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EVALUATION OF FIBRE DIMENSIONS OF *Terminalia catappa* Linn AS RAW MATERIAL FOR PULP AND PAPER PRODUCTION

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Abstract:

Terminalia catappa fibre dimensions were evaluated as raw material for pulp and paper production. Sapwood samples of T. catappa were collected from five matured trees with diameter at breast height (dbh) of 1.82m, 1.57m, 1.02m, 1.05m and 0.76m from stem portions of top, middle and base portions, respectively within Makurdi metropolis. The samples were air dried and sliver of 1cmx2cmx2cm dried sapwood were macerated in a test-tube containing equal volume of acetic acid and hydrogen peroxide in ration 1:1 at 100^oC for 24 hours. Macerated solution of fibre was dropped on a slide and mounted on a Zeiss light microscope (standard 25) under 80 xs. Fifteen straight and unbroken fibres were randomly selected to the fibre dimensions. Derived indices were determined with standard formula. Fibre lengths of T. catappa ranged from 0.72 – 1.80mm. Fibre diameter was between 20.76µm and 16.25µm; mean lumen width ranged from 12.78µm - 8.35µm while mean cell wall thickness were 3.85µm - 6.28µm at different dbh and stem portions. Means of all fibre dimensions were not significant (p>0.05). Results on fibre indices ranged from 0.65 - 1.05 in Runkel ratio; 34.53% - 60.09% elasticity coefficient; 16.07% - 32.89% in rigidity coefficient; 22.00 - 36.73 in slenderness ratio; 0.37 - 0.47 in Luce's shape factor; 39.20 - 64.22 in F factors and 236.71in - 296.15in Solid factor. Means of all derived fibre indices were not significant (p>0.05). Results obtained have substantially proved Terminalia catappa to be very good raw material for pulp and paper production

Key words: *diameter at breast height; derived indices; fibre; paper; Terminalia catappa; stem portions.*

INTRODUCTION

Terminalia catappa Linn belongs to the plant family of Combretaceae which consists of roughly 600 species (Santos *et al*. 2016). It is commonly called tropical almond tree. It originated from Southern Asia and flourishes in the tropical ecosystems (Douati *et al.* 2017). The tree can grow from 25m to 40m tall and about 9 m in diameter with an upright, symmetrical crown, spiral phyllotaxis and horizontal branches (Douati *et al.* 2017; Marjenah and Putri 2017). *Terminalia catappa* is deciduous during dry season, and may lose their leaves twice in a year in some environments (Thamson and Evans 2006).

Terminalia catappa is a large, tall and fast growing tree species which spreads throughout the tropics in coastal environments. The species is tolerant of storm or strong wind, salt spray, and moderately high salinity in the root zone (Marjenah and Putri 2017). It is one of the few known legumes found in the tropics and in Nigeria ecosystem. It is a large tree commonly planted as ornamental tree, shade tree, for meal and medicinal herb for its fruits and seeds (Marjenah and Putri 2017). This species produces edible fruits for foods, especially for children and birds and other animals. Its kernels, which are also edible, are a source of proteins and lipids (Cavalcante *et al.* 1986; Matos *et al.* 1992; Ivani *et al.* 2008).

The stem of *T. catappa* is typically straight, cylindrical or crooked and leaning depending on the environment where it is located. The timber is a useful, all-purpose hardwood suitable for conversion into furniture and interior building timbers (Thomson and Evans 2016). The wood can be used for plywood

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production and as well as furniture. The wood is strong and pliable, and is used for the construction of buildings, boats, bridges, crates, planks, carts, wheelbarrows, barrels floors, boxes, and water troughs among other. It also a good source of firewood for rural and urban dwellers. However, the wood is not suitable for long-term ground contact (Thomson and Evans 2016).

Terminalia catappa is a fast-growing but unutilized tree species in Makurdi even though it has been researched for many uses. Globally, there is dearth of information on its potential capacity for pulp and paper production. A fast growing tree species as *T. catappa* are sourced for paper production so as to meet the ever increasing global consumption of paper and paper products. Therefore, the purpose of this study was to evaluate fibre characteristic of *T. catappa* as raw material for pulp and paper production.

MATERIALS AND METHODS

Sample Collection

Through non destructive method, sapwood samples of *Terminalia catappa* were collected from five matured trees with diameter at breast height (dbh) of 1.82m, 1.57m, 1.02m, 1.05m and 0.76m from top, middle and base portions, respectively within Makurdi metropolis. The samples were air dried before maceration of fibre.

