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Research Paper

VARIATIONS IN ANATOMICAL PROPERTIES OF *RHIZOPHORA RACEMOSA* (Leechm) AND *RHIZOPHORA HARRISONII* (G. mey) IN A NIGERIAN MANGROVE FOREST ECOSYSTEM

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Abstract: This study was carried out to determine the variation in the anatomical properties of the two most prominent species (*R. racemosa* and *R. harrisonii)* in Nigerian mangrove forest ecosystem. This was done with the aim of assessing their suitability for pulp and paper manufacturing. The trees samples were obtained from Stubbs Creek forest reserve, in Delta State. The diameter of all the tree samples was between 10 and 30 cm. After harvesting, the wood samples were collected from the sapwood and heartwood sections (radial direction) and at 10, 50 and 90% of the trees' height (the longitudinal positions). The mean fibre length values obtained were 1.767, 1.547 for sapwood and Heartwood of *R. racemosa*, while that of *R harrisonii* were 1.794 and 1.634 for sapwood and heartwood respectively. The mean fibre diameters of these two species were, 36.92 and 35.25 for the sapwood and heartwood of R racemosa and 34.307 and 34.090 for the sap wood and heart wood of *R. harrisonii* respectively. The Runkel ratio means for *R. racemosa* were 0.94 and 0.96 for sap and heartwood respective, while the values for *R. harrisonii* were 0.96 and 0.99 for sapwood and heartwood respectively. The results of this work indicate that the anatomical properties of these two species compared favourably with other species like *Gmelina arborea*, *Pinus caribaea and Eucalyptus* popularly grown for pulp and paper in Nigeria. The values indicate the suitability of *this* mangrove genus for pulp and paper production in a place where there is shortage of wood material for this purpose.

Keywords: Wood fibre characteristics, pulp and paper, Runkel ratio, *R. racemosa, R. harrizonii*

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Introduction

The successful conversion of pulp into a marketable the ever increasing demand for pulp and paper products product depends on the original fibre characteristics and globally, it become imperative to beam search light on the response of the fibre to the processing variables (Oluwadare & Ashimiyu, 2007). Wood density and fiber dimensions are related to many structural, physical and chemical properties in wood. It affects many wood-product manufacturing, like pulping process, behavior in the drying process and resistance to cutting and machining (Roque & Fo, 2007). Wood fibres are elongated cells whose length is a very large multiple of the diameter. They are arranged in a roughly parallel alignment in growing plants or trees where at various stages it serves as strength to the stem and trunk. Generally, fibers may be regarded as the strengthening element of plant structure that is relatively simple in form (Hay green & Bowyer, 1982). Fibers are the principal elements responsible for the strength of wood and are the threadlike components of plant cell wall. The rigidity of many woods is due to their fibre content and this determines the value and end use of many ood species (Akachukwu, 2001).

Fibre characteristics are important in considering the utilization of any plant for pulp and paper making. Fibres are the most important factor for determining the degree of efficiency of wood species in pulping (Ogunwusi, 2001).The strength property of paper is a function of the fibre characteristics used. Fibre characteristics of wood have been described to vary widely and thus exert varied influences on bulk density, fibre strength and inter-fibre bonding (Dinwoodie, 2000). Wood possessing long fibres is the most desirable in the paper industry (Panshin, 1998; Jorge *et al*, 2000). Pulp can be made from many species of wood but the commercial utility of a particular species depend on factors such as the suitability of their fibres in paper making. The use of tropical hardwood species, as alternative to the temperate soft wood species like Pines and Cyprus, as raw material for pulp and paper production is yielding commendable results today. Hardwood pulps are easier to bleach and possess the capability of being used to manufacture a wide range of specialty grades when blended with softwood chips.

