Histochemical Characteristics of *Ricinodedron Heudelotii* (Baill, Pierre Ex Pax) Wood and Its Potential for Pulp and Paper Production

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ABSTRACT*: The chemical (extractives and lignin) content and histological property (microscopic structure) of tissues of Ricinodendron heudelotii (Baill, Pierre ex Pax), an angiosperm, were investigated for its potential as a fibrous raw material for pulp and paper production. Bolts of about 70 cm were cut from the felled trees at three different merchantable height levels of 10%, 50%, and 90% to obtain: corewood, middlewood and outerwood samples. The fiber characteristics of the selected trees viz: the fiber length, fibre diameter and lumen diameter were measured while the cell wall thickness was derived from the measured fibre dimensions. The average fiber length, cell wall thickness, and lumen width, were 1.40 mm, 4.6 µm, and 32.3 µm, respectively. The extractive and lignin contents were determined. Klason lignin content was about 30%. Extractive content of R. heudelotii ranged from 0.41 to 0.5%. Based on these findings R. heudelotii is suitable for pulp and paper production.*

I. INTRODUCTION

The continued production of pulp and paper and in large quantity are essential to meeting the increasing demand for paper consumption. It was estimated that global paper consumption will increase to 500 million tons by 2020 instead of its present consumption estimate of 400 million tons per year [1]. Deforestation at an alarming rate with unmarching afforestation rate and cost of importation of conventional raw material for pulp and paper production are a wake up call that has aroused the interest of wood scientists in expanding the fibrous raw materials sources. Increasing the range of fibrous raw material source is a central component of current efforts to increase fibre supply for pulp and paper production [2]. Therefore, the investigation for potential utilisation of some naturally grown wood species in the Nigeria as fibrous raw material for pulp and paper production is a right step towards mitigating the challenges associated with importation of pulp. The two most important parameters which determine suitability of wood as raw material for pulp and paper production are its fibre characteristics and chemical composition [3]. The morphological properties of fibre are related to paper strength while the amount of chemical composition is mainly related to pulping behaviour.

In the pursuit of recommending any wood species for pulp production, obtaining adequate anatomical and chemical (extractive and lignin content) properties is very important. The relationship between the anatomical or chemical properties and paper performance has been investigated by several researchers. Horn and Setterholm [4] found that the majority of The fibre length and cell wall thickness were attributed to the variation observed in the burst and tensile strength of the hardwood pulp sheets.

The unique structural and chemical characteristics of wood make it desirable multipurpose applications [5]. Wood is used pulp and paper production, but its chemical composition affects some pulping parameters: cooking liquor consumption, bleaching potential, and its consequent pulp yield. It could be assumed that, in order to optimise the selection of a particular tree species for various end-uses, a basic knowledge of its structure and chemical composition is of great importance [6]

Furthermore, the physical attributes of fibres, such as fibre length, cell wall thickness and diameter are major determinants of pulp and paper qualities, including brightness, opacity, absorption, light scattering, tear, tensile and burst strength. Therefore, wood quality is of critical importance to the wood products (paper) industry [7]. The importance of wood fibre dimensions on pulp and paper's mechanical strength is well documented [8,9]. Madakadze *et al.* [9] found that lignin and cellulose content dictates the paper strength; cellulose content is directly proportional to pulp tensile strength. Removal of lignin will enhance the paper strength, however, energy and chemicals cost will be high when high quantity of lignin is to be removed. Apart from the challenge associated with lignin, wood extractives has been found to adverse effect on the production and production site of the pulp and paper industry [10]. These challenges include: higher operating costs, blockages (responsible for production reduction levels), and an increased incidence of quality defects [11]. The viscous lumps that accumulate on equipment during pulp and paper production are referred to as pitch, which contains considerable amounts of wood lipophilic compounds [12]. Lipophilic compounds, which have different chemical behavior during and after pulping, consist of fatty acids, waxes, resin acids, terpenes, alcohols, sterols, sterol esters and glycerides [13]. For example, resinous woods are associated with the pitch control problem while some lipophilic extractives are difficult to remove in neutral to acidic process condition [14]. Conversely, the composition of the extractives play a significant role during the alkaline process, especially in kraft process than the total extractives content [15]. Waxes, sterols and sterol esters have a tendency to cause deposit accumulation resulting in pitch problem because they do not form soluble soaps under the alkaline conditions in kraft pulping [16].

Unfortunately, there is little or no detail information available on the use of *R. heudelotii* as potential source of pulp production. Therefore, this study seeks to investigate the potentials of this wood species for pulp and paper production by characterising its chemical and histological properties. However, the short fibre characteristic of hardwood species is a challenge.