Determination of Fibre dimensions of *Terminalia catappa*

Determination of fibre characteristics was carried out at Forest Research Institute of Nigeria (FRIN) Ibadan.To determine fibre dimensions (fibre length, fibre diameter, lumen width and cell wall thickness), small slivers (1cmx2cmx2cm) from the dried sapwood collected were placed into a test-tube containing equal volume of acetic acid and hydrogen peroxide in ration 1:1 and kept in an oven at 100^{o}C for 24 hours. The macerated mixture was stirred up to lose individual fibres. Macerated solution of fibre was placed on a slide and then mounted on a Zeiss light microscope (standard 25) under 80xs. Fifteen straight and unbroken cellulose fibres were randomly picked to measure fibre length, fibre diameter, lumen width and cell wall thickness.

Determination of derived indices of *Terminalia catappa*

From the measured fibre dimensions, seven derived indices were determined using the formula below:

$$FR/S = FL/FD \quad (1)$$
$$EC\,(\%) = (LW/FD)100 \quad (2)$$
$$RC\,(\%) = CWT\,x2/FD \quad (3)$$
$$RR = (CWT \times 2)/LW \quad (4)$$
$$LSF = (FD^2 - LW^2))/(FD^2 + LW^2) \quad (5)$$
$$Ff\,(\%) = (FL/CWT) \times 100 \quad (6)$$
$$SF = (FD^2 - LW^2)FL \quad (7)$$

where: FL = fibre length; FD = fibre diameter; LW = lumen width; CWT = cell wall thickness; FR/S = Felting rate/slenderness; EC = Elasticity coefficient; RC = Rigidity coefficient, RR = Runkel ratio; Ff = F factor (%); SF = Solids factor; LSF = Luce's shape factor.

Data Analysis

Data from this study were analysed with one way Analysis of Variance (ANOVA) to determine the significant effects of dbh and stem portion on fibre properties. Duncan Multiple Range Test (DMRT) was used as follow up tests where significant differences exist.

RESULTS AND DISCUSSION

FIBRE DIMENSIONS OF *Terminalia catappa*

Table 1 presents fibre dimensions of *Terminalia catappa* at different dbh and stem portions.

Fibre Length

At dbh of 1.82m, 1.57m, 1.03m, 1.02m and 0.76m, fibre lengths were between 0.80 – 1.80mm, 0.99 – 1.15mm, 0.72 – 1.03mm, 0.96 – 1.13 and 0.89 – 1. 12mm, respectively while the mean fibre length for the five different dbh was 1.04mm. Fibre lengths of *Terminalia catappa* at different dbh and stem portions were not significant at p>0.05. These values are agrees fibre length of hardwood with 1.29mm in *Gmelina arborea* reported by Roger *et al*. (2007), 0.67 – 1.06mm in *Eucalyptus spp.* reported by Dutt and Tyagi (2011);

Ververis *et al.* (2004). However, the values of *T. catappa* obtained in this study is lower that the value of long fibres from *Bambus vulgaris* (2.10mm), softwood (3.6mm) Sadiku *et al.* (2016). Wood fibres are cellulosic substances obtained from trees for numerous benefits that include the production of pulp and paper (H'ng *et al*. 2016; Ofosu *et al.* 2019). Fibre length is reported to influence lots of pulp strength properties. It has positive correlations between fibre lengths and tear index for *Pinus radiata* and *Pinus elliotttii* (Wright and Sluis-Cremer 1992), folding endurance (Ona *et al*. 2001), tear strength (Haygreen and Bowyer 1996) and burst strength (Ona *et al.* 2001). A higher fibre length relates to a higher tearing resistance of paper that attributed to stress dissipation. The longer the fibre, the greater the area over which the stress on paper is dissipated (Gallay 1962). Ademiluyi and Okeke (1979) also noted that the longer the fibre, the higher the tear resistance of paper and the better the quality of paper produced from it. According to Anon (1984), a mean fibre length from 1.6mm and above is classified as long fibre. Therefore, fibre length from *T. catappa* can be classified as short fibre.