The planned level of production in the pulp and paper mill in Nigeria has not been achieved due to insufficient availability of local materials. The most crucial of this, as identified by Adegbehin and Omijeh (1989) is the limitation of long fibre supply, which play a dominant role in the strength properties of paper. Most tree species used for pulp and paper production like *Gmelina* and *Pinus caribaea* are threatened due to high rate of deforestation and increasing demand of their wood for other economic purposes. There is need therefore, to carry out a comparative study on the fibre characteristics of *R.racemosa* and *R.harrisonii* species to enable us find out if these species can be used for pulp and paper production as suitable alternatives

For more availability in paper products, the Nigerian Government in 1975 established three paper industries. They are; The Nigeria Paper Mill (NPM) at Jebba Niger State, Nigeria Newsprint Manufacturing Company (NNMC) Oku Ibokun at Akwa Ibom State, and Iwopin Pulp and Paper Company(IPPC) in Ogun State to produce Paper (Famuyide and Adejoba 2004). These paper Mills were established to make Nigeria a self-sufficient country in pulp and paper production. *Gmelina arborea Roxb* and *Pinus caribaea* are the prime sources of pulpwood due to their conformity with the qualities of an ideal pulpwood. Their pulping properties are superior to most of the other hardwood species. As a result, large scale plantations of *G. arborea* have been raised in for the paper industries in Nigeria.

The tropical forests are disappearing as a result of uncontrolled felling of trees for fuel wood and timber at an alarming rate today and the rate of replenishment by reforestation is far lower than the rate of exploitation. Thus rate of deforestation is put at 1.36% per annum by Salami (2006) and 3.5% per annum by Oyebo (2006). This trend has continually imposed additional stress avenues of wood exploitation on the plantations of *G. arborea* and *Pinus caribaea* which were originally established for the use of the paper industries. This development has in turn, brought about an increasing awareness in finding alternative sources of wood fibres for paper making with two goals in mind, firstly to reduce cost of production which might be forced to rise owing to scarce raw materials resulting from the ever expanding consumption of paper and secondly, to avoid the imminent consumption for a scarce *G. arborea* and *Pinus caribaea* as the only raw material for pulping due to increasing demand for their wood for other economic purpose such as timbers, plywood, veneer, fuel wood etc.

R. racemosa and *R. harrisonii* are important indigenous mangrove species in Nigeria and not much of study had been done on the anatomical properties of these species. These properties determine the strength and quality of paper that can be produced from their wood. It is therefore important to characterize and assess the quality of the fibre from these species to ascertain their suitability for paper making. This will go a long way to increase their utilization and there can be substantial saving in foreign exchange that could arise from reduced importation of species with long fibres. If there is focus on the use of indigenous hardwood species for the production of pulp and paper, there could be reduction on the nation's dependency on importation of raw materials for paper production. This could also lead to the realization of economic stability.

Wood has been used for centuries for several purposes such as house construction, furniture making, bridge building, telegraph and electrical poles,. It is an organic material, a natural composite of cellulose fibres (which are strong in tension) embedded in a matrix of lignin which resists compression. Paper is a web of pulp fibres derived from wood or other plants from which lignin and other non-cellulose components are separated when cooked with chemicals at high temperature. The scarcity of softwood fibre produced locally for the pulp and paper industry has resulted in the need to search for alternative fibre sources. Though softwood plays a very important role in the production of high quality pulp and paper, it is unlikely that they could satisfy the future requirements for paper and pulp all over the world and in particular Nigeria with the increasing demand for paper products.