II. MATERIAL AND METHODS

The *Ricinodedron heudelotii* wood was used for this study. It was obtained from a free, natural forest at Ilaramokin, Ondo State. The forest is located between 7.321°N 5.145°E and 7.389°N 5.097°E of Ondo state, Nigeria. Three trees were selected and felled for this study based on ASTM 143-14 [17]. Wood samples were obtained at different sampling height of 10, 50 and 90% of the merchantable height from the corewood, middlewood and outerwood regions for both chemical and histological studies. The bolts were sawn through the pith into four parts while three radial positions from each part: core-wood, middle-wood and outer-wood were obtained (Fig. 1).

2.1. Histological properties

Studies on microscopic structure of *R. heudelotii* tissues were carried out in accordance with the ASTM D 1030-95 [18] and ASTM D 1413-61 [19] at the Forestry Research Institute of Nigeria (FRIN), Jericho, Ibadan. Wood samples were obtained at different sampling height of 10%, 50% and 90% of the merchantable height (MH) from the corewood (CW), middlewood (MW) and outerwood (OW) regions. The samples were prepared into slivers of 3 mm (thickness) × 10 mm (width). The slivers were softened in a solution of acetic acid and hydrogen peroxide (1:1), boiled in a water bath at a temperature of 100°C for 10 minutes in accordance with a procedure adopted by Ogbonnaya *et al.* [20]. Random selected of some softened fibres were was employed while the selected fibers were mounted on slides for examination under a Reichet microscope. A stage micrometer and an eye piece micrometer were used to measure the fibres length, fibre diameter and lumen diameter. The cell wall thickness was derived from the measured fibre dimensions in accordance with Jorge *et al.* [21], with the total fiber samples, n = 20 per slide.

2.2. Lignin composition

The extractive and lignin contents were determined based on the original wood. Pulverized wood samples (5 g of known moisture content, in duplicate) were Soxhlet extracted with dichloromethane (CH_2Cl_2) (150 mL) for 16 h according to ASTM D 1108 [22] and lipids were determined gravimetrically. Klason + acid soluble lignin were performed on extractives free samples according to ASTM D 1106 [23] and Schoening and Johansson [24], respectively. Extractives free biomass (200 mg) was incubated in 72% H_2SO_4 (2 mL) for 1 h at 30°C, then diluted to 4% H_2SO_4, and subjected to a secondary hydrolysis in an autoclave (117 KPa and 121°C) for 30 min. Klason lignin was determined gravimetrically. The hydrolysis filtrate was made up to 250 mL and an aliquot portion taken to determine acid soluble lignin content at 205 nm using an absorption coefficient of 110 L g^{-1} cm^{-1}.

III. RESULTS AND DISCUSSION

3.1. Lignin content

Table 1 shows the average lignin content of *R. heudelotii* wood. Klason lignin content ranged between 29.3% at 50% MH for CW and 31.6% at 90% MH for OW (Table 1). Acid soluble (AS) lignin content ranged between 6.4 at 10% MH for CW and 7.4 at 10% MH for OW**.** The total average of the lignin content was 37.3%, which is higher than the total lignin content of 23.9%, 26.8%, 25.9% and 27.7% for *Eucalyptus globulus, Acacia*, Maple and Red oak, respectively [25]. Although, there was no particular trend of variation along and across the radial position observed in this study; lignin content values were similar among the selected trees and within the wood of *R. heudelotii*. The findings in this study were similar to those reported by Carrillo-Para, [26] for *Prosopis laevigata* (29.8 - 31.4%), Marques *et al.* [27] and Sixta *et al.* [28] for some hardwood species (18.2 - 30.9%). Prinsen *et al.* [29] estimated approximately 24 - 25% Klason lignin for some selected eucalypt hybrids. Lignin content of *R. heudelotii* is higher than what was reported by Ogunjobi *et al*. [30] for Gmelina (28%).

Since Gmelia is popularly known for pulp and paper production, the higher Klason lignin content of *R. heudelotii* (29.8-31.1%) than that of Gmelina would require a higher temperature and chemical charges than for pine and Gmelina wood in order to reach a satisfactory kappa number. Note that hardness, bleachability and other pulp properties are associated with the lignin content [31]. The consumption of cooking liquor and the length of the cooking cycle are dictated by the quantity of lignin in fibrous raw material, therefore, higher lignin content requires additional pulping time and chemical charge. For the production of high quality pulp, *R. heudelotti* pulp will need to undergo more severe bleaching with utilization of more chemicals which will be detrimental to pulp. However, one of the advantages that would associate with the high Klason lignin content of *R. heudelotti* pulp is that its stifness would be better than for Gmelina fiber: the higher the lignin content, the greater the stiffness of the fibres [31].