Fibre diameter

The average fibre diameter of *Terminalia catappa* at different dbh was between 20.76µm and 16.25µm. This result agrees with 20.3µm for *Triplochiton scleroxylon* obtained by Ogunsanwo (2000). Olaoye *et al.,* (2019) reported a lower fibre diameter mean of 10.67 - 12.64µm for *Aningeria robusta.* Higher values of 41.5µm was recorded by Ogunleye *et al.* (2017) in *Ricinodendron heudelotii* wood while Roger *et al.* (2007) also reported higher mean of 30.67µm for *Gmelian arborea.* Similarly, 36.09µm and 34.25µm were reported for *Rhizophora racemosa* and *Rhizophora harrisonii*, respectively by Emerhi (2012). Drew and Pammenter (2006) reported that wood species with long and large diameter fibre elements can produce paper that shows vessel elements that are picked from the surface of paper during printing process which are deposited on the printing surface. Hence, wood with short vessel elements with small diameters is preferable for paper production. Fibre diameter of *Terminalia catappa* at different dbh and stem portions were not significant at p>0.05.

Larger lumen width provided for better pulp beating as a result of the penetration of pulping liquid into empty spaces of the fibres (Emerhi 2012). Thicker cell wall would give higher pulp yield and increase in tear resistance, (Ogunleye *et al.* 2017). Omotoso and Owolabi (2015) reported that lumen width affects the beating of the pulp. As lumen width becomes larger, they beating of pulp become better due to the penetration of liquids into empty spaces of the fibers.

Lumen Width

Mean lumen width of 12.78µm - 8.35µm were recorded for the different dbh and stem portions of *T. catappa* and they are not significant (p>0.05). This result agrees with values of 9.55µm, 9.56µm, 8.80µm and 9.34µm for *Bambusa vulgaris* collected at different locations in Narawa State by Egbewole *et al.* (2015). However, several authors have reported higher lumen widths in some plant species. Ogunleye *et al.* (2017) obtained 32.3µm in *Ricinodedron Heudelotii;* 30.67µm for *Gmelina arborea* (Roger *et al.* 2007); 20.06µm for *Gmelina arborea* and 18.69 - 28.93µm for different Ficus species, respectively (Ogunkunle 2010). The mean value of 12.78µm - 8.35µm obtained in this study is also lower than 15.60µm for 20 years old *Tectona grandis* (Izekor and Fuwape 2011) and 12.5µm for *Triplochiton scleroxylon* (Ogunsanwo 2000); 18.92µm and 17.55µm for *Rhizophora racemosa* and *Rhizophora harrisonii*, respectively (Emerhi 2012). Lumen width has influence on pulping process such that larger lumen width enhances better pulp beating by favouring the penetration of liquid into empty spaces of cellulose fibres (Emerhi 2012).

Cell wall thickness

Mean cell wall thickness of 3.8 µm, 3.99µm, 4.32µm, 3.77µm, and 6.28µm were recorded for different dbh and stem portions of *T. catappa* and were not not significant at p>0.05. This agrees 4.6µm for *Ricinodendron heudelotii* observed by Ogunleye *et al.* (2017); 4.02µm for *Gmelina arborea* (Roger *et al.* 2007); 3.83µm for *Gmelina arborea* (Ogunkunle 2010) and 1.94 - 4.99µm for different Ficus species (Ogunkunle 2010). On the contrary, higher values of 8.58µm for *Rhizophora racemosa* and 9.45µm for *Rhizophora harrisonii* (Emerhi 2012), 7.89µm for 20 years old *Tectona grandis* (Izekor and Fuwape 2011) are reported. Joransen (1960) observed that thicker cell wall produce a higher pulp yield and enhances tear resistance. Also, thicker wall produce coarse, bulky sheets. More so, the thicker wall of fibre cause reduction in burst and tensile and fold of paper. The thickness of the cell wall has an essential bearing on most paper properties. Paper produced with thick-walled cellulose fibre would be bulky with lower bust, tensile, other than a high tearing strength of paper (Haygreen and Bowyer 1996). Biermann (1993) reported that paper produce from thick-walled cells resulted in low folding endurance. Colley (1973) reported that cell wall thickness affects specific gravity of fibrous raw materials which in turn has a marked effect on the pulp sheet properties. Thick-walled cells cannot bend easily and will no collapse upon pulping, which slows down chemical bonding (Zobel and van Buijtenen 1989).

