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Anatomical Characteristics of *Terminalia catappa* Wood

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Abstract
The potentials and capability of pulp and paper industry in Nigeria can only be met if proper and adequate information on raw materials are well known. This study investigated the comparative anatomical structures of *Terminalia catappa* wood grown in Nigeria. Wood specimens were extracted from two parts of the tree (stem and branch); each part was radially sectioned into three portions (outer, middle, core). Properties such as fibre derivatives and anatomical features of the wood were investigated at two variables (tree part and wood portion). The results ranged from 1.29 mm to 1.99 mm, 0.02 mm to 0.04 mm, 0.01 mm to 0.02 mm, 0.01 mm to 0.03 mm and 0.19 mm to 0.30 mm for fibre length, fibre diameter, lumen width, cell wall thickness and vessel diameter respectively. Also, the values obtained for slenderness ratio, flexibility coefficient, runkel ratio, Luce's shape and solid factor ranged from 40.24 to 59.29, 0.30 to 0.57, 0.94 to 2.52, -0.095 to - 0.267 and 0.001 and 0.004 respectively. It was shown that variables investigated were not significant in fibre length, fibre diameter, cell wall thickness, slenderness ratio, flexibility coefficient and solid factor but significant in vessel diameter, Luce's shape and runkel ratio. The outcome of anatomical features revealed that gum deposits were more pronounced in stem than in branch while the branch was found to be more of libriform fibres than in stem. The outcome of this research revealed that *Terminalia catappa* can be considered as a raw material for the production of pulp for papers making.

Keywords: Anatomical, *Terminalia catappa,* Fibre, Pulp, Pap

Introduction

Historically, the unique characteristics and comparative abundance of wood have made it a natural material for home, structure, furniture, tools, vehicles and other decorative objects (Desch and Dinwoodie (1991). Today, wood is known for a multitude of uses based on the characteristics displayed. The difference in cellular structure makes wood heavy or light, stiff or flexible and hard or soft. Wood is a porous material which consists of matrix of fibre walls and air spaces. It is a non-uniform heterogeneous material. Its structure, chemical components and mechanical properties varies from pith to back, from the tree base to the top, from the stems to the branches and root (Rupert *et al*., 2002). Wood varies systematically within one growth ring and at the cellular level. The chemistry, the micro fibril angle and mechanical properties change significantly, from one cell wall layer to another (Izekor, 2010).

Wood is the oldest and the most widely used of all structural material and is of plant origin. However, not all plant possessing woody stems that can produce timber suitable for as an industrial material. According to Word Resources Institute (1990), wood is the third most valuable commodity in the world after petroleum and natural gas. Panshin and Zeeuw (1980) gave certain features that serve to distinguish woody plants, these features are vascularise, single persistent stem, perennial stem and secondary thickening. This is because there is no competitive material that has all the attributes of wood. Some of these attributes are its availability in vast quantities and the renewability of its supply. It has been estimated that there are currently more than 50,000 plant species worldwide. Astonishingly, only about 1000 different tree species are utilized globally while the other are either under-utilized, not utilized, or used inappropriately (Sutton, 1999; FAO, 2006). The present human population, estimated at approximately 6.5 billion in 2005 (Aktuell, 2007), has wood consumption needs within the range of 0.3 to 0.6 m^3/year/habitant. As a result, the annual wood and wood based products consumption have been calculated to be around 3.5 billion m^3, approximately 66% of which are hardwoods used mainly as fuel and the rest are softwoods used principally in industry (Youngquist and Hamilton, 1999). Many tree plants are found to be under this categorises, which are under-utilized or used inappropriately. *Terminalia catappa* L plants are found in many places like schools, churches, offices and residential areas, used as shade and fodder for animals grazing.

Terminalia catappa L. is a native species of Southeast Asia. It is presently found in many countries of the tropics, including northern Australia, Pakistan, India, Sri Lanka and many other south Asian countries (Gunasena, 2007). This species gradually extended it origin to Africa, most especially in Nigeria, Ghana, Cameroon and other countries. *Terminalia catappa* L. is commonly used as a shade tree in most of the countries, due to its shape with long horizontal branches and large leaves (Gunasena, 2007). The tree has many properties of multipurpose uses, particularly for medicinal purposes that can be derived from oil made from the seeds and leaves (Gunasena, 2007). The parts of the tree have been used for treating dermatitis, cancer, diabetes and hepatitis in Asia countries (Kinoshita *et al*., 2006 , Gao *et al*., 2004 ,Nagappa *et al*., 2003 and Masuda *et al*., 1999). *Terminalia* L. is a pan tropical genus of at least 200 species, shrubs and trees, many of these species are important tall forest trees. Some are widely grown as shade trees or ornamentals and timber trees in both local and international timber market. These species are Idigbo and Afara (*Terminalia ivorensis* A. Chev and *Terminalia superba* Engl & Diels) Stace and Clive, 2002). The wood of *T. catappa* L. is moderately heavy with a specific gravity of 0.59. It can be air dried easily and used as fuel. The density of the red brown wood is 450 – 720 kg/m^3 at 12% moisture content (Anonymous, 1995). The wood is pale brown to reddish brown and heartwood is light brick red to brownish red, attractive and hard but not very durable. It is commonly used for making furniture, veneer, millwork, and cabin work. It is also used in general construction, bridge ties, flooring and making boxes and crates (Anonymous, 1980; Burgess, 1966). Wood, the major forest products, and a variety of purposes, such as building construction, composite manufacture, pulp and paper products, and a variety of finished materials including furniture, ports, pilings and distribution poles (Kumar and Gupta, 2006). Unknowingly, there are some wood species that are found within the residential area that could also serve the same utilization purposes of endangered wood species but information on the fungi infestation of those wood species are little and insufficient for end users. *T. catappa* being a lesser used wood species with likely higher utilization potentials are widely found in residential areas. Information abound on the physical and agronomical properties of this tree plants (Kumar and Gupta, 2006), however, little information exists about the micro structural features (such as cell wall, fibre lengh, diameter, lumen width, slenderness ratio, flexibility, runkel ratio, luce's shape factor and solid factor.) of *T. catappa.*