3.2. Extractive content

Wood extractive (lipophilic) of *R. heudelotii* ranged from 0.41 at 90% merchantable height for corewood to 0.50 at 50% for outerwood and corewood of the merchantable height with average of 0.48% (Table 2). The value obtained in this study is relatively low compared to the range of 1.0-3.9% recorded in some hardwood species [28,32,33]. TAPPI [34] states that CH_2Cl_2 extraction gives lower amounts of extractives than either acetone or ethanol/benzene. However, lipophilic (the targeted extractives in this study) was still relatively low compared to 0.9% recorded for grey alder (*Alnus incana*) wood by Bikovens *et al*. [35]. There was no specific pattern of variation in the lipophilic extractive content of *R. heudelotii* wood from base to top while the variation from outerwood to corewood was not significant. This is contradictory to the finding of Koch [36] for *Pinus palustris* in which the extractives content decreased from pith to bark. The large concentration of resin near the pith was attributable to an abundance of resin ducts that occur in the first few rings in southern pine [37]. The within ring variation was attributed to the high variation in extractives content. In fact, distinct visual differences in color is observed at every 10 mm interval within a wood ring. This is quite different with *R. heudelotii* wood because the visual observation revealed that the colour of the wood from the base to top and CW to OW did not differ; so it could be deduced that there is no region with high deposition of resin than the other. From chemical pulping point of view, the higher the lipophilic content, the more expensive (demand for large quantity of chemicals) the pulping, therefore, the low quantity of lipophilic content in *R. heudelotii* wood makes it suitable for pulp production. Also, the insignificant variation from corewood to outerwood reveals that any part of this wood species could be used for pulp production without special consideration for any part during pulping.

3.3. Fiber dimension

The fibre length, fibre diameter, lumen width and cell wall thickness of 1.40 mm, 41.5 µm, 32.3 µm, and 4.6 µm, respectively as illustrated in Fig. 2 and 4. The fibre length obtained for *R. heudelotii* wood is in agreement with previously published studies on other wood species [38-42]. The average fibre length (1.36 mm) observed in this study is greater than 1.29 mm for *Gmelina arborea* reported by Roger *et al*. [40]; 1.35 mm for *Triplochiton scleroxylon* by Ogunsanwo [39]; 1.28 mm and 0.99 - 1.24 mm for *G. arborea* and Ficus spp, respectively by Ogunkunle [41]. However, it is less than 1.66 mm for *Rhizophora racemosa* and 1.72 mm for *R. harrisonii* [42], 1.57 mm for 42 years old *Hevea brasliensis* [43], 1.73 mm for 20 years old Teak [44] and 1.76 mm and 1.54 for R*hizophora racemosa* and *R. harrisonii* in a Nigerian mangrove forest ecosystem [42]. Hindi *et al*. [45] reported that fibre length of 1.13 mm, 1.04 mm and 0.50 mm recorded for *Leucaena leucocephala, Azadirachta indica* and *Simmondsia chinens*, respectively. Since, the strength of the pulp and paper produced from the same fibrous material are affected by the length of fibre [46], paper made from *R. heudelotii* is expected to show higher quality than the others woods like *L. leucocephala, A. indica* and *S. chinens* with shorter fibres. Higher fibre length results in greater resistance of the paper to tearing [47].

The longitudinal variation of wood fibre length was characterised by a slight decrease from the base to the top (Fig. 2). This is in agreement with some previous studies [21, 39]. The theory of auxin gradient also holds for this pattern of variation in the fibre length similar to that of wood density. In relation to the radial variation of fibre length, a significant increase from Corewood to outerwood was observed. This trend was also observed [21, 39, 48]. Additionally, Tomazello and Filho [49] and Bhat *et al*. [50] also found the same trend of radial variation in *Eucalyptus spp*. The increase of fibre length from corewood to outerwood could be explained on the basis of the increase in length of cambial initials with increasing cambial age and crown formation [21].

Fibre diameter decreased from base to top while a general increase from corewood to outerwood (Fig. 3). The fibre diameter (41.5 µm) of *R. heudelotii* wood compares favorably with *Pinus patula* (36.0 – 40.0 µm) reported by PPRI [51]. However, it is lower than that of teak and *Gmelina arborea* grown in Nigeria, which were 32.83 µm [44] and 23.57 [41], respectively. Since Pine is used for commercial paper production, *R. heudelotii* wood could also be recommended for paper production based on its fiber diameter.

The lumen width (diameter of the internal cavity) at the middle and top as well as at middlewood and corewood are similar (Fig. 3). The *R. heudelotii* lumen width (32.3 µm) observed in this study is greater than the value reported by Ogunkunle [41] for *G. arborea* and different Ficus species which were 20.06 µm and 18.69 - 28.93 µm, respectively. However, it compared favorably with 30.67 µm reported by Roger *et al.* [41] for *G. arborea*. The lumen width affects the beating of pulp. Large lumen width enhances liquid penetration into the fiber, thereby causing better beating [43]. The fiber of *R. heudelotii* wood would have better beating than *G. arborea*.

