibre morphology of *Ficus exasperata* stem. Wood samples of *Ficus exasperata* were collected from five (5) different trees varied in size ranging from 2.20m – 0.72m in diameter and growing in a scattered vegetation within the Federal University of Agriculture Makurdi. Three samples of the sapwood part of the stem were taken from the base, middle and top respectively. The representative samples were chipped and placed in an equal volume of glacial acetic acid and hydrogen peroxide in the ratio 1:1 for maceration and fibre features were measured with the aid of Reichert visopan microscope while derived fibre indices were calculated. Data were subjected to Analysis of variance (ANOVA). The result of the combined means of fibre length, fibre diameter, lumen width and cell wall thickness of *Ficus exasperata* samples range between 1.86mm – 1.20mm, 31.96µm – 20.98µm, 18.90µm – 10.42µm, 6.95µm – 3.76µm respectively. Results of combined means of felting rate, elasticity coefficient, rigidity coefficient, Runkel ratio and F factor ranged between 94.71 – 44.56, 60.97% - 49.11%, 25.45% - 19.52%, 1.09 – 0.75, 560.32 – 243.56 respectively. In conclusion, *Ficus exasperata* demonstrates suitability in pulp and papermaking and it was observed that the younger the age of *Ficus exasperata* the higher the suitability for pulp and papermaking due to their appreciable fibre length and Runkel ratio.

1. Introduction

The world of industrial production regards pulp and paper production as one of the high demands sectors. The projection of total global consumption of paper-making was said to increase from 316 million tons in 1999, 351 million tons in 2005 to about 425 million tons by 2010 (García et al., 2008). A number of strategies have been suggested for meeting the increased demand for fibre. Changes in consumption patterns can help reduce waste while improved recovery rates will ensure a significant contribution to recycling. Increasing the range of raw materials in a central component of current efforts to increase fibre supply (Market Initial Ice, 2007). Until recently, the non-wood fibre was mainly produced in the developing world (FAO, 1994) and non-wood pulping capacity has been growing at a faster rate than wood pulping capacity (Hunter, 1998). Non-wood pulp capacity was estimated at 5% of total paper capacity in 2004 (SCA, WRI, 2007).
Most of the tree species used for pulp and paper production are threatened due to the high rate of deforestation and increasing demand for their wood for other economic purposes. This trend has

increased pressure on *Gmelina arborea* established for the use of paper industries. The major species used as the raw material for pulp and paper making are the long fibre exotic softwood such as Gmelina, Eucalyptus and Pines. Lintu, (1991) disclosed that the high consumption rate of paper has skewed from advanced countries to the developing countries. This is an indication of great challenges to the developing countries in terms of meeting the requirements of paper demand by the end of the 21st century. Hence, the increase in paper demand calls for screening of other species as possible alternatives for pulp and paper production, (Ogunjobi et al., 2013).

The role of pulp and paper products in modern civilization and with an increase in the level of literacy cannot be over-emphasized. Paper has become indispensable and has incredible significance in both advanced and developing countries like Nigeria (Onilude, 2011). The earliest paper production was from non-woody plants. Current use of non-wood pulp is included in the grades of paper such as writing papers and printing, newsprint, corrugated medium, tissue speciality paper and liner boards (Hunter, 2001). Presently, over 95% of paper is made from wood, while others consist of fibrous materials, such as agricultural residues. The global consumption of wood is increasing yearly, and there has been a continuous research to find an alternative source of fibre for pulp and paper making especially in Africa. In order to remedy the increasing economic difficulties that overdependence on imported pulp fibre has brought to bear on the continent, there must be search for fast growing indigenous wood species that can used for pulp and papermaking (Ekhuemelo and Udo, 2016).

The preceding has informed a search by researchers to collect pulp and paper-based data on tropical woody species to determining their suitability for pulp and paper making (PPM). *Ficus exasperata* Vahl belong to the family Moraceae and commonly called “Sandpaper leaf tree” because of its rough leaves surface. The plant typically grows well in evergreen forests and margins of forest as well as secondary forest and riparian vegetation (Ahmed et al., 2012). Different parts of F. *exasperata* is indigenously used in household, industrial and medicinal purposes. The wood of Ficus species have been apparently utilized for containers, yokes, canoes, tent-poles, house posts, utensils, furniture, drums, and paper pulp. There is a shortage of information regarding the pulp and papermaking status of the different diameter of *Ficus exasperate.* The aim of this study therefore was to evaluate pulp and paper potential of Makurdi grown *Ficus exasperata* at different diameter at breath height (dbh) to ascertain the best size suitable for pulp and paper production.

1. Materials and Method

2.1 Study Area

The study was conducted at the Federal University of Agriculture, Makurdi (FUAM), Benue state. Benue state is generally regarded as the ‘Food basket’ of Nigeria because the ecology of the state supports extensive arable cropping and livestock production as well as fruit, palm, grains, legumes, root and tuber production. Makurdi lies between Latitude 7^{o}38' - 7°50' North, and Longitude 8^{o} 24' - 8^{0}38' East. The town lies within the guinea savannah vegetation zone and experiences two distinct seasons, the wet/rainy season and the dry/summer season. The rainy season lasts from April to October with annual rainfall in the range of 100-200mm. The dry season begins in November and ends in March. The temperatures fluctuate between 23-37 ^{o}C in the year (Ministry of Information and Orientation, 2012).