Table 1

Fibre Characteristics of Terminalia catappa at Different dbh and stem portions

DBH (m)	Tree Portion	Fibre Length (mm)	Fibre Diameter (µm)	Lumen Width (µm)	Cell Wall Thickness (µm)
		Mean±SDV	Mean ± SDV	Mean ± SDV	Mean ± SDV
1.82	Base	0.88 ± 0.11^{bc}	13.94 ± 4.37^{a}	7.41 ± 1.91^{ab}	3.26 ± 1.45^{a}
	Middle	0.84 ± 0.18^{ab}	25.23 ±6.67^{d}	16.18 ± 6.47^{e}	4.52 ± 1.72^{a}
	Top	1.80 ± 0.27^{de}	21.08 ± 6.05^{c}	13.53 ± 6.06^{de}	3.77 ± 1.24^{a}
	Total	**1.17±0.19**	**20.08±5.70**	**12.37±4.81**	**3.85±1.47**
1.57	Base	1.07± 0.13^{cde}	22.03± 6.11^{cd}	14.08± 5.33^{de}	3.98± 1.38^{a}
	Middle	1.15± 0.22^{b}	19.51±4.72^{a}	10.88± 3.55^{ab}	4.32± 1.14^{b}
	Top	0.99± 1.15^{a}	20.74 ± 8.28^{a}	13.39± 7.76^{b}	3.67 ± 1.21^{b}
	Total	**1.07±0.5**	**20.76±6.37**	**12.78±5.55**	**3.99±1.24**
1.03	Base	0.96± 0.18^{bcd}	15.64 ± 5.26^{ab}	9.52± 4.63^{a}	3.06 ± 1.02^{a}
	Middle	1.03± 0.19^{a}	16.86±4.49^{a}	9.31± 2.80^{a}	3.77± 1.27^{b}
	Top	0.72± 0.17^{a}	18 .49± 2.46^{bc}	6.25± 3.49^{a}	6.12 ± 1.72^{b}
	Total	**0.90±0.18**	**16.25±4.07**	**8.35±3.64**	**4.32±1.34**
1.02	Base	1.13± 0.23^{e}	18.02±5.05^{abc}	10.40±3.13^{bcd}	3.80± 1.37^{a}
	Middle	1.07± 0.18^{ab}	17.68±7.18^{a}	10.34± 6.04^{ab}	3.67± 1.32^{ab}
	Top	0.96± 0.16 ^{bcd}	18.02 ± 4.25^{a}	10.34± 3.40^{ab}	3.84± 1.21^{ab}
	Total	**1.05±0.19**	**17.91±5.50**	**10.36±4.19**	**3.77±1.30**
0.76	Base	1.12± 0.17^{ab}	16.86± 3.87^{a}	10.33± 3.24^{ab}	3.26 ± 1.01^{a}
	Middle	0.89± 0.18^{bc}	20.69±4.94^{c}	11.88 ± 4.28^{cd}	11.88± 4.28^{c}
	Top	0.99± 0.19^{bdce}	18.29 ±7.65^{abc}	10.88±6.19^{bcd}	3.70± 1.22^{a}
	Total	**1.00±0.18**	**18.61±5.49**	**11.03±4.57**	**6.28±2.17**
Grand mean Total		**1.04±0.22**	**19.26±6.31**	**11.12±5.59**	**4.85±3.16**

Derived Indices of *Terminalia catappa*

Results of derived indices of *Terminalia catappa* at different dbh and stem portions are showed in Table 2.

Runkel ratio

Values of Runkel ratio are commonly used to predict the stiffness, flexibility and conformability of paper (Istikowati *et al.* 2016; Ogunleye *et al.* 2017). From this study, the mean of Runkel ratio of *Terminalia catappa* at different dbh and stem portion ranged from 0.65 - 0.90, 0.65 - 0.82, 0.75 - 1.05, 0.75 - 0.83, 0.69 - 1.00 and were significantly different (p>0.05) excepting the means of top portion (1.05) and middle portion (1.00) of dbh 1.03 and 0.76 that were significantly different (p<0.05). This value are higher than 0.39 for *Gmalina arborea* and fall within 0.26 - 0.68 reported for some Ficus species (Ogunkunle 2010). Ververis *et al.* (2004) noted that higher Runkel ratio fibres produce bulkier paper of lower bonded areas in contrast with lower Runkel ratio fibre. Cellulose fibres that have Runkel ratio < 1 are good for paper production since cellulose fibres are more flexible, collapse effortlessly and poduce paper with large bonded area. However, cellulose fibres that have Runkel ratio > 1 are regarded as thick-walled fibres that less flexible, stiffer, and form a heavy sheet of paper that has lower bonded area (Dutt *et al*. 2009). Ona *et al*. (2001) noted that Runkel ratio also influence pulp yield, paper conformability, and fibre density. The thick-walled and narrow lumen fibres tend to retain its tubular structure on pressing and thus, offer less surface contact for fibre bonding (Dutt *et al*. 2004). From the foregoing, fibres of *T. catappa* wood can be regarded as suitable for pulp and paper production because the average Runkel ratio is 0.79. Quality paper strength features are obtained when the Runkel Ratio is < 1 (Sharma *et al.* 2011; Ibrahim and Abdelazim 2015; Takeuchi *et al.* 2016).