Cell wall thickness decreased from base to top longitudinally while a general increase from corewood to outerwood was observed radially (Fig. 4). The cell wall thickness of *R. heudelotii* (4.6 µm) is comparable with the value reported by Roger *et al.* [40] for *G. arborea* (4.02 µm). It is less than 8.58 µm and 9.45 µm for *Rhizophora racemosa* and for *R. harrisonii* [42]. Paper properties are dictated by the cell wall thickness. Fibers with thin cell walls will easily collapse more thank thick cell walls, thereby enhances large surface area for bonding, yields a higher density and reduces bulkiness [52]. Consequently, the produced paper from such collapse fibers will be well formed and dense, then will be characterized with a higher tensile strength, tensile stiffness, burst strength, and compression strength. However, high porosity and bulkiness will characterize the thick cell wall (uncollapsed fibres). The benefits associated with paper produced from the uncollapsed fibers is that of easy dewatering and high tear strength. So, based on the high cell wall thickness, this species will be suitable for pulp and paper production.

IV. Figures and Tables

Table 1: The value of lignin content in *R. heudelotii* wood.

Radial Position	Base (10%)	Middle (50%)	Top (90%)	Pooled Mean
Klason lignin				
Outer-wood	30.81±1.16	30.71±1.46	31.64±0.52	**31.06±0.51**
Core-wood	29.95±1.36	29.32±2.75	30.07±0.86	**29.78±0.41**
Pooled Mean	**30.38±0.61**	**30.01±0.98**	**30.86±1.11**	**30.42±0.42**
Acid Soluble lignin				
Outer-wood	7.38±0.27	6.36±0.87	7.01±0.53	**6.92±0.52**
Core-wood	7.11±0.91	6.49±1.20	7.18±1.37	**6.93±0.38**
Pooled Mean	**7.23±0.19**	**6.42±0.90**	**7.10±0.12**	**6.92±0.44**

Table 2: Variation in the extractiveh content of *Ricinodendron heudelotii* wood.

Radial Position	Base (10%)	Middle (50%)	Top (90%)	Pooled Mean
Extractive (lipophilic content)				
Outer-wood	0.47±0.14	0.50±0.07	0.47±0.18	**0.48±0.02**
Core-wood	0.49±0.22	0.50±0.13	0.41±0.19	**0.47±0.04**
Pooled Mean	**0.48±0.01**	**0.50±0.00**	**0.44±0.04**	**0.48±0.00**

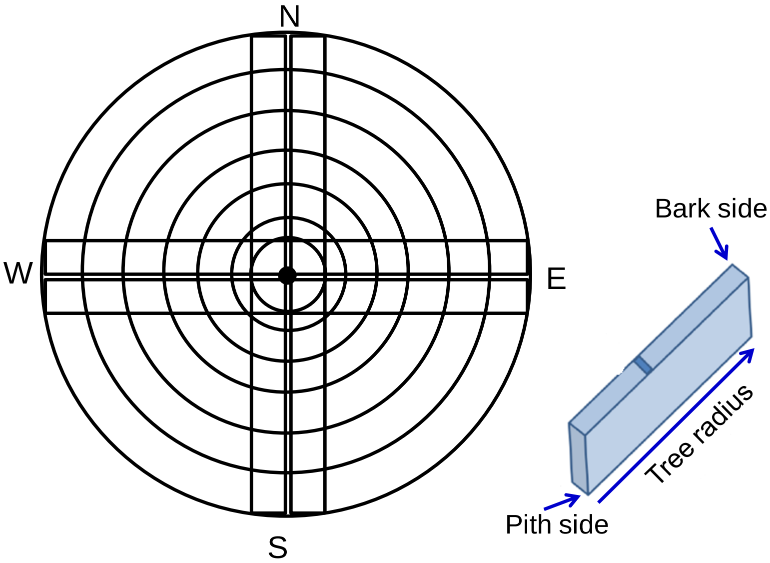

Fig. 1. Sketch showing method used in cutting samples for testing.