2.2 Collection and Preparation of Plant Materials

Wood samples of *Ficus exasperata* were collected from 5 different trees growing in the wild in a scattered vegetation within FUAM. Samples were collected from different sizes ranging from 2.20 - 0.72m in diameter. The collection of the samples was done with an axe without felling the trees. and according to the practice in pulp and paper industries where a mixed population of trees and branches of different age and sizes are harvested for pulping rather than those of a particular age or size. Wood samples were taken by cutting chips of sapwood along the bole of the tree, the base (10%), the middle (30%), and at the top (60%). The samples were dried at room temperature for two weeks.

2.3 Determination of Fibre characteristics

Fibre characteristics determination was carried out at the Forest Research Institute of Nigeria (FRIN), Ibadan. Each sample was prepared into slivers of about 1 mm x 2 mm x 2 mm. The slivers were macerated in an equal volume of ethanoic acid and hydrogen peroxide (1:1) inside an oven at about 100° C for 2 hours. The resultant solution was agitated in order to separate it into individual fibres. Using a stage micrometre mounted on a Zeiss light microscope (Standard 25) under 80 ×, random samples of macerated fibres were mounted on slides and measured. Twenty (20) fibres were measured from each representative sample slide, following the approach employed by Jorge (1999) when at least 20 fibres per slide were measured to keep error below 5% for a 95% confidence level. The microscopy was performed by the ASTM D1413-48 of 1983 and ASTM D1413-61 procedure of 2007. The fibre from each material was mounted on a slide and the fibre length (L), fibre diameter (D), lumen width (d), and cell wall thickness was measured. From these, derived fibre characteristics were calculated as follows:

i. **Felting rate (Slenderness)** = Fibre length ÷ Fibre diameter -------------------------------- (1)

ii. **Elasticity coefficient (%) =** Lumen ÷ Fibre diameter x 100 ---------------------------------(2)

iii. **Rigidity coefficient (%) =** Cell wall thickness ÷ Fibre diameter x 100 ------------------ (3)

iv. **Runkel ratio =** (Cell wall thickness x 2) ÷ Lumen diameter ------------------------------- (4)

v. **F factor (%) =** Fibre length ÷ cell wall thickness × 100 ------------------------------------ (5)

2.4 Data Analysis

Data collected were subjected to one-way analysis of variance (ANOVA) to determine the significant effects of different portion on the properties. Follow up test was carried out using Duncan Multiple Range Test (DMRT) where significant differences exist

3. Result

Table 1 shows the means of fibre length, fibre diameter, lumen width and cell wall thickness of *Ficus exasperata* at DBH 2.20m and at different stem portions of base (2.20m), middle (1.30m) and top (0.71m). The means of fibre length ranged between 1.28 mm and 1.39 mm while the means of fibre diameter ranged between 21.93 µm and 19.53 µm. The means of lumen width ranged between 11.22 µm and 9.08 µm whereas the means of cell wall thickness ranged between 5.36 µm and 5.23 µm. The result shows that, the means of fibre length, fibre diameter, lumen width and cell wall thickness of *Ficus exasperata* at DBH 2.20m are not significantly different among stem portions at $p<0.05$. However, the base means of fibre diameter and lumen width of *Ficus exasperata* at DBH 2.20m are significantly different from means of middle and top stem portions at $p<0.05$.

Table 2 shows the means of fibre length, fibre diameter, lumen width and cell wall thickness of *Ficus exasperata* at DBH 1.95m at different stem portions. The means of fibre length, fibre diameter, lumen width and cell wall thickness ranged between 1.39 mm - 1.13mm, 32.49 µm - 27.85 µm, 18.36 µm - 14.28 µm and 8.26 µm - 4.74 µm respectively. The result reveals that the means of fibre length at the base and middle are not significantly different from each other but differ significantly from a mean of the stem portion at the top at $p<0.05$. The result also reveals that the means of fibre diameter, Lumen width and cell wall thickness at the base and top stem portion differ significantly from the means of middle stem portion at $p<0.05$.

Table 1: Mean Values of Fibre Characteristics of *Ficus exasperata* at DBH 2.20m

Fibre characteristics	Stem Portion	Size of stem portion (m)	N	Mean ± SD (m)
Fibre Length (mm)	Base	2.20	20	1.38±0.31[a]
	Middle	1.30	20	1.39±0.25[a]
	Top	0.71	20	1.28±0.18[a]
	Total		60	1.35±0.25
FibreDiameter(µm)	Base	2.20	20	21.93±5.06[c]
	Middle	1.30	20	21.47±2.97[ab]
	Top	0.71	20	19.53±0.89[a]
	Total		60	20.98±3.53
Lumen Width (µm)	Base	2.20	20	11.22±3.90[c]
	Middle	1.30	20	10.97±3.19[ab]
	Top	0.71	20	9.08±1.62[a]
	Total		60	10.42±3.16
Cell wall thickness (µm)	Base	2.20	20	5.36±1.49[a]
	Middle	1.30	20	5.25±0.60[a]
	Top	0.71	20	5.23±0.64[a]
	Total		60	5.28±0.98

Table 3 shows the means of fibre length, fibre diameter, lumen width and cell wall thickness of *Ficus exasperata at* DBH 1.20m at different stem portions. The means of fibre length, fibre diameter, lumen width and cell wall thickness ranged between 1.65mm-1.35mm, 38.30µm-27.10µm, 25.60µm-13.98µm and 6.56µm-6.15µm respectively. The result reveals that the means of fibre length at the base and top are not significantly different from each other but differ significantly from the mean of the stem portion at the middle at $p<0.05$. The result also reveals that the means of fibre diameter and lumen width at the base, middle and top stem portions are significantly different, whereas means of cell wall thickness mare not significantly different at the base, middle and top stem portions at $p<0.05$. However, means of fibre length at base and top are not significantly different but differ significantly from the mean of the middle portion at $p<0.05$.