This research project aims to provide basic information on anatomical characteristics of *Terminalia catappa* and its effects for pulp and paper production. This will increase the knowledge of the qualities of *Terminalia catappa* for structural application and paper making.

Materials and Methodology

Three stands of *Terminalia catappa of about 18 years were retrieved from the Federal College premises at Ibadan. The boles were processed into samples.* Each sample was prepared into slivers of about 1 cm x 2mm x 2mm. The slivers were macerated in equal volume of ethanoic acid and hydrogen peroxide (1:1) inside an oven at about 100° C for 2 hours. After this the resultant solution was agitated in order to separate it into individual fibres. Using a stage micrometer 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. Sectioning of wood into three planes namely, the transverse, tangential and radial sections was done using a microtone sledge machine. Each thin section was 20µ thick. Microscopic examination was done under a light microscope while wood micrographs were produced using a photo micrographic microscope. The microscopy was performed in accordance with the ASTM D1413-48 of 1983 and ASTM D1413-61 procedure of 2007.

Determination of Anatomical Properties

Wood samples were boiled inside water for about 2 hours to about in order to soften them and eliminate air. Each sample was later sectioned on a sliding microtome; each section was about 20 micrometer thick. Sections were washed with distilled water and covered with safranin stain for two minutes after which the sections were later washed with distilled water until the water became colourless. Dehydration was done by passing the wood sections through a series of bath of increasing concentrations of ethanol which replaced water. The specimens were later put inside clove oil for 1 hour in order to drive off alcohol. The sections were placed on a clean slide, excess clove oil was drained off using filter paper; a slight amount of Canada balsam (a mounting medium and a synthetic substance) was added while the slide was cover with a cover glass and air bubbles were removed by applying heat gently.

The fibre length, fibre diameter and lumen width were measured using a stage micrometer and eye piece micrometer. Cell wall thickness, slenderness ratio, flexibility, runkel ratio, luce's shape factor and solid factor of the fibres were computed from the measured fibre dimensions. 20 fibres were measured from each representative sample in accordance with the ASTM D1413-48 of 1983 and ASTM D1413-61 procedure of 2007. The methods used in processing the data obtained for the appraisal of the study variables incorporated in this study included graphical analysis and analysis of variance. The graphical analysis provides an easy means of observing the trend of any relationship which might exist between the study variables and anatomical properties. All statistical analysis were conducted using 2 x 3 factorial experiment in completely randomized design while the separation of means was done using Duncan Multiple Range Test (DMRT) at 5 % level of probability. The Statistical Package for Social Science (SPSS) version 20.2 was used for the analysis of variance procedures.

Results

Anatomical properties of *Terminalia catappa*

The results obtained for the anatomical properties showed that pores were solitary and diffuse; axial parenchyma cells were predominantly paratracheal, aliform and confluent. Rays were multiseriate (about 4-5 cell wide) and both homocellular and heterocellular type III (Plate 1). Fibre derivatives of *T catappa* in this study are present in Tables 1 and 2. The results for fibre dimensions of *T. catappa* ranged from 1.29 mm to 1.99 mm, 0.02 mm to 0.04 mm, 0.01 mm to 0.02 mm, 0.01 mm to 0.03 mm and 0.19 mm to 0.30 mm for fibre length, fibre diameter, lumen width, cell wall thickness and vessel diameter respectively (Table 1). The mean values of fibre length, fibre diameter, lumen width, cell wall thickness and vessel diameter from stem portion of the tree were as follow; fibrelength:1.99 mm, 1.29 mm and 1.74 mm; fibre diameter: 0.04 mm, 0.04 mm and 0.03 mm; fibre lumen width: 0.01 mm, 0.01 mm and 0.01 mm; fibre cell wall: 0.01 mm, 0.01 mm and 0.03 mm, while 0.27 mm, 0.30 mm and 0.24 mm were recorded for vessel diameter for outer wood, middle wood and core wood (Table 1).