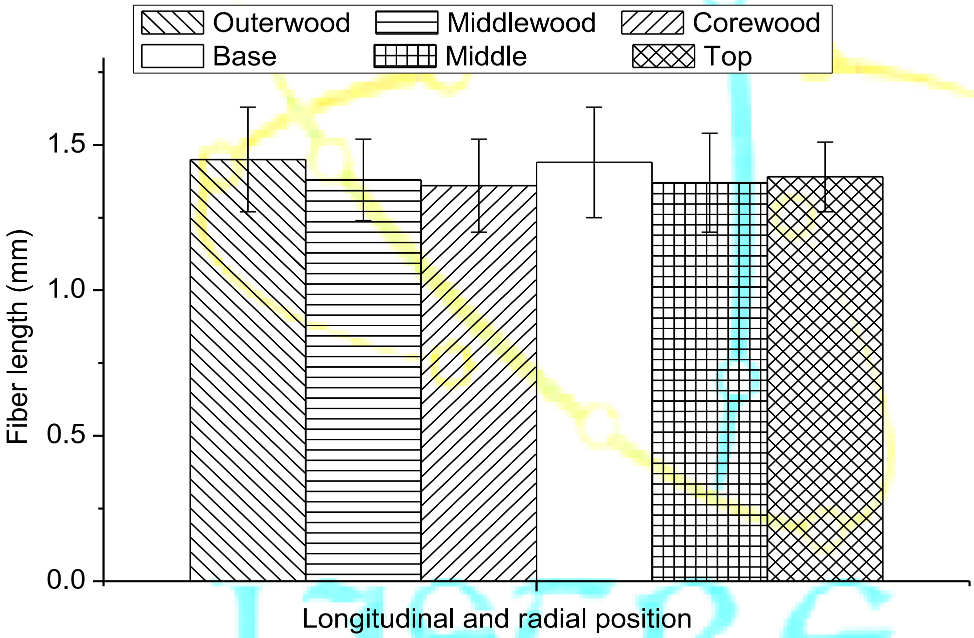

Fig. 2: Variations in the fiber length in the longitudinal and radial positions of Ricinodedron heudelotii wood

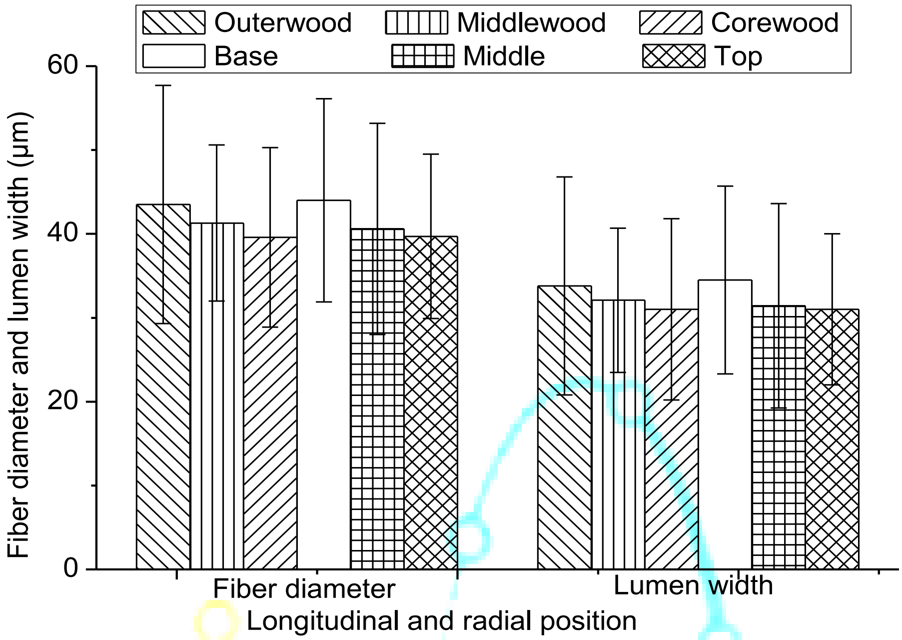

Fig. 3: Variations in the fiber diameter and lumen width in the longitudinal and radial positions of Ricinodedron heudelotii wood