Table 4 shows the means of fibre length, fibre diameter, lumen width and cell wall thickness of *Ficus exasperata at* DBH 0.85m at different stem portions, with base (0.85m), middle (0.76m), top (0.51m). The means of fibre length ranged between 1.60mm and 1.20mm and the means of fibre diameter ranged between 34.43µm and 30.96µm. The means of lumen width ranged between 21.22µm and 15.13µm, whereas the means of cell wall thickness ranged between 9.65µm and 4.87µm. The result further shows that the mean of fibre length at the base parts differ significantly from means of middle and top portions. The result also reveals that the means of fibre diameter, lumen width and cell wall thickness at the middle and top stem portion differ significantly from the means of base stem portion at $p<0.05$.

Table 2: Mean Values of Fibre Characteristics of *Ficus exasperata* at DBH 1.95m

Fibre characteristics	Stem Portion	Size of stem portion (m)	N	Mean ± SD
fibre Length (mm)	Base	1.95m	20	1.39±0.19[b]
	Middle	1.50m	20	1.35±0.27[b]
	Top	0.60m	20	1.13±0.20[a]
	Total		60	1.29±0.25
Fibre Diameter (μm)	Base	1.95m	20	32.49±5.90[b]
	Middle	1.50m	20	27.85±4.68[a]
	Top	0.60m	20	29.99±5.68[ab]
	Total		60	30.11±5.69
Lumen Width (μm)	Base	1.95m	20	15.97±4.88[ab]
	Middle	1.50m	20	18.36±5.00[c]
	Top	0.60m	20	14.28±5.21[a]
	Total		60	16.20±5.23
Cell Wall thickness (μm)	Base	1.95m	20	8.26±2.76[b]
	Middle	1.50m	20	4.74±1.06[a]
	Top	0.60m	20	7.85±1.57[b]
	Total		60	6.95±2.47

Table 3: Mean Values of Fibre Characteristics of *Ficus exasperata* at DBH 1.20m

Fibre characteristics	Stem Portion	Size of stem portion (m)	N	Mean ± SD (m)
Fibre Length (mm)	Base	1.20	20	1.65±0.26[b]
	Middle	0.80	20	1.35±0.31[a]
	Top	0.66	20	1.60±0.35[b]
	Total		60	1.53±0.33
Fibre Diameter (μm)	Base	1.20	20	38.30±5.5[c]
	Middle	0.80	20	30.14±2.42[b]
	Top	0.66	20	27.10±5.16[a]
	Total		60	31.85±6.56
Lumen Width (μm)	Base	1.20	20	25.60±6.44[c]
	Middle	0.80	20	17.85±3.94[b]
	Top	0.66	20	13.98±2.79[a]
	Total		60	19.14±6.68
Cell Wall thickness(μm)	Base	1.20	20	6.35±1.92[a]
	Middle	0.80	20	6.15±1.20[a]
	Top	0.66	20	6.56±1.77[a]
	Total		60	6.35±1.64

Table 5 shows the means of fibre length, fibre diameter, lumen width and cell wall thickness of *Ficus exasperata at* DBH 0.72m at different stem parts. The means of fibre length, fibre diameter, lumen width and cell wall thickness ranged between 1.41mm -1.29mm, 24.23μm-22.24μm, 14.33μm-12.14μm and 5.56μm-4.95μm respectively. The result reveals that the means of fibre length, fibre diameter, Lumen width and cell wall thickness *Ficus exasperata at* are not significantly different from each other among stem portions at p<0.05.

Table 4: Mean Values of Fibre Characteristics of *Ficus exasperata* at DBH 0.85m

Fibre characteristics	Stem Portion	Size of stem portion (DBH)	N	Mean ± SD
Fibre Length (mm)	Base	0.85m	20	1.20±0.34[a]
	Middle	0.76m	20	1.60±0.25[b]
	Top	0.51m	20	1.60±0.18[b]
	Total		60	1.47±0.32
Fibre Diameter (µm)	Base	0.85m	20	30.96±5.67[ab]
	Middle	0.76m	20	30.504.92[a]
	Top	0.51m	20	34.43±6.01[b]
	Total		60	31.96±5.74
Lumen Width (µm)	Base	0.85m	20	21.22±5.00[b]
	Middle	0.76m	20	20.35±3.95[b]
	Top	0.51m	20	15.13±2.76[a]
	Total		60	18.90±4.79
Cell Wall thickness (µm)	Base	0.85m	20	4.87±1.19[a]
	Middle	0.76m	20	5.08±1.04[a]
	Top	0.51m	20	9.65±2.40[b]
	Total		60	6.53±2.76

Table 6 shows the combined means of fibre length, fibre diameter, lumen width and cell wall thickness of *Ficus exasperata*. The result of the combined means of fibre length, fibre diameter, lumen width and cell wall thickness of *Ficus exasperata* samples range between 1.86mm – 1.20mm, 31.96µm – 20.98µm, 18.90µm – 10.42µm, 6.95µm – 3.76µm respectively. The result further reveals that the combined means of fibre length of *Ficus exasperata* (sample A – E) are not significantly different from each other at p<0.05. The result also reveals that the combined means of fibre diameter, lumen width and cell wall thickness of Sample A and E of *Ficus exasperata* are significantly different from Sample B, C and D of *Ficus exasperata* at p<0.05.