There are three major genera, namely; Rhizophora, Avicenia and Laguncularia in the tropical mangrove ecosystem of the Niger Delta area, Nigeria (Adegbehin & Nwaigbo, 1992). The two species investigated in this study belonged to the genus Rhizophora which is the most important and abundant of the three genera in the ecosystem (Adekanmbi & Ogundipe, 2009). There are three species in the genus, namely *Rhizophora racemosa, R.harrisonii* and *R. mangle*. *Rhizophora racemosa* is the commonest and largest of the *Rhizophoracea* family. *Rhizophora* trees, sometimes collectively called true mangrove species, are generally found in inter tidal areas, which are inundated daily by saline water, they exhibit a number of adaptation to this environment including stilt roots that elevates the plants above the water allowing them to respires oxygen even while their lower roots are submerged and a cytological molecular "Pump" mechanism that allows them to remove excess salts from their cells. Their seedlings grow rapidly to avoid being submerged at high tide. They can grow by 60cm in the first year (Akpofure and Ekeke, 1995) and they are often used to replant mangroves either for conservation or as part of forest management to produce timber for different purpose such as construction or charcoal production. It colonizes the mud on the outer most fringe of vegetation between high and low tide, the species inhibit the borders of river deltas, estuaries and lagoons. The wood is reddish very hard of close texture, brittle and gummy, While *Rhizophora harrisonii* is inhabits the middle belt of the mangrove forest zone,

Anatomical characteristics of wood

Anatomical characteristics form the basis for wood utilization in pulp and paper making industry. The properties of paper depend on the fibre properties, anatomy and method of separation of the fibres. Fibre characteristics that influence the quality of paper are: length, fibre diameter, fibre lumen width, fibre cell wall thickness, runkel ratio, Co-efficient flexibility and the relative fibre length (Frimpong-Mensah, 1992). The fibre length is the number of bonding sites that is available on an individual fibre to form an interwoven network of fibres. It is measured from one end to another end. Long fibre lengths are preferable for manufacture of paper. Long fibres give a more open and less uniform sheet structure. Fibre length influences the tearing strength of paper. The higher the fibre length, the greater the resistance of the paper to tearing (Oluwadare & Ashimiyu, 2007). Fibre diameter is the diameter of fibre measured from side to side end (Jang et al, 2002) and it is usually measured across the fibre length. The fibre lumen width is the diameter of the internal cavity. It is the distance between the inside diameter and the outer cavity. It is measured in a transverse direction. Fibre lumen width affects the beating of pulp. The larger the fibre lumen width, the better will be the beating of pulp because of the penetration of liquids into empty spaces of the fibres. Fibre cell wall thickness is the thickness of the cell wall which is determined by the age of the tree. Its proportion varies in trees. It was reported that matured wood are thick walled while juvenile wood fibres are thin walled (Gbadamosi, 2001). Thick wall fibres adversely affect the bursting strength, tensile strength and folding endurance of paper. The paper manufactured from thick walled fibres will be bulky, coarse surface and contain a large amount of void volume. So, paper with thin walled fibre will be dense and well formed.

The runkel ratio is the ratio of fibre cell wall thickness to its lumen that determines the suitability of a fibrous material for pulp and paper production. If a wood species has a high runkel ratio, its fibre will be stiff and less flexible and poor bonding ability. High runkel ratio fibres produce bulkier paper than fibres with low runkel ratio. For any wood species to be of good quality for pulp and paper production, its runkel ratio must be ≤ 1 (Kpikpi, 1992). The co-efficient of flexibility, usually expressed in percentage, is derived from the ratio of lumen width to its fibre diameter. Co-efficient of flexibility gives the bonding strength of individual fibre and by extension the tensile strength and bursting properties. Relative fibre length is the ratio of the Fibre length to its diameter; it gives the tearing resistance of a paper.

Nigerian paper and pulp manufacturing sub-sector of the economy, especially in the last three decades, has not been at its best. The failure of this sector, which was caused in part by a number of factors, has inflicted colossal losses on the economy on Nigeria (RMRDC, 2003). Huge amount will be saved, if only the major operating firms in the sub-sector are revived. The industry's revamp would however, require a combination of infrastructural improvement, power sector reactivation, availability of local raw material resources, and a programmed institution of well tailored and well backed up policies. The objectives of this study therefore are to determine the anatomical properties of two mangrove tree species (*R.racemosa* and *R.harrisonii)* in order to assess their suitability for pulp and paper production.