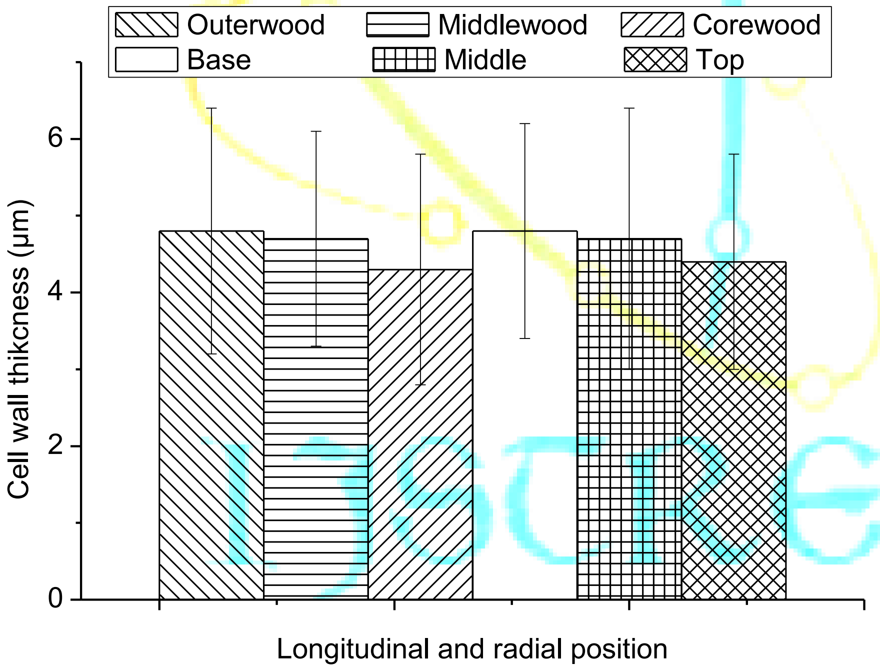

Fig. 4: Variations in the cell wall thickness in the longitudinal and radial positions of Ricinodedron heudelotii wood

V. Conclusion

In this study, *Ricinodendron heudelotii* was chemically and histologically evaluated for its potential as a fibrous raw material for pulp and paper production. Lipophilic (extractive) content was of low quantity in *R. heudelotii* wood compared to Gmelina and pine. The lignin content of *R. heudelotii* was higher than mostly reported value for *G. arborea*; therefore it will require a higher temperature and more chemical charges to reach a satisfactory kappa number. Based on its lignin content, it will also produce fibres with greater stiffness, but its pulp will have to undergo more severe bleaching with utilisation of more chemicals. However, the low lipophilic content makes it suitable for pulp production. In addition, *R. heudelotii* wood can be considered as suitable for pulp and paper production when its chemical characteristics were compared to that *Gmelina arborea* and *Eucalytpus species*, which have been in use in pulp industry worldwide. However, The basic information on the fiber characteristics of *Ricinodedron heudelotii* for possible utilisation as a source of fibrous raw material for pulp and paper production investigated revealed that wood fibre length, cell wall thickness and lumen width decreased from the base (10% merchantable height) to top (90% merchantable height). The fibre length observed in this study was longer than 1.29 mm for *Gmelina arborea.* Hence, it would produce a paper that has greater resistance to tearing than that of *G. arborea*. However, since it has longer fibres than that of Gmelina, more open and less uniform sheet structure would be produced from it. Its fibre diameter, lumen width and cell wall thickness are larger than that of *G. arborea.* So, since the larger lumen width gives better pulp beating because of the penetration of liquid into empty spaces of the fibres, *R. heudelotii* would be preferred to that of *G. arborea*. Thicker cell wall *R. heudelotii* would give a higher pulp yield and an increase in tear resistance, but, bulky sheets than *G. arborea.*

REFERENCES

[1] M.Sharma, L. Sharma, and Y. B. Kumar. Evaluation of fibre characteristics in some weeds of Arunachal Pradesh, India for pulp and paper making. *Research Journal of Agriculture and Forestry Sciences 1(3)*, (2013), 15-21.

[2] Markets Initiative. Environmental leadership in the paper supply chain. The new paper fibre basket. Trend Report, (2007): 9.

[3] T. Kayama. Pulping and paper making properties and wood properties of tropical hardwoods. *Forpride Digest*, 8, (1979):42-59.

[4] R.A.Horn, and V.C. Setterholm. Fiber morphology and new crops. In: Janick, J., Simon, J.E. (Eds.), Advances in New Crops. Timber Press, Portland, OR, (1990): 270–275.

[5] A. Raimo. Forest products chemistry, structure and chemical composition of wood. (2000): 12-57.

[6] A. O. Oluwadare. Wood properties and selection for rotation length in Caribean pine (*Pinus caribaea* Morelet) grown in Afaka, Nigeria. *American-European Journal of Agricultural Environment and Science*, *2(4)*, (2007): 359-363.

[7] M. Du-Plessis. A fibre optimisation index developed from a material investigation of *Eucalyptus grandis* for the Kraft pulping process by. Dissertation presented for the degree of Doctor of Forestry (Wood Products Science) at the University of Stellenbosch. (2012)

[8] R. M. Kellogg, and E. Thykeson. Predicting kraft mill paper strength from fiber properties. *TAPPI Journal 58(4)*, (1975):131-135.

[9] I. C. Madakadze, T. Radiotis, J. Li, K. Goel, and D. L. Smith. Kraft pulping characteristics and pulp properties of warm season grasses. *Bioresource Technology*, *69*, (1999): 75–85

[10] L.H. Allen. Pitch control during the production of aspen kraft pulp. *Pulp and Paper Canada 89(10)*, 1988:87–91.