Elasticity coefficient (%)

Mean value of elasticity coefficient at different dbh and stem portions of *Terminalia catappa* were 60.09%, 49.50%, 34.53%, 57.18% and 58.70%, respectively. The means of base portion (28.70) of dbh 1.57 and top portion (33.53) of dbh 1.03 were significantly different (p<0.05). These results agree with 37% - 65% reported by Pirralho *et al.* (2014) in several Eucalyptus species. Sharma *et al*. (2013) reported higher values of 76 and 82 for *Gmelina arborea* and *Pinus kesiya* respectively. Ogunkunle (2010) obtained 63 - 79% for various Ficus species. Ogunleye *et al.* (2017) also recorded a higher value of 77% for *Ricinodedron heudelotii.* Ona *et al.* (2001) reported higher values of 70% and 72% in *Eucalyptus camaldulensis* and *Eucalyptus globulus,* respectively.

Elasticity coefficient is one of the essential derived indices that positively influence the strength properties of paper and is determined by lumen diameter and fibre diameter. It positively relates with paper strength, such as burst factor and tear factor (Moriya 1967). It governs the degree of fibre bonding in paper sheet. The values for hardwood and softwoods are between 55 – 70% and 75%, respectively (Smook 1997). Fibres with elasticity coefficient greater than 75% and between 50 - 75% are regarded as highly elastic and elastic fibres, respectively (Bektas *et al*. 1999). Ashori and Nourbakhsh (2009) reported that the elasticity coefficient exhibits the possibility of fiber to collapse during beating or drying of the paper web. Collapsed fibers provides a better bonding area and hence a stronger paper. The elasticity coefficient of *Terminalia catappa* as obtained in this study can be classified as elastic and rigid fibres.

Rigidity coefficient (%)

Rigidity coefficient of 16.07%, 20.03%, 22.36%, 21.51% and 32.89% were recorded for *T. catappa* at different dbh and stem portions. The means of top portion (33.25) of dbh 1.03 and middle portion (57.61) of dbh 0.76 were significantly different (p<0.05). Sadiku (2016) reported a lower rigidity coefficient of 15% for **Berberis** *vulgaris* while Dutt and Tyagi (2011) reported higher rigidity coefficient of 63% for *Eucalyptus tereticornis* and 53% and 33% for *Eucalyptus camadulensis* and *Eucalyptus grandi,s* respectively. Rigidity coefficient is ratio of double cell wall thickness of fibre to its width. It gives the rigidity of fibres to form paper. It shows the bending resistance of paper (Takeuchi *et al.* 2016). Fibres with a rigidity coefficient of <= 50 are normally seen to be good pulpwood because it increases the collapsibility of fibres to make a flexible and strong paper sheet (Tamolang and Wangaard 1961). Therefore, *T. catappa* with rigidity coefficient of between 16.07% - 32.89% which is < 50 is considered to be very good for paper production.

Felting rate/Slenderness ratio

The range of average slenderness ratio or felting rate recorded for *T. catappa* at different dbh and stem portions in this study were 22.00 - 32.47, 29.40 - 29.60, 22.53 - 34.06, 27.53 - 33.53 and 28.21 - 36.73 and were not significantly different (p>0.05). Takeuchi *et al.* (2016) reported higher slenderness ratio of 58.7% and 60.8% for *Musa bancana* and *Musa pearsonii*, respectively. Sadiku and Abdukareem (2019) also reported higher felting power for *Syzygium guineense, Anogeissus leiocarpa, Albizia zygia, Irvingia gabonensis, Vernonia colorata, Vitellaria paradoxa, Isoberlina doka, Lannea welwitchii, Khaya ivorensis* and *Afzelia africana* in their study to range from 40 - 90 with *Anogeissus leiocarpa* having the highest (90) felting power followed by *Vernonia colorata* (80). Slenderness ratio was reported for *Eucalyptus grandis* (55.18), *Eucalyptus tereticornis* (52.66) and *Eucalyptus camadulensis* (53.33) (Dutt and Tyagi 2011; Pillai *et al.* 2013) while Sharma *et al.* (2013) obtained 39.1 in *Gmelina arborea.* Sadiku *et al.* (2016) also reported a very higher value of 144 slenderness ratio for *Bambusa vulgaris.*