Similarly, the mean values obtained for fibre length, fibre diameter, lumen width, cell wall thickness and vessel diameter from branch portion of *Terminalia catappa* were as follow, fibre length: 1.79 mm, 1.74 mm and 1.88 mm; fibre diametr:0.02 mm, 0.03 mm and 0.04 mm; fibre lumen width: 0.01 mm, 0.01 mm and 0.02 mm; fibre cell wall:0.01 mm, 0.01 mm and 0.01 mm; vessel diameter: 0.19 mm, 0.21 mm and 0.23 mm for the outer wood, middle wood and core wood respectively (Table 1). The results presented in Table 1 show that stem part of the tree had higher vessel diameter than the branch while the core wood of T. catappa had the highest lumen width than the others. The fibre length of *T. catappa* were 1.67 mm and 1.81 mm for stem and branch portions of the wood while the fibre length for outer wood, middle wood and core wood were 1.89 mm, 1.51 mm and 1.81 mm respectively. These values are higher than the values obtained in the previous findings for other wood species (Ogunsanwo 2000, Roger *et al*., 2007, Ogunkunle 2010; Hindi *et al*., 2010). The fibre length obtained in this study was similar to the fibre length of some wood species like; *Rhizophora racemosa* of 1.66 mm; 1.72 mm for *Rhizophora harrisonii* (Emerhi, 2011), 1.57 mm for 42 years old *Hevea brasliensis* (Tembe *et al*., 2010) and 1.73 mm for 20 years old teak (Izekor and Fuwape, 2011). The fibre length values obtained in this study is also higher than the values obtained at 90 % stem portion but agree with fibre length obtained at 10 % of stem portion of merchantable height in the previous studies on *Ricinodendron neudelotti* wood, it was also higher than fibre length of 1.35 mm for *Triplochiton scleroxylon*; 1.29 mm grown *Gmelina arborea* and 1.24 mm for *Ficus* spp (Ogunsanwo 2000 and Ogunkunle 2010). It was observed that fibre length increase from core wood to outer wood (Figure 1), this observation could be explained on the basis of the increase in the length of the cambial initials with increasing cambial age and crown formation (Jorge *et al.,* 2000). The molecular and physiological changes that occur in the vascular cambium during the aging process could also be responsible for the increase in the fibre length (Plomion *et al*., 2001).

It was noticed in the Figure 1, 2 and 4 that the stem and branch of *T. Catappa. This can be attributed to the different status of the portions of the wood.*. The values for cell wall thickness derived from the stem portion were the same for outer wood and middle wood but increase in core wood while in branch portion of the tree, the cell wall thickness for all the portions were the same (Figure 3). Furthermore, the vessels diameter derived from both the stem and branch increase from outer to the core portion of the tree (Figure 5). There are no significant difference in the main factors and two factors interaction at 5 % level of probability for fibre length, fibre diameter and cell wall thickness. Moreover, the variables considered were not significant for lumen width and vessel diameter, were at 5 % level of probability.

The values obtained in this study for fibre diameter of *T. catappa* were higher than the values obtained for wood like *Rhincenoderon*, *Gmelina arborea, Ficus spp, R. Racemosa, R. Harrisonii, Tectona grandis* and *T. scleroxylon* of 41.5 um, 30.67 um, 28.93 um, 36.09 um, 34.24 um, 29.47 um and 20.3 um respectively (Roger *et al*., 2007, Emerhi 2012, Ogunleye *et al*., 2016, Izekor and Fuwape 2011 and Ogunsanwo 2000). The fibre diameters were lower in stem than the branch and decrease in radial directions, which is from outer wood, middle and core wood. Based on this observation, this study therefore agrees with previous finding by Ogunleye *et al*., (2016), Ogunsanwo (2000) and Izekor and Fuwape (2011). And the reason for this trend might be attributed to the influence of cambium age on development and maturation of fibre from pith to bark. The fibre diameter values from the middle and core wood are within the range of values obtained for wood like *Rhince* and *R. Racemosa*. But the cell wall, lumen width and vessel diameters of *T. catappa* appears differently, the values were higher for cell wall and vessel diameters in stem than branch while for lumen width it appeared opposite for both stem and branch. It increases from core wood to outer wood but for lumen width, it increased from outer to core wood (reversing). A similar trend was reported by Izekor and Fuwape (2011) for Teak. The variations in fibre wall and vessel diameter from tree to tree and within individual trees are similar, this patterns of variation correlate with the density of the wood and as a result of the relationship between these two wood properties, the utilization potentials of the wood can as well be known (Bhat *et al*. 1990).