[11] W.E. Hillis, and M. Sumimoto. Effect of extractives on pulping. *In*: Natural Products of Woody Plants II. Ed. J.W. Rowe. Springer-Verlag, Berlin, 1989.pp. 880–920.

[12] D.B. Mutton,. Wood resins. *In*: Wood Extractives. Ed. W.E. Hillis. "Academic Press, New York, 1962 pp. 331-363).

[13] E. Sjöström. *Wood Chemistry Fundamentals and Applications (2nd edition)*. (San Diego, CA: Academic Press, Inc. 1993)

[14] A. Gutiérrez, J.C. del Río, F.J. González-Vila, and F. Martín. Chemical Composition of Lipophilic Extractives from *Eucalyptus globulus* Labill. Wood. *Holzforschung, 53,* (1999):481– 486

[15] D. Dunlop-Jones, N. H. Jialing, and L.H. Allen. An analysis of the acetone extractives of the and bark from fresh trembling aspen: Implications for deresination and pitch control. *Journal of Pulp Paper Science 17(2)*, (1991):J60–J66.

[16] R. Leone, and C. Breuil. Filamentous fungi can degrade aspen steryl esters and waxes. *International Biodeterioration and Biodegradation 41*, 1998:133–137.

[17] American Society for Testing and Materials (ASTM). ASTM D143-14. Standard Test Methods for Small Clear Specimens of Timber, ASTM International, West Conshohocken, PA, 2014.

[18] American Society for Testing and Materials (ASTM). ASTM D 1030-95 - Standard test method for fibre analysis of paper and paperboard. West Conshohocken, PA. 2007.

[19] American Society for Testing and Materials (ASTM). ASTM D1413-61 - Preparation of decayed wood for microscopical examination, ASTM International, West Conshohocken, PA, 2007.

[20] C. I. Ogbonnaya, H. Roy-Macauley, M. C. Nwalozie, and D. J. M. Annerose. Physical and histochemical properties of kenaf (*Hibiscus cannabinus* L.) grown under water deficit on a sandy soil. *Industrial Crops and Production*, 7, (1997): 9–18.

[21] F. Jorge, T. Quilho, and H. Pereira. Variability of fibre length in wood and bark in *Eucalyptus globules. IAWA Journal 21(1),* (2000):41-48.

[22] American Society for Testing and Materials (ASTM). ASTM D1108 - 96 - Standard Test Method for Dichloromethane Solubles in Wood, ASTM International, West Conshohocken, PA. (2013)

[23] American Society for Testing and Materials (ASTM). ASTM D1106-96 - Standard Test Method for Acid-Insoluble Lignin in Wood, ASTM International, West Conshohocken, PA. (2013)

[24] A.G. Schoening, and G. Johansson. Absorptiometric determination of acid-soluble lignin in semichemical bisulfite pulps and in some woods and plants. *Svensk Papperstid. 68,* (1965):607-613.

[25] R. B. Santos, E. A. Capanema, M. Y. Balakshin, H. M. Chang, and H. Jamel. Lignin structural variation in hardwood species. Proceedings of the 16th ISWFPC, Tianjin, China, June 8-10, (2011)

[26] A. Carrillo-Para. Technological investigation of *Propis laevigata* wood from Northeast Mexico. Ph.D. dissertation. Faculty of Forest Sciences and Forest Ecology, University of Göttingen. (2007) 149P.

[27] A. P. Marques, D. V. Evtuguin, S. Magina, F. M. L. Amado, and A. Prates. Chemical composition of spent liquors from acidic magnesium-based sulphite pulping of *Eucalyptus globulus*. *Journal of Wood Chemistry and Technology 29,* (2009):322–336.

[28] H. Sixta, A. Potthast, and A. W. Krotschek. Chemical pulping processes. *In Handbook of Pulp*. Sixta H. (ed.) Wiley-VCH. Verlag, (2006): 109–366.

[29] P. Prinsen, A. Gutiérrez, J. Rencoret, L. Nieto, J. Jiménez-Barbero, A. Burnet, M. Petit-Conil, J. L. Colodette, Á. T. Martínez, and J. C. del Ríoa. Morphological characteristics and composition of lipophilic extractives and lignin in Brazilian woods from different eucalypt hybrids. *Industrial Crops and Products 36*, (2012):572–583

[30] K.M. Ogunjobi, A.C. Adetogun, and A.O. Omole. Assessment of variation in the fibre characteristics of the wood of *Vitex doniana* sweet and its suitability for paper production. *Journal of Research In Forestry, Wildlife And Environmental, 6(1),* 2014: 39-51.

[31] D. Dutt, J. S. Upadhyaya, B. Singh and C. H. Tyagi. Studies on Hibiscus cannabinus and Hibiscus sabdariffa as an alternative pulp blend for softwood: An optimsation of kraft delignification process. *Industrial Crops and Products 29,* (2009):16-26.