Fibre slenderness significantly influenced the breaking length, bursting, tearing and stretch of the pulp sheets (Ogunjobi *et al*. 2014). The acceptable value of slenderness ratio required for paper making should be greater than > 33 according to Xu *et al*. (2006). An increase in the rigidity of fibres results in decrease in fibre bonding. The strength properties of papers were positively correlated with the slenderness ratio. Slenderness ratio 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 of paper (Ona *et al.* 2001). However, the average slenderness ratio (25.94) obtained for *T. catappa* in this research is below 33 although the maximum mean values recorded at each dbh are within the range of 33. Hence, folding endurance and tearing resistance of paper produced from *T. catappa* would be low.

Luce's Shape Factor

Luce's shape factor of 0.47, 0.37, 0.45, 0.39 and 0.46 were recorded for *T. catappa* at different dbh and stem portions. ean of top portion (0.77) of dbh 1.03 was significantly different ($p<0.05$). This finding agrees with the mean values of 0.410 - 0.0.414 for the inner and outer *Chrysophyllum albidum* wood from the axial positions reported by Ofosu *et al.* (2019). Similar results were reported by Oluwadare and Sotannde (2007) for **Leucaena** *leucocephala* (0.41) and **Eucalyptus** globulus (0.39 - 0.44) of 14-year-old (Ohshima *et al.,* 2005). Ogunleye *et al.* (2017) reported lower value of Luce's shape factor 0.26 for *Ricinodedron heudelotii.* Ogunkunle (2010) also reported lower values for *Gmelina arborea, Ficus mucuso, Ficus exasperate* as 0.29, 0.25 and 0.16, respectively. Acoording to Ojo (2013), Luce's shape factor for *Gmelina arborea, Afzelia africana and Detarium senegalense* were 0.20, 0.47 and 0.73, respectively. However, Pirralho *et al.* (2014) reported higher value of Luce's shape factor in their study **Eucalyptus** maculate (0.69), **Eucalyptus** *ovata* (0.6) and **Eucalyptus** *sideroxylon* (0.62).

Luce's Shape Factor has negative relationship with the density and breaking length of paper. That is, the length of the paper that will break by its own weight when hang up vertically from its end (Sharma *et al*. 2015a; Syed *et al.* 2016). Luce's Shape Factor is one of the indices used to ascertain the bending resistance of paper and resistance of pulp to beating. Low values for Luce's indicates low resistance of pulp to beating and high resistance of paper to bending (Takeuchi *et al*. 2016). Cellulose fibres that have low Luce's Shape Factor are more suitable for papermaking as they produce papers with high-quality strength properties (Sharma *et al.* 2015a; Sharma *et al.* 2018b). These findings suggest that *T. catappa* can be regarded as been suitable for pulp and paper production.

F factor

F factor recorded for *T. catappa* at different dbh and stem portions were 52.71, 39.20, 47.04, 64.22 and 58.91, respectively and are not significant ($p<0.05$). Higher F factors were obtained for beech juvenile wood as140.38, while it was 240.55 in black pine juvenile wood (Akgul and Tozluoglu 2009). Studies on hardwoods by Kar (2005) showed that F factor was 235.92 for *Populus euramericana* and 206.78 for *Populus tremula*. For softwoods, 606.66 was reported for *Pinus brutia* and 410.34 for *Cedrus libani* (Erdin 1985). For *Pinus pinaster*, As (1992) reported 745.40, 695.81 for spring wood tangent, 603.9 for summer wood radial while it was 493.20 for summer wood tangent.

Solid factor

Solid factor of 247.38, 296.15, 252.69, 244.04 and 236.71 were recorded for *T. catappa* at different dbh and stem portions and are were not significant ($p>0.5$). Ogunleye *et al.* (2017) reported higher value of Solid factor 14.2×10^{-3} for *Ricinodedron heudelotii.* Sadiku *et al.* (2016) reported Solid factor of 1.16×10^{-4} - 9.87×10^{-5} for ages 2, 3 & 4, and 1.29×10^{-4} - 9.02×10^{-5} for base, middle and top positions of *Bambusa vulgaris.* Ona *et al.* (2001) reported values for the solids factor of 46×103μm^3 and 91.2×103μm^3 for 14-year-old *Eucalyptus camaldulensis* and *Eucalyptus globulus*, respectively. Mean values of solids factor of $167\times10^3\mu m^3$ for *Macaranga bancana* and $182\times10^3\mu m^3$ for *Macaranga pearsonii* was reported by Takeuchi *et al.* (2016).