Table 7 shows the means of felting rate, elasticity coefficient, rigidity coefficient, runkel ratio and F factor of *Ficus exasperata* at of DBH 2.20m at different stem portions. The means of felting rate, elasticity coefficient, rigidity coefficient, runkel ratio and F factor ranged between 67.51- 65.71, 50.59% - 46.35%, 26.83% - 24.71%, 1.21 - 1.02, 274.60 - 247.71 respectively. The result also reveals that the means of felting rate, elasticity coefficient, rigidity coefficient and F factor are not significantly different among stem portions at p<0.05. However, the middle and top means of runkel ratio are significantly different from the base stem portion at p<0.05.

Table 5: Mean Values of Fibre Characteristics of *Ficus exasperata* DBH 0.72m

Fibre characteristics	Stem Portion	Size of stem portion (DHB)	N	Mean±SD
Fibre Length (mm)	Base	0.72	20	1.29±0.24[a]
	Middle	0.51	20	1.41±0.22[a]
	Top	0.48	20	1.37±0.23[a]
	Total		60	1.36±0.23
Fibre Diameter (µm)	Base	0.72	20	23.82±4.00[a]
	Middle	0.51	20	22.24±3.08[a]
	Top	0.48	20	24.23±4.34[a]
	Total		60	23.43±3.88
Lumen Width (µm)	Base	0.72	20	12.70±3.81[a]
	Middle	0.51	20	12.14±2.63[a]
	Top	0.48	20	14.33±4.51[a]
	Total		60	13.06±3.78
Cell Wall thickness (µm)	Base	0.72	20	5.56±1.25[a]
	Middle	0.51	20	5.05±0.96[a]
	Top	0.48	20	4.95±0.62[a]
	Total		60	5.19±1.00

Table 6: Combined mean values of fibre characteristics of *Ficus exasperata*

Fibre Characteristics	*Ficus exasperata* (samples A-E)	Size of stem portions (m)	N	Combined Mean±SD
Fibre Length (mm)	Sample A	2.20, 1.3 and 0.17	60	1.35±0.25[ab]
	Sample B	1.95, 1.50 and 0.60	60	1.29±0.25[a]
	Sample C	1.20, 0.80 and 0.66	60	1.53±0.33[b]
	Sample D	0.85, 0.76 and 0.51	60	1.47±0.32[ab]
	Sample E	0.72, 0.51 and 0.48	60	1.36±0.23[ab]
Fibre diameter (µm)	Sample A	2.20, 1.3 and 0.17	60	20.98±3.53[a]
	Sample B	1.95, 1.50 and 0.60	60	30.11±5.69[c]
	Sample C	1.20, 0.80 and 0.66	60	31.85±6.56[c]
	Sample D	0.85, 0.76 and 0.51	60	31.96±5.74[c]
	Sample E	0.72, 0.51 and 0.48	60	23.43±3.88[b]
Lumen width(µm)	Sample A	2.20, 1.3 and 0.17	60	10.42±3.16[a]
	Sample B	1.95, 1.50 and 0.60	60	16.20±5.23[c]
	Sample C	1.20, 0.80 and 0.66	60	19.14±6.68[d]
	Sample D	0.85, 0.76 and 0.51	60	18.90±4.79[d]
	Sample E	0.72, 0.51 and 0.48	60	13.06±3.78[b]
Cell wall thickness (µm)	Sample A	2.20, 1.3 and 0.17	60	5.28±0.98[b]
	Sample B	1.95, 1.50 and 0.60	60	6.95±2.47[c]
	Sample C	1.20, 0.80 and 0.66	60	6.35±1.64[c]
	Sample D	0.85, 0.76 and 0.51	60	6.53±2.76[c]
	Sample E	0.72, 0.51 and 0.48	60	5.19±1.00[b]

Table 7: Mean Values of Fibre Derivatives of *Ficus exasperata* DBH 2.20m

Fibre Derivatives	Stem Portion	Stem portion at DBH (m)	N	Mean±SD
Felting rate	Base	2.20	20	67.51±27.40[a]
	Middle	1.30	20	65.71±14.05[a]
	Top	0.71	20	65.79±10.04[a]
	Total		60	66.34±18.40
Elasticity coefficient (%)	Base	2.20	20	50.59±9.21[a]
	Middle	1.30	20	50.39±7.09[a]
	Top	0.71	20	46.35±7.27[a]
	Total		60	49.11±8.03
Rigidity coefficient (%)	Base	2.20	20	24.71±4.61[a]
	Middle	1.30	20	24.81±3.55[a]
	Top	0.71	20	26.83±3.63[a]
	Total		60	25.45±4.01
Runkel ratio	Base	2.20	20	1.03±0.33[b]
	Middle	1.30	20	1.02±0.24[a]
	Top	0.71	20	1.21±0.38[a]
	Total		60	1.09±0.33
F Factor	Base	2.20	20	274.60±99.61[a]
	Middle	1.30	20	268.07±57.7[a]
	Top	0.71	20	247.71±38.78[a]
	Total		60	263.46±69.90

Table 8 shows the means of felting rate, elasticity coefficient, rigidity coefficient, Runkel ratio and F factor of *Ficus exasperata at* DBH 1.95m at different stem portions; base (1.95m), middle (1.50m) and top (0.60m). The means of felting rate ranged between 50.53 - 38.82 while the means of elasticity coefficient ranged between 64.95% - 46.86% while the rigidity coefficient ranged between 26.57% - 17.53%. The means of Runkel ratio ranged between 1.22 - 0.38 whereas means of F factor ranged between 391.84 - 149.83. The result shows that the means of felting rate and elasticity coefficient at the base are not significantly different from each other but differ significantly from mean of stem portions at the middle and top at $p<0.05$. The result also reveals that the means of rigidity coefficient and Runkel ratio at the base and top portions do not differ significantly from the mean of the stem portion at the middle at $p<0.05$. The result further reveals that the means of F factor at the base and middle are not significantly different from each other but differ significantly from the mean of stem portion at the top at $p<0.05$.