Table 1: Mean Values for the Anatomical Properties of *Terminalia catappa*

Tree parts	Portio n	Anatomical properties				
		Fiber length (mm)	**Fiber diameter (mm)**	**Lumen width (mm)**	**Cell wall**	**Vessel diameter (mm)**
Stem	Outer	1.99 ± 0.19	0.04 ± 0.02	0.01 ± 0.00	0.01 ± 0.01	0.27 ± 0.02
	Middle	1.29 ± 1.05	0.04 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.30 ± 0.01
	Core	1.74 ± 0.06	0.03 ± 0.00	0.01 ± 0.00	0.03 ± 0.05	0.24 ± 0.03
Branch	Outer	1.79 ± 0.08	0.02 ± 0.15	0.01 ± 0.00	0.01 ± 0.00	0.19 ± 0.03
	Middle	1.74 ± 0.11	0.03 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.21 ± 0.04
	Core	1.88 ± 0.06	0.04 ± 0.00	0.02 ± 0.00	0.01 ± 0.00	0.23 ± 0.01

Each valu e represents the mean and standard deviation of 81 samples

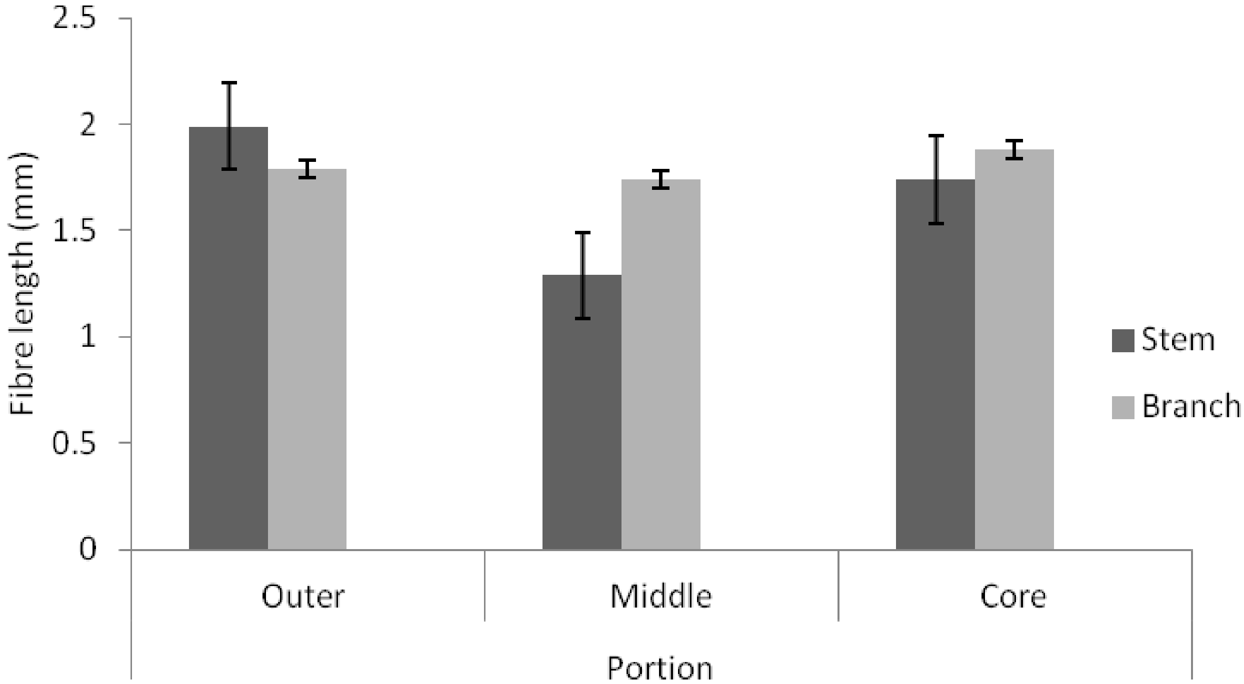

Figure 1: Effect of variables on fibre length

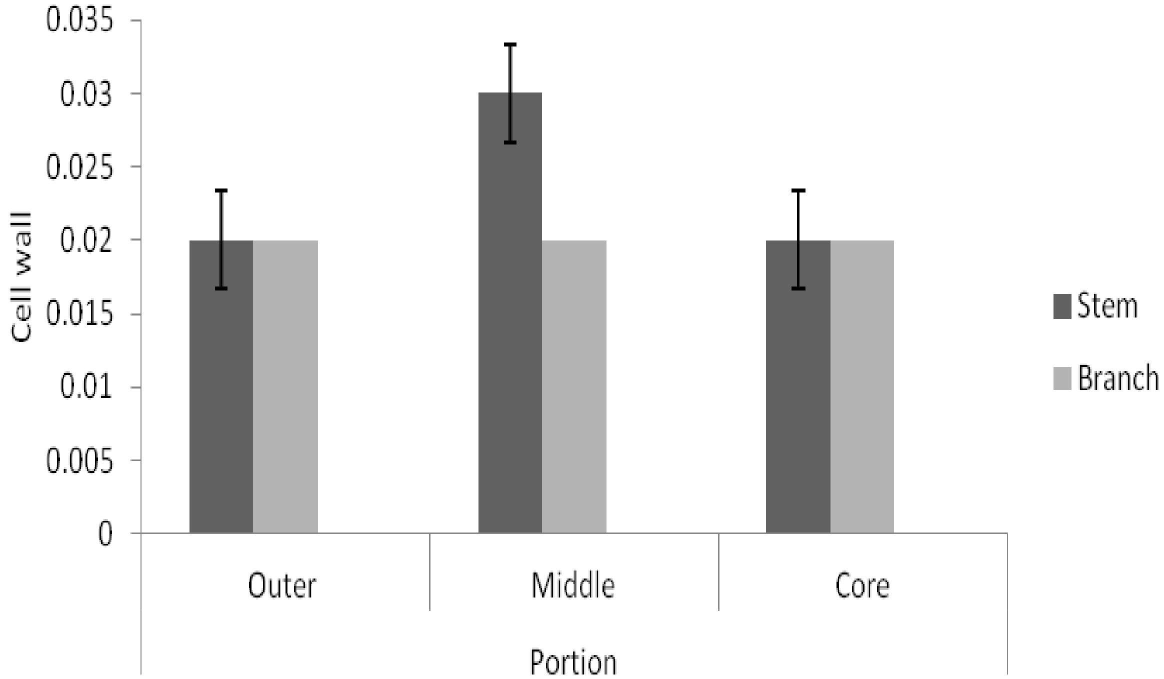

Figure 2: Effect of variables on fibre diameter

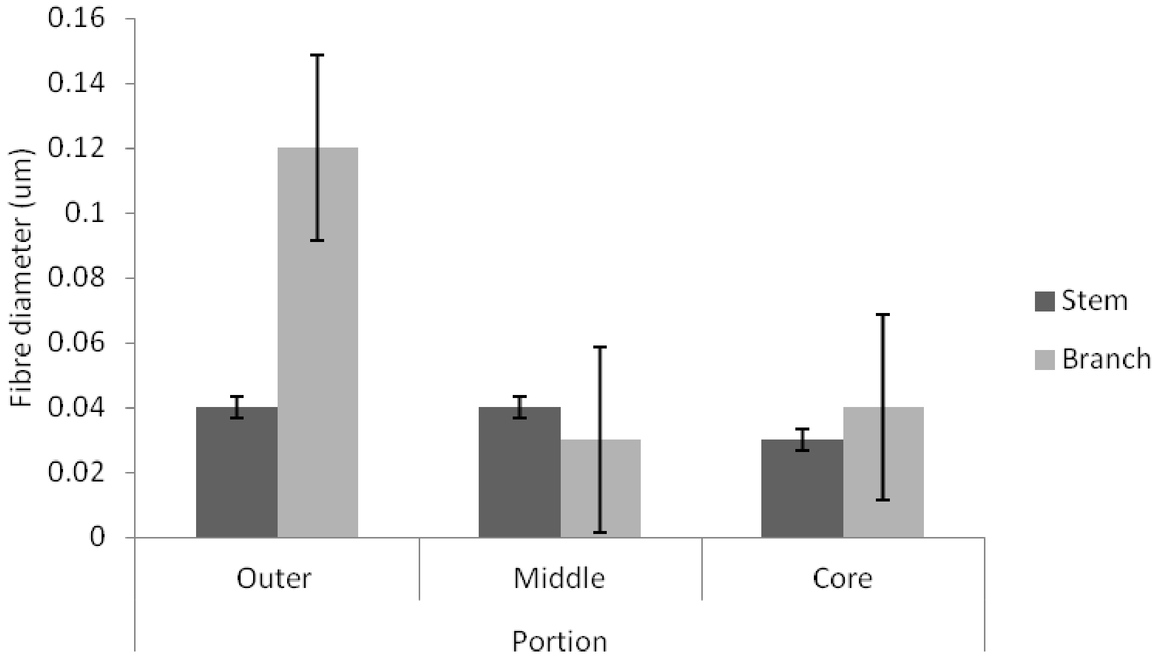

Figure 3: Effect of variables on cell wall

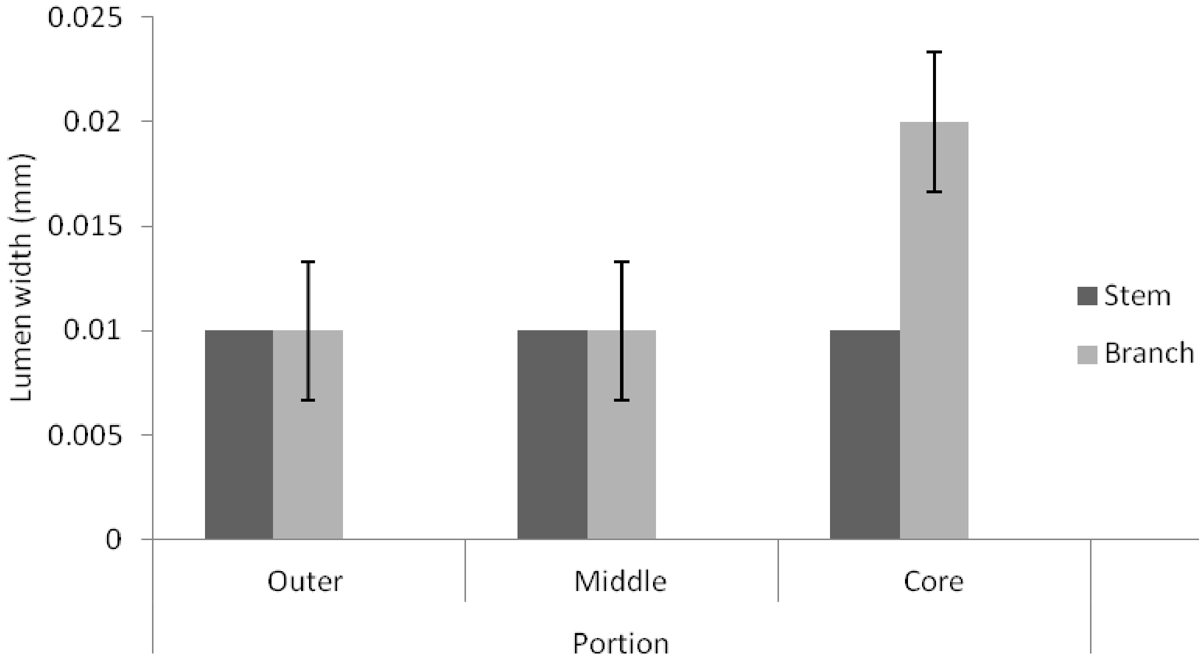

Figure 4: Effect of variables on lumen width

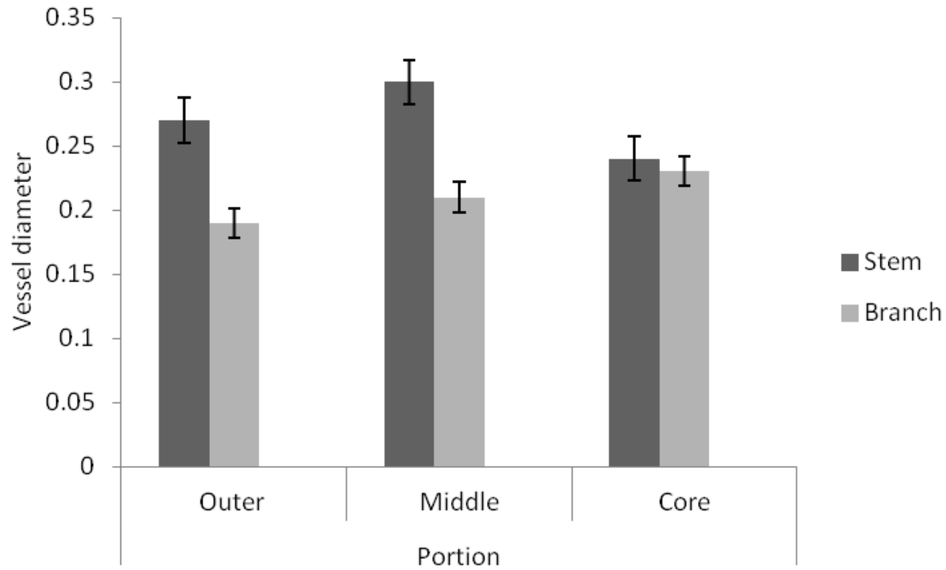

Figure 5: Effect of variables on vessel diameter

Fibre Derivatives of *Terminalia catappa* Plant

The results obtained for the fibre derivatives of *Terminalia catappa* in this study are present in Tables 1 and 2 and with Plates 1 to 6. The properties such as flexibility coefficient, slenderness ratio, Solid factor, runkel ratio and Luce's shape are presented in this study. The mean values obtained for fibre derivatives of *T. catappa* are presented in Table 2. the mean values for slenderness ratio, flexibility coefficient, runkel ratio, Luce's shape and solid factor of *T. catappa* ranged from 40.24 to 59.29, 0.30 to 0.57, 0.94 to 2.52, -0.095 to – 0.267 and 0.001 and 0.004 respectively. The fibre derivative values obtained from the stem portion of *T. catappa* were 45.79, 0.36, 2.06, -0.135 and 0.002 for slenderness ratio, flexibility coefficient, runkel ratio, Luce's shape and Solid factor respectively. The fibre derivative values obtained from the branch portion of the wood were 53.01, 0.45, 1.19, -0.231 and 0.002 for slenderness ratio, flexibility coefficient, runkel ratio, Luce's shape and Solid factor respectively.