Ona *et al*. (2001) noted that solids factor was discovered to influence paper sheet density and significantly correlated to breaking length of paper. Similar to Luce's Shape Factor, Solids Factor is used to determine the bending resistance of paper and resistance of pulp to beating. Low values for Solids Factor indicates low resistance of pulp to beating and high resistance of paper to bending (Takeuchi *et al*. 2016). Cellulose fibres having low Solids Factor are preferred for papermaking because they produce papers with superior strength properties (Sharma *et al*. 2015a, Sharma *et al*. 2018b).

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Table 2

Derived Indices of Terminalia catappa at different dbh and stem portions

DBH (m)	Tree Portion	Runkel Ratio	Elasticity Coefficient (%)	Rigidity Coefficient (%)	Slenderness ratio/ Felting Power (%)	Luce's Shape Factor (LSF)	F factor	Solid Factor (SF)
		Mean ± SDV	**Mean ±SDV**	**Mean ±SDV**	**Mean ±SDV**	**Mean ±SDV**	**Mean ±SDV**	**Mean ±SDV**
1.82	Base	0.90 ± 0.34^{a}	54.53±9.56^{b}	22.75±4.63^{a}	32.47 ±13.74^{c}	0.54±0.12^{a}	69.20±21.97^{e}	132.67±94.33^{a}
	Middle	0.65 ± 0.38^{a}	63.13±13.53^{b}	6.72±1.73^{a}	22.00 ±10.99^{b}	0.43±0.17^{a}	35.27±10.34^{a}	315.26±168.66^{c}
	Top	0.67 ± 0.31^{a}	62.60±12.53^{b}	18.74±6.24^{a}	31.07 ±12.10^{c}	0.43±0.15^{a}	53.67±14.38^{bcd}	294.2.±156.09^{c}
	Total	**0.74±0.34**	**60.09±11.87**	**16.07±4.20**	**28.51±12.28**	**0.47±0.15**	**52.71±15.56**	**247.38±139.69**
1.57	Base	0.65± 0.30^{a}	28.70±12.22^{a}	18.62±6.08^{a}	29.60±13.82^{bc}	0.44±0.15^{a}	50.27±19.65^{bc}	297.93±161.59^{c}
	Middle	0.82± 0.20^{a}	58.00±7.40^{b}	22.20±3.80^{a}	29.60 ±11.39^{ab}	0.47±0.27^{a}	62.80±15.25^{a}	326.13±136.15^{b}
	Top	0.67 ± 0.31^{a}	61.87±12.25^{b}	19.27±6.03^{a}	29.40±9.52^{ab}	0.20±0.77^{a}	4.53±22.25^{a}	264.40.±177.99^{ab}
	Total	**0.71±0.27**	**49.50±77.29**	**20.03± 5.30**	**29.53±11.58**	**0.37±0.40**	**39.20±19.05**	**296.15±158.58**
1.03	Base	0.75± 0.29^{a}	58.80±11.02^{b}	20.61±5.48^{a}	34.06±10.32^{c}	0.49±0.14^{a}	67.80±25.28^{e}	152.1±87.28^{ab}
	Middle	0.84± 0.23^{a}	55.33±8.10^{b}	22.53±3.89^{a}	29.47±10.83^{ab}	0.42±0.29^{a}	64.67±23.34^{a}	212.7±119.09^{a}
	Top	1.05± 1.37^{c}	33.53±17.3^{a}	33.25±8.57^{b}	22.53±3.85^{a}	0.77±0.18^{b}	40.0±11.19^{ab}	219.4±89.81^{abc}
	Total	**0.78±0.42**	**34.53±49.37**	**22.36±5.59**	**27.74±10.19**	**0.45±0.31**	**47.04±19.43**	**252.69±132.93**
1.02	Base	0.75± 0.23^{a}	58.47±7.95^{b}	20.85±3.88^{a}	33.53±13.48^{c}	0.49±0.10^{a}	66.40±19.13^{de}	265.13±156.27^{bc}
	Middle	0.83± 0.28^{a}	56.00±10.65^{b}	22.07±5.32^{a}	32.93±12.80^{ab}	0.23±0.81^{a}	70.0±28.71^{a}	242.26±172.72^{ab}
	Top	0.80± 0.25^{a}	57.07±9.42^{b}	21.60±4.61^{a}	27.53±8.88^{a}	0.45±0.23^{a}	56.27±12.69^{a}	224.73±109.46^{ab}
	Total	**0.79±0.25**	**57.18±9.34**	**21.51±4.60**	**31.33±11.72**	**0.39±0.38**	**64.22±20.18**	**244.04±146.15**
0.76	Base	0.69± 0.28^{a}	60.67±9.8^{b}	19.93±4.79^{a}	36.73±9.42^{b}	0.37±0.30^{a}	70.87±23.25^{a}	207.33±107.51^{a}
	Middle	1.00± 0.00^{b}	57.64±12.39^{b}	57.61±12.4^{c}	28.21±2.67^{a}	0.50±0.16^{a}	45.92±14.21^{abc}	258.07±139.5^{bc}
	Top	0.77 ± 0.26^{a}	57.80±9.16^{b}	21.14±4.56^{a}	28.80±8.55^{bc}	0.50±0.11^{a}	59.93±18.12^{cde}	244.73±190.6^{abc}
	Total	**0.82±0.18**	**58.70±10.45**	**32.89±7.25**	**24.58±6.88**	**0.46±0.19**	**58.91±18.53**	**236.71±145.87**
Total		**0.79±0.02**	**56.59±14.49**	**25.55±13,67**	**25.94±13.70**	**0. 51±0.17**	**54.51±151.19**	**240.20±20.91**