Table 9 shows the means of felting rate, elasticity coefficient, rigidity coefficient, Runkel ratio and F factor of *Ficus exasperata* at DBH 1.20m at different stem portions as a base (1.20m), middle (0.80m) and top (0.66m). The means of felting rate, elasticity coefficient, rigidity coefficient, Runkel ratio and F factor ranged between 62.27-43.57, 66.51%-51.92%, 24.04%-16.75%, 0.95-0.56, 277.93-225.22 respectively. The result reveals that the means of Felting rate at the base and middle do not differ significantly from each other but differ significantly from the mean of stem portion at the top at $p<0.05$. The result also reveals that the means of elasticity coefficient and rigidity coefficient at the middle are not significantly different from each other but differ significantly from the mean of stem portion at the base and top at $p<0.05$. The result further reveals that the means of Runkel ratio and F factor at the base and middle are not significantly different from each other but differ significantly from mean of stem portion at the top at $P<0.05$.

Table 8: Mean Values of Fibre Derivatives of *Ficus exasperata* DBH 1.95m

Fibre Characteristics	Stem Portion	Size of Stem portion (DBH)	N	Mean±SD
Felting rate	Base	1.95m	20	44.33± 11.56[a]
	Middle	1.50m	20	50.53±15.24[ab]
	Top	0.60m	20	38.82±9.91[b]
	Total		60	44.56±13.14
Elasticity coefficient (%)	Base	1.95m	20	49.44±12.32[a]
	Middle	1.50m	20	64.95±11.12[b]
	Top	0.60m	20	46.86±9.92[a]
	Total		60	53.75±13.61
Rigidity coefficient (%)	Base	1.95m	20	25.28±6.16[b]
	Middle	1.50m	20	17.53±5.56[a]
	Top	0.60m	20	26.57±4.96[b]
	Total		60	23.13±6.81
Runkel ratio	Base	1.95m	20	1.14±0.51[b]
	Middle	1.50m	20	0.58±0.28[a]
	Top	0.60m	20	1.22±0.42[b]
	Total		60	0.98±0.49
F Factor	Base	1.95m	20	188.72±75.45[a]
	Middle	1.50m	20	391.84±532.1[a]
	Top	0.60m	20	149.83±43.52[b]
	Total		60	243.56±324.15

Table 10 shows the means of felting rate, elasticity coefficient, rigidity coefficient, Runkel ratio and F factor of *Ficus exasperata* at DBH 0.85m at different stem portions. The means of felting rate, elasticity coefficient, rigidity coefficient, Runkel ratio and F factor ranged between 53.29 -40.42, 66.45% - 44.43%, 27.79% - 15.92%, 1.30 - 0.49, 327.32 - 174.65 respectively. The result reveals that the means of felting rate and rigidity coefficient at the base and middle are not significantly different from each other but differ significantly from mean of stem portions at the top at $p<0.05$. The result reveals that the means of elasticity coefficient, Runkel ratio and F factor at the base and middle stem portion differ significantly from the means of the top stem portion at $p<0.05$.

Table 11 shows the means of felting rate, elasticity coefficient, rigidity coefficient, Runkel ratio and F factor of *Ficus exasperata* at DBH 0.72m at different stem portions as a base (0.72m), middle (0.51m) and top (0.48m). The means of felting rate, elasticity coefficient, rigidity coefficient, Runkel ratio and F factor ranged between 64.02 – 55.84, 57.98% - 52.79%, 23.61% - 21.01%, 0.76 – 0.94, 239.93 – 282.83 respectively. The results reveal that the means of felting rate, elasticity coefficient, rigidity coefficient, Runkel ratio and F factor of *Ficus exasperata at* DBH 0.72m do not differ significantly from each other at stem portions at $p<0.05$. However, the means of Runkel ratio and F factor at the base and top portion are significantly different from the means at the middle stem portion at $p<0.05$.

Table 9: Mean Values of Fibre Derivatives of *Ficus exasperata* at DBH 1.20m

Fibre Derivatives	Stem Portion	Size of Stem portion (DBH) m	N	Mean±SD
	Middle	0.80	20	45.12±11.05[b]
	Top	0.66	20	62.27±23.23[a]
	Total		60	50.32±17.51
Elasticity coefficient (%)	Base	1.20	20	66.51±10.05[c]
	Middle	0.80	20	58.82±9.49[b]
	Top	0.66	20	51.92±6.28[a]
	Total		60	59.08±10.50
Rigidity coefficient (%)	Base	1.20	20	16.75±5.03[a]
	Middle	0.80	20	20.59±4.74[b]
	Top	0.66	20	24.04±3.14[c]
	Total		60	20.46±5.25
Runkel ratio	Base	1.20	20	0.56±0.40[a]
	Middle	0.80	20	0.75±0.34[a]
	Top	0.66	20	0.95±0.22[b]
	Total		60	0.75±0.36
F Factor	Base	1.20	20	277.93±87.89[a]
	Middle	0.80	20	225.22±61.15[b]
	Top	0.66	20	266.96±117.62[a]
	Total		60	256.70±93.11