In Table 2, the flexibility coefficient, runkel ratio and Solid factor decrease from core wood to outer wood while slenderness ratio and Luce's shape increase from core wood to outer wood. Statistically, there were no significant different in the variables for slenderness ratio, flexibility and solid factor but there were significant different among the variables for runkel ratio and Luce's factor at 5 % level of probability. This implies that the runkel ratio and Luce's factor from stems and branches of *T. catappa* were significantly different to each other. Based on this result, the stem portion of *T. catappa* had higher values in runkel ratio and Luce's factor than the branch portion of the wood (Table 2). The Runkel ratio for *T. catappa* is between the ranges of 0.94 to 8.32 was less than 0.39 for *G. arborea* and fall within 0.26 to 0.68 reported for other *Ficus* species (Ogunkunle 2010). No definite variation was observed with both longitudinal and radial positions. Runkel ratio is a measure of the suitability of fibre for paper production. Higher Runkel ratio fibres form bulkier paper of lower bonded areas in comparison with lower Runkel ratio fibre (Ververis *et al.,* 2004).

The flexibility coefficient values obtained in this study falls within the range of 0.30 and 0.52 for *T.catappa*. As reported by (Smook 1997) the flexibility coefficient values for hardwood and softwoods are 0.55-0.70 and 0.75 respectively, it appears that *T. catappa* falls to hardwood specie and fibres having flexibility coefficient more than 0.75 and between 0.50-0.75 are considered as highly elastic and elastic fibres (Bektas *et al*. 1999). The flexibility ratio of *G. arborea* and *Pinus kesiya* was 0.76 and 0.82 (Sharma *et al*. 2013). It also appears in this study that fibres in *T. catappa* wood are less flexible in stem than the branch. The flexibility coefficient values obtained for branch of *T.catappa* satisfies the requirement for their suitability for pulp and paper production. The slenderness ratio for *T. catappa* in this study was 42.36 to 53.49 which is within the same range of values obtained for *G. arborea of* 50.06 and 42.38 to 71.99 reported for different Ficus species (Ogunkunle 2010). Along the longitudinal plane, slenderness increased from the base to the top while the same pattern of variation was observed across the radial direction from the core wood to outer wood. Nevertheless, low slenderness ratio means production of weak paper; hence t. catappa will produce strong paper like the *G. arborea* and some Ficus species. The Luce's shape factor for *T. catappa* range from 0.09 to 0.27, these values were lower to the values observed by other researchers, Ogunkunle (2010) reported that *Gmelina arborea, Ficus mucuso, F. exasperate had* 0.29, 0.25 and 0.16. Ojo (2013) gave Luce's shape factor for *Gmelina arborea, Afzelia Africana and Detarium senegalense* as 0.20, 0.47 and 0.73, respectively. The data reported by Oluwadare and Sotannde (2007) on *Leucaena lencocephala* gave its Luce's shape factor 0.41. It means that t. catappa wood is suitable for pulp and paper production. The average solid factor for *T. catappa* range from 9 x 10^{-4} to 31.1 x 10^{-4}, this values is lower to the values reported by Ogunleye *et al*., (2016) for *R. heudelotii* wood of 14.2×10^{-3}. The values computed for Solid factor of various wood species were 4.4×10- 4, 2.1×10^{-4}, 1.5×10^{-4}, 1.0×10^{-4}, 4.1×10^{-4} and 1.0×10^{-4} for *Gmelina arborea, Ficus mucuso, F. exasperate, Afzelia Africana, Detarium senegalense and Leucaena lencocephala (*Ogunkunle 2010, Ojo 2013 and Oluwadare and Sotannde, 2007). The Solids factor was found to be related to paper sheet density and could be significantly correlated to breaking length of paper (Ona *et al*. 2001).

Table 2: Mean Values for the Fibre Derivatives of *Terminalia catappa*

Portion	Level	Flexibility coefficient	Slenderness ratio	Solid factors	Runkel ratio	Luce's shape
Stem	Outer	0.34 ± 0.11	47.1 ± 9.93	0.002 ± 0.002	2.21 ± 1.26	-0.12 ± 0.07
	Middle	0.30 ± 0.09	42.36 ± 4.23	0.0019 ± 0.001	2.52 ± 1.04	-0.09 ± 0.06
	Core	0.43 ± 0.11	47.24± 2.40	0.0009 ± 0.0004	1.46 ± 0.75	-0.19 ± 0.09
Branch	Outer	0.31 ± 0.24	42.62± 34.91	0.0313 ± 0.0532	8.32 ± 2.25	-0.10 ± 0.18
	Middle	0.51 ± 0.02	53.49 ± 2.75	0.0006 ± 0.0001	0.96 ± 0.09	-0.26 ± 0.02
	Core	0.52 ± 0.05	46.24 ± 8.94	0.0009 ± 0.0005	0.94 ± 0 .17	-0.27 ± 0.05

Anatomical Features (Qualitative Anatomy) of *Terminalia catappa* wood

Generally, vessels are predominantly solitary and diffuse. MTD (Mean tangential diameter of vessels) was more than 200µ with simple perforation. Axial parenchyma cells were predominantly paratracheal, vasicentric, aliform and confluent. Fibres were medium walled and non-septate. Rays were multi seriate, about 3-4 cell wide, heterocellular Krib's type III. However, gum deposits were more pronounced in the stem of the wood than its branch as seen in Plates 1-6. The wood branch was more of libriform fibres than that of the wood stem.