[32] C. Conde-Mejia, A. Jimenez-Gutierrez, M. A. El-Halwagi.Comparison of pre-treatment methods for bioethanol production from lignocellulosic materials. *Process Safety and Environmental Protection, 90,* (2012):189–202.

[33] DN.-S. Hon, N. Shiraishi. Wood and cellulosic chemistry. (New York, USA: Marcel Dekker. 2001)

[34] Technical Association of Pulp and Paper industry (TAPPI 204 om-97). Solvent extractives of wood and pulp (Proposed revision of T 204 cm-97). Atlanta, GA (2007):1-6.

[35] O. Bikovens, L. Roze, A. Pranovich, M. Reunanen, and G. Telysheva. Chemical composition of lipophilic extractives from grey alder (*Alnus incana*). *BioResources, 8(1),* (2013):350-357.

[36] P. Koch. Utilization of southern pines. Agricultural Handbook 420:188-189. USDA Washington, USA. (1972).

[37] Larson, P.R., Kretschmann D.E., Clark III A. and Isebrands J.G. (2001). Formation and properties of juvenile wood in southern pines: a synopsis. Gen. Tech. Rep. FPL-GTR-129. 49 pp

[38] I. E. Kherallah, and H. I. Aly. Fibre length, specific gravity and chemical constituents of two tropical hardwood peeler logs. *Journal of King Saud University,* 1, (1989): 103-112.

[39] O.Y. Ogunsanwo. Characterisation of wood properties of plantation grown Obeche (*Triplochiton scleroxylon*) in Omo Forest Reserve, Ogun State. Ph.D. thesis. Dept of Forest Resources Management, University of Ibadan. (2000) 253P.

[40] M. R. Roger, T. F. Mario, and C. A. Edwin. Fibre morphology in fast growth *Gmelina arborea* plantations. *Madera Bosques, 13(2),* (2007):3-13.

[41] A. T. J. Ogunkunle. A Quantitative modelling of pulp and paper making suitability of Nigerian hardwood species. *Advances in Natural and Applied Sciences*, *4(1),* (2010):14-21.

[42] E. A. Emerhi. Variations in anatomical properties of *Rhizophora racemosa* (Leechm) and *Rhizophora harrisonii* (G. Mey) in a Nigerian mangrove forest ecosystem. *International Journal of Forest, Soil and Erosion, 2(2),* (2011): 89-96

[43] E. T. Tembe, J. I. Amonum, and S. A. Shomkegh. Variations in the fibre length of rubber wood (*Hevea brasiliensis* (Kunth) Muel Arg) grown in south eastern Nigeria. *Journal of Research in Forestry, Wildlife and Environment,* 2(2), (2010):214-220

[44] D. N. Izekor, and J. A. Fuwape. Variations in the anatomical characteristics of plantation grown *Tectona grandis* wood in Edo State, Nigeria. *Archives of Applied Science Research, 3(1),* (2011): 83-90

[45] S. S. Hindi, A. A. Bakhashwain, and A. El-Feel. Physico-chemical characterization of some Saudi lignocellulosic natural resources and their suitability for fibre production. *JKAU: Meteorology, Environment* and *Arid Land Agriculture, 21(2),* (2010): 45-55.

[46] K. A. Kaila, and J. Aittamaa. Characterization of wood fibres using fibre property distribution. *Chemical Engineering and Processing, 45,* (2006):246-254.

[47] A. O. Oluwadare, and O. A. Sotannde. The relationship between fibre characteristics and pulp-sheet properties of *Leucaena leucocephala* (lam.) De Wit. *Middle-East Journal of Science Resources, 2(2)* (2007): 63-68.

[48] T. F. Shupe, E. T. Choong, D. Stokke, and D. M. Bibson. Variation in the cell dimensions and fibril angle for two fertilized even-aged loblolly pine plantations. *Wood and Fibre Science, 28(2),* (1996):268-275.

[49] F. Tomazello, and M. Variacano. Radial density and basic anatomical structure of wood *Eucalyptus globules, E. pellita* and *E. acmenioides* Inst. Pesq. Estud. Forest, Piracicaba, (1987) 36P.

[50] K. Bhat, K. Bhat and T. Dhamdodaran. Wood density and fibre length of *Eucalyptus grandis* grown in Kerala, India. *Wood and Fibre Science 22(1),* (1990): 54-61.

[51] PPRI (Pulp and Paper Resources and Information). Paper on the web. http:www.paperonweb.blogspot.com/ visited 28 August, 2017.

[52] A. Johansson. Correlations between Fibre Properties and Paper Properties. Master's Thesis, Royal Institute of Technology (KTH), Stockholm, Sweden. 2011.