Table 10: Mean Values of Fibre Derivatives of *Ficus exasperata* at DBH 0.85m

Fibre Derivatives	Stem Portion	Size of stem portion (DBH) m	N	Mean ± SD
Felting rate	Base	0.85	20	40.42±13.82[a]
	Middle	0.76	20	53.29±10.67[b]
	Top	0.51	20	47.55±8.24[b]
	Total		60	47.09±12.18
Elasticity coefficient (%)	Base	0.85	20	68.16±7.38[b]
	Middle	0.76	20	66.45±6.66[b]
	Top	0.51	20	44.43±6.30[a]
	Total		60	59.68±12.78
Rigidity coefficient (%)	Base	0.85	20	15.92±3.69[a]
	Middle	0.76	20	16.78±3.33[b]
	Top	0.51	20	27.79±3.15[b]
	Total		60	20.16±6.39
Runkel ratio	Base	0.85	20	0.49±0.19[b]
	Middle	0.76	20	0.52±0.19[a]
	Top	0.51	20	1.30±0.37[a]
	Total		60	0.77±0.46
F Factor	Base	0.85	20	259.48±89.96[b]
	Middle	0.76	20	327.32±83.61[c]
	Top	0.51	20	174.65±42.85[a]
	Total		60	253.82±97.03

Table 11: Mean Values of Fibre Derivatives of *Ficus exasperata* at DBH 0.72m

Fibre Derivatives	Stem Portion	Size of stem portion (DBH) m	N	Mean ± SD
Felting rate	Base	0.72	20	55.84±14.56[a]
	Middle	0.51	20	64.02±9.42[a]
	Top	0.48	20	58.35±15.33[a]
	Total		60	59.40±13.58
Elasticity coefficient (%)	Base	0.72	20	52.79±8.72[a]
	Middle	0.51	20	54.38±6.42[a]
	Top	0.48	20	57.98±8.58[a]
	Total		60	55.05±8.14
Rigidity coefficient (%)	Base	0.72	20	23.61±4.36[a]
	Middle	0.51	20	22.81±3.21[a]
	Top	0.48	20	21.01±4.29[a]
	Total		60	22.48±4.07
Runkel ratio	Base	0.72	20	0.94±0.28[b]
	Middle	0.51	20	0.87±0.23[ab]
	Top	0.48	20	0.76±0.25[a]
	Total		60	0.85±0.26
F Factor	Base	0.72	20	239.93±57.49[a]
	Middle	0.51	20	283.14±41.15[b]
	Top	0.48	20	282.83±71.90[b]
	Total		60	268.64±60.77

Table 12 shows the combined means of felting rate, elasticity coefficient, rigidity coefficient, Runkel ratio and F factor of *Ficus exasperata*. Results of combined means of felting rate, elasticity coefficient, rigidity coefficient, Runkel ratio and F factor ranged between 94.71 – 44.56, 60.97% - 49.11%, 25.45% - 19.52%, 1.09 – 0.75, 560.32 – 243.56 respectively. The result also shows that combined means of felting rate, elasticity coefficient and rigidity coefficient are significantly different for *Ficus exasperata* (sample A – E) at $p<0.05$. The result also reveals that the combined means of Runkel ratio and F factor for Sample C, D and E of *Ficus exasperata* are significantly different from the combined means of sample A and B of *Ficus exasperata* at $p<0.05$.

Table 12: Combined Mean values of fibre derivatives of *Ficus exasperata*

Fibre Derivatives	*Ficus exasperata* (samples A-E)	Size of stem portions (m)	N	Combined Mean±SD
Felting rate	Sample A	2.20, 1.3 and 0.17	60	66.34±18.40[c]
	Sample B	1.95, 1.50 and 0.60	60	44.56±13.14[a]
	Sample C	1.20, 0.80 and 0.66	60	50.32±17.51[ab]
	Sample D	0.85, 0.76 and 0.51	60	47.09±12.18[a]
	Sample E	0.72, 0.51 and 0.48	60	59.40±13.58[bc]
Elasticity coefficient (%)	Sample A	2.20, 1.3 and 0.17	60	49.11±8.03[a]
	Sample B	1.95, 1.50 and 0.60	60	53.75±13.61[b]
	Sample C	1.20, 0.80 and 0.66	60	59.08±10.50[cd]
	Sample D	0.85, 0.76 and 0.51	60	59.68±12.78[d]
	Sample E	0.72, 0.51 and 0.48	60	55.05±8.14[ab]
Rigidity coefficient (%)	Sample A	2.20, 1.3 and 0.17	60	25.45±4.01[d]
	Sample B	1.95, 1.50 and 0.60	60	23.13±6.81[c]
	Sample C	1.20, 0.80 and 0.66	60	20.46±5.25[ab]
	Sample D	0.85, 0.76 and 0.51	60	20.16±0.39[a]
	Sample E	0.72, 0.51 and 0.48	60	23.48±4.07[bc]
Runkel ratio	Sample A	2.20, 1.3 and 0.17	60	1.09±0.33[c]
	Sample B	1.95, 1.50 and 0.60	60	0.98±0.49[bc]
	Sample C	1.20, 0.80 and 0.66	60	0.75±0.36[a]
	Sample D	0.85, 0.76 and 0.51	60	0.77±0.46[a]
	Sample E	0.72, 0.51 and 0.48	60	0.85±0.46[a]
F factor	Sample A	2.20, 1.3 and 0.17	60	263.46±69.90[a]
	Sample B	1.95, 1.50 and 0.60	60	243.56±324.15[a]
	Sample C	1.20, 0.80 and 0.66	60	256.70±93.11[a]
	Sample D	0.85, 0.76 and 0.51	60	253.82±97.03[a]
	Sample E	0.72, 0.51 and 0.48	60	268.64±60.77[a]