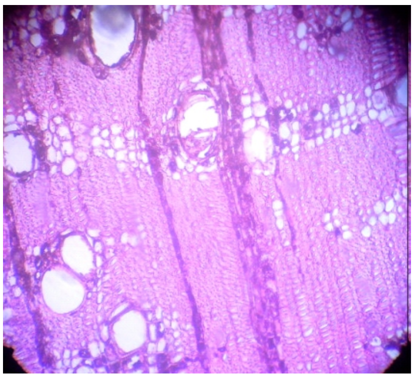

Plate 1: Branch, Tr. Sec.

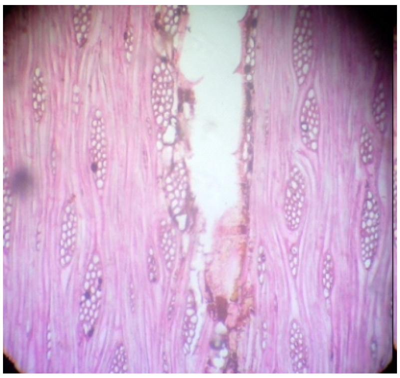

Plate 2: Branch, TLS

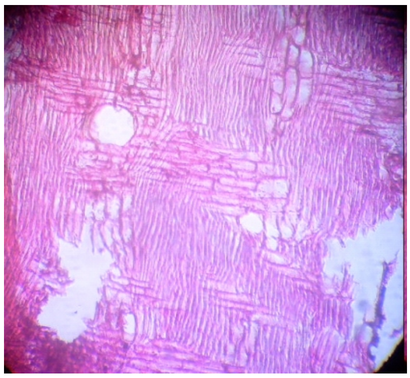

Plate 3: Branch, RLS

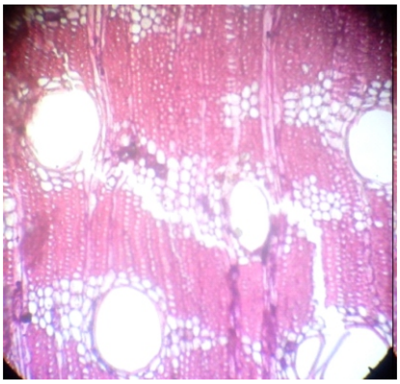
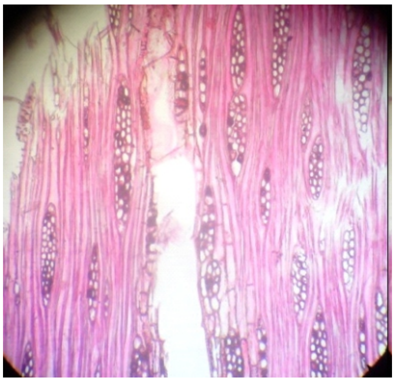
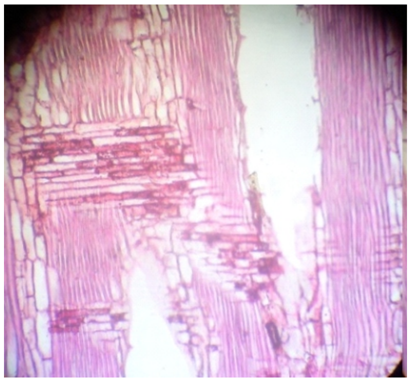

Plate 4: Stem, Tr. Sec. Plate 5: Stem, TLS Plate 6: Stem, RLS

Conclusion

This study revealed the fibre potentials of *T. catappa* for the purpose of producing pulp and paper. The wood with thick cell walls tends to produce paper with a poor printing surface and poor burst strength. Thick-walled cells do not bend easily and do not collapse upon pulping while Thinner-walled cells collapse upon pulping, bond well together chemically, and produce a smoother paper surface. Paper quality and strength are negatively impacted upon with decreased fibre length; thicker cell wall gives a higher pulp yield and increase in tear resistance, give coarse, bulky sheets. In addition, the thicker wall causes decrease in burst and tensile and fold. The thickness of the cell wall had an important bearing on most paper properties. Paper manufactured with thick-walled fibre would be bulky with lower tensile, bust, but with a high tearing strength. The fibres derivatives of Runkel's ratio for *T. catappa* is almost equal to 1 (0.94) and greater than 1 is considered as thick-walled fibres, which are stiffer, less flexible and form a bulky paper sheet of lower bonded area. From this point of view, fibres of *R. heudelotii* wood can be considered as moderately suitable for pulp and paper production because its Runkel ratio is greater than that of *G. arborea*. The results from the anatomical properties and fibre derivatives of *T. catappa* revealed that the wood could be suitable for the production of paper making and it is therefore recommended that plantations of *Terminalia catappa* should be established to support the production of pulp and paper factory in Nigeria. Revitalisations of paper industries in Nigeria require urgent attention for economical buoyant and employment opportunity for the teeming youths.

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