Suitability of *Terminalia catappa* for pulp and paper making based on fibre length and Runkel ratio is shown in Table 3. The results shown that average values of fibre length ranged from 1.17mm – 0.90mm and are classified as short fibre. The mean Runkel ratio that ranged between 0.71 – 0.82 implies that *Terminalia catappa* irrespective of the dbh and stem portions, is good for paper production.

Table 4 revealed the summary of the elasticity coefficient of *Terminalia catappa* stem portions. The results shown that *T. catappa* fibre was elastic at dbh of 1.82m (60.09%); 1.02m (57.18%) and 0.76m (58.70%), respectively. At dbh 1.03m and 1.57m the elasticity coefficient were 34.53% and 49.50% are both rigid fibres, respectively.

Table 3

Suitability of Terminalia catappa for pulp and paper making based on fibre length and Runkel ratio

DBH (m)	Fibre length		Runkel ratio	
	Mean Value	**Fibre class**	**Mean Value**	**Ranking**
1.82	1.17	Short	0.74	Good
1.57	1.07	Short	0.71	Good
1.03	0.90	Short	0.78	Good
1.02	1.05	Short	0.79	Good
0.76	1.00	Short	0.82	Good

Note:
- ✓ *Fibre length <1.60mm = short fibre; Fibre length >1.60mm = long fibre*
- ✓ *Runkel ratio <1 = Good; Runkel ratio >1 = Not good*

Table 4

Summary of the Elasticity Coefficient of Terminalia catappa Stem Portions

DBH (m)	Elasticity coefficient (EC) (%)	
	Mean Value	**Types of fibre**
1.82	60.09	Elastic
1.57	49.50	Rigid fibres
1.03	34.53	Rigid fibres
1.02	57.18	Elastic
0.76	58.70	Elastic

Note:
- ✓ *High elastic fibres = EC > 75%; Elastic fibres = EC btw 50 – 75%; Rigid fibres = EC between 30 – 50; Highly rigid fibres = Elastic <30%.*

CONCLUSION

Fibre dimensions of *T. catappa* indicate that the species will be good for pulp and paper production though the fibre length were short fibre (0.90 – 1.17). The mean Runkel ratio (0.71 – 0.82) of *T. catappa* also implies that the wood species is a good raw material for paper production irrespective of dbh and stem portions. The elasticity coefficient was both elastic and rigid fibres. Rigidity coefficient *of T. catappa* of was ≤50 which is required standard for a very good for paper production. Mean values of slenderness ratio of *T. catappa* indicates that it would produce paper with low folding endurance and tearing resistance. This study has therefore shown that *T. catappa* will serve as viable raw material for pulp and paper production.

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