4. Discussion

3.1 Fibre Morphology

Fibre Length

The average mean fibre length obtained from *Ficus exasperata* of DBH 2.20m and 1.20m ranged between 1.35 mm - 1.53 mm and fall within 0.75mm - 1.75mm obtained from 10 -12-year-old stands of *Gmelina aborea* in Costa Rica as reported by Rogue and Fo (2007) and 1.26 mm for *Ficus exasperata* as reported by Adeniyi et al., (2013). However, the values are lower than 1.65mm - 2.33mm reported by Izekor and Fuwape (2011) for 25-year-old Teak in Eastern Nigeria and 1.57m for 42 years old *Hevea brazilensis* (Tembe et al., 2010).

Fibres below 1.60mm are classified as short while that above 1.60mm in length is said to be long fibres

(Metcalfe and Chalk, 1983; Anon, 1984). Ogunkule and Oladele (2008) reported a fibre length of less than 1.60mm for 12 *Ficus* species. Long fibres are preferred for the manufacture of paper because they give a more open and less uniform sheet structure (Oluwadare and Ashimyu, 2007). Short fibres lack formation of good surface content and fibre-fibre bonding (Ogbonnaya *et al* 1992). Ademiluyi and Okeke, (1979) reported that the longer the fibre, the higher the tear resistance and the better the quality of the paper produced. The fibre length of *Ficus exasperata* from this study falls under short fibre and would produce good quality paper.

Fibre Diameter

The mean value of fibre diameter obtained in this study shows that *Ficus exasperata* of DBH 1.20m had the highest mean (38.30µm) while DBH 2.20m had the lowest mean (19.53µm). The values fall within the range of *Pinu spatula* (36.0 - 40.0µm) reported by Pulp and Paper Recourses and Information, (PPR and I, 2011) and 18.5-27.5µm for *Gmelina aborea* according to Rogue and Fo, 2007. Adeniyi et al., (2013) reported 18.29 µm for *Ficus exasperata*. Fibre diameter was reported to be associated with molecular and physiological changes that occur in the vascular cambium as well as an increase in cell walls during the tree growing process (Plomion et al., 2001 and Rogue *et a*, 2007).

Lumen Width

In this study, the lumen width ranged between 9.08 – 25.60µm with DBH 1.20m of *Ficus exasperata* having the highest (25.60µm) and DBH 2.20m of *Ficus exasperata* having the lowest (9.08µm). These mean values are greater than the average (2.47-4.94µm) and the mean of 3.31µm reported on some indigenous hardwood species in the tropical rainforest ecosystem by (Awaku 1994). The means are within the range of 13.0µm for *Tectona grandis* reported by Izekor and Fuwape (2011) and 13.0µm for *Gmelina arborea* as well 9.87µm, for *Leucaena leucocephala* according to Ajala (1997) and 10.37 µm as reported by Adeniyi et al., (2013) for *Ficus exasperata*. Fibre lumen width affects the beating of pulp in the sense that, the larger the fibre lumen width, the better will be the beating of pulp due to the penetration of liquids into vascular spaces of the fibres (Paschim and de Zeeuww, 1980). The mean values recorded for fibre lumen width of *Ficus exasperata* in this study implies that the species will be very good during beating up of pulp.

Cell wall thickness

Means of cell wall thickness of *Ficus exasperata* in this study *ranged* between 9.65 µm - 4.74µm, with DBH 0.85m of having the highest (9.65µm) and DBH 1.95m of having the lowest (4.74µm). It falls within the range (1.94-4.99µm) reported by Ogunkunle (2010) for *Ficus* species and 5.00-10.00µm reported for pine by Pulp and Paper Recourses and Information, (PPR and I, 2011), 3.96 µm reported by Adeniyi et al., (2013) for *Ficus exasperata* but lower than 2.82µm for *Gmelina arborea* reported by Ogunkule (2010). Fibres with thin cell wall are dense and having good formation hence the suitability of *Ficus exasperata* as a raw material for pulp and paper production.

Derived fibre morphological indices

Felting power/Slenderness ratio

This is produced by shorter and thicker fibres which in turn reduced tearing resistance drastically. There is a positive correlation between the slenderness ratio and folding endurance (Ona et al., 2001). Slenderness ratio of cellulosic material more than 33 is considered to be good for pulp and paper production. It also affects the flexibility and resistance to rupture of the fibres and paper product made there from (Xue et al., 2006). Felting power has a positive effect on strength, tear, and burst, breaking off, double folding resistance according to the physical test result of the paper. Felting power required for good paper is between 70-90 for soft woods and 40-60 for hardwoods. Therefore, the felting rate of

Ficus exasperata ranges between 67.51 – 38.82 with *Ficus exasperata* at DBH 2.20m having the highest mean and *Ficus exasperata* at DBH 1.95 having the lowest mean, which falls within the range of 50.06 for *Gmelina arborea* and 42.38 to 71.99 as reported by Ogunkunle (2010) for different *Ficus* species. This implies that *Ficus exasperata* of smaller ages are suitable for paper making.

Runkel Ratio

The result of the runkel ratios obtained in this study shows that *Ficus exasperata* at DBH 2.20 has its runkel ratio greater than 1 (> 1) at 1.09, while the middle stem portion of *Ficus exasperata* at DBH 1.95m is less than 1 (< 1) at 0.58, and its base and top stem portions greater than 1 (> 1) at 1.14 – 1.22. Also, *Ficus exasperata* at DBH 1.20 has its runkel ratio less than 1 (<1) at 0.75, the base and middle stem portions of *Ficus exasperata* at DBH 0.85m is less than 1 (< 1) at 0.49 and 0.52, and its top stem portion greater than 1 (> 1) at 1.30. Whereas, *Ficus exasperata* at DBH 0.72 is less than (< 1) at 0.85.

The Runkel ratios less than 1 (< 1) falls within the range of 0.79 for tropical pine species (Ajala, 1997), 0.99 reported for both *Anthonathama crophylia* and *Dalium guinensis* hardwood species in Nigerian Rainforest Ecosystem (Ezeibekwe et al., 2009). It also falls within the range (0.28 and 0.68) reported for *Gmelina aborea*a and *Ficus spp* respectively (Ogunkule, 2010) and 0.59 as reported for *Leucaena leucocephala* (Oluwadare and Sotannde, 2007) also 0.76 for *Dacryodes edulis* (Ajuziogu et al., 2010). Bektas et al., 1999 stated that higher Runkel ratio gives lower paper strength properties especially lower burst, tear and tensile indexes, this was corroborated by Olwudare and Egbewole., 2008 who stated that Runkel ratio is closely associated with cell wall thickness and it influences paper strength properties. Runkel ratio should be < 1 for wood with good quality for pulp production (Kpikpi, 1992) thus, the suitability of *Ficus exasperata* for pulp and paper making depends largely on the size of tree (age) and the portion where it is collected. The average runkel ratio is 0.75 which less than 1 (< 1) this indicates that the suitability of *Ficus exasperata* as a raw material for pulp and paper production increases with a decrease in age, that is, the smaller the age the higher the suitability of *Ficus exasperata* or pulp and paper production but those greater than 1 (> 1) are not suitable for paper production.

Runkel ratio determines the suitability of a cellulosic material for pulp and paper production. Runkel ratio is directly affected by cell wall thickness, and not really by lumen diameter (Ona et al., 2001). It is also related to paper conformity, pulp yield and fibre density. High runkel ratio fibres produce bulkier paper than fibres with low runkel ratio. Wood species that is meant for pulp and paper production must have its runkel ratio to less than one (< 1), (Kpikpi, 1992).

Elasticity Coefficient

Elasticity coefficient is another important criterion for evaluating fibre quality. Elasticity coefficient (flexibility ratio) are classified into four groups of fibres (Bektas et al., 1991) High elastic fibres having elasticity coefficient greater than 75; elastic fibres having elasticity ratio between 50-75; rigid fibres having elasticity ratio less than 30-50 and highly rigid fibres having elastic less than 30.

Going by this classification, elasticity coefficient of all DBHs of *Ficus exasperata* in this study are within the rigid and elastic fibres (44.43 - 68.16) %. Because rigid fibres do not have efficient elasticity, they are not suitable for paper production and they are used more on fibre plate, rigid cardboard production (Akgul and Tozkiogu, 2009). Elastic fibres can be stretched making it a suitable raw material for papermaking in other to get high resistance.

Rigidity Coefficient

The values of rigidity coefficient obtained in this study ranged from (15.92 - 27.79) % for all samples of *Ficus exasperata*. These mean values are within the range reported by (Hus et al., 1975) for juvenile beech wood (22.95%) and 27.66% for Eucalyptus. The high rate of rigidity coefficient affects tensile, tear, burst and double fold resistance of paper negatively (Hus et al., 1975). This implies that paper made from these samples with low rigidity would have less tensile, tear, burst and double fold resistance making it a suitable raw material for pulp and papermaking.

F factor (%)

F factor of *Ficus exasperata* in this study ranged within (149.83 – 282.83) %. F factor for beech juvenile wood was found as 140.38% and 240.55% for blank pine juvenile wood (Akgul, 2009). On related studies of hardwoods, the F factor was found to be 235.92% for *Populu seur Americana* and 206.78% for *Populus tremula* (Kar, 2005). In a similar study on softwoods, F factor was found to be 606.66% for *Pinus brutia*, 410.34% and for *Cedrus libani* (Erdin, 1985). Springwood radial of *Pinus pinnaster* (Izmit, land, Bonitet-1) was determined as 745.40%, spring wood tangent as 69.81%, Summer wood radial as 603.9% and summer wood tangent as 493. % (As, 1992). It, therefore, implies that the F factor of *Ficus exasperata* is similar to that of beech juvenile wood and beech juvenile wood.

5. Conclusion

Based on the results from this study, younger *Ficus exasperata* was best and can be used for pulp and papermaking. As the suitability of *Ficus exasperata* greatly depends on the size. From the study, the smaller the dbh of *Ficus exasperata*, the higher the suitability for pulp and papermaking due to its appreciable fibre length and Runkel ratio. *Ficus exasperata* at DBH 1.20m and DBH 0.72m were best suited for paper making. The middle part of *Ficus exasperata at* DBH 1.95 m was suitable as well as base and middle part of DBH 0.85m. *Ficus exasperata at* DBH 2.20m was generally not suitable for paper making.

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