Materials and Method

Study Area

The wood samples were collected from Sapele local government Area, in Stubb creek forest reserve in Delta state. The area is located in the Delta State central senatorial district and it is in the tropical rain forest zone. It has a temperature range of 32.3^{0}C with rainfall range of 1400mm to 1749.3mm per annum. Rainy Season is between April and October. Stubb Creek forest reserve lies between latitude 08^0 14N and longitude 08^0 45E of the equator.

Method of Collection

Wood samples of *R.racemosa* and *R.harrisonii* were collected from felled logs. The felling was done with power chain saw. The diameter of the logs ranged from 10 – 40cm. Wood sample collections were done according to the practice in pulp and paper industries where mixed population of trees and branches of different ages are harvested for pulping rather than those of a particular age. Wood samples were taken by cutting three discs along the bole of the tree, one at the breast height (about 1.4m from the butt), one at the middle and the other below the crown. From each of these three discs, two portions from the heart wood and sapwood were collected with hand saw.

Experimental Procedure

The wood silver of 1cm x 1cm were obtained from the wood sample with the aid of knife and placed inside test tubes containing a mixture of equal volumes of acetic acid and hydrogen peroxide in a ratio of 1:1 according to Oluwadare, (1998) and Oluwadare & Ashimiyu 2007). The test tubes were properly labeled according to the wood positions from where they were cut. Hydrogen peroxide was used as an oxidizing agent to bleach the wood silvers completely to white and the acetic acid served as the cooking medium that softened the fibres. The test tubes containing the various samples were oven-dried for four hours at a temperature of 80^0 C to macerate. This allowed the lignin and hemicellulose to dissolve leaving only the cellulose fibres. The samples were then separated into into individual fibre after washing with distil water to remove the chemicals. Slides for microscopic view were prepared from the defiberized fibres. The dimension of the fibres were determined with the use of Rheichert Visopan Microscope with magnification of 10x and eye piece of 8x from and twenty-five randomly selected fibres and their length, diameter, lumen width, and cellwall thickness were obtained. These were used to derive the morphological indices; runkel ratio,coefficient flexibility, relative fibre length of the fibres.

The cell wall thickness was obtained with the formula:

Cell wall thickness $= \frac{FD-LU}{2}$

Where: FD = Fibre diameter and LU = Lumen width

The Runkel ratio was obtained with a mathematical expression:

$RR = \frac{2CW}{2}$

Where, RR = Runkel Ratio, CW = Cell Wall Thickness and LU = Lumen width

The Co-efficient flexibility was obtained as:

$CF = \frac{LU}{FD} x100$

Where, CF = Co-efficient Flexibility, LW = Lumen width and FD = Fibre diameter

The Relative fibre length was also obtained:

$RFL = \frac{FL}{FD}$

Where, RL = Relative Fibre Length, FL = Fibre Length and FD = Fibre diameter

Data Analysis

The statistical design used was the four-factor (2 x 2 x 3) factorial experiment, arranged in completely randomized design. This was adopted for each of the anatomical properties. Each data was made up of six replicates i.e. the number of wood samples for each analysis. Where significant differences were observed, mean separation was done using the Duncan Multiple Range Test (DMRT). All analyses were carried out with SPSS computer software (SPSS, 2003).

Results and Discussion

The anatomical properties of the two Rhizopha species of the tropical mangrove forest ecosystem obtained in this study reveal that they are suitable as raw material for pulp and paper production in Nigeria. The results of the four-factor factorial shown by the analysis of variance table (Table 1) indicated a non significant difference in the mean fibre length and cell wall thickness of the two species. But there was significant difference in fibre diameter and lumen width of the species. The results also revealed that there were no significant differences in all the measured variables (fibre length, fibre diameter, lumen width and cell wall thickness) of the wood samples from the base, middle and top positions for the two species and also the sapwood and the heartwood. However, there was a difference in fibre length of the sapwood and heartwood. From this ANOVA table, there were no significant differences in the levels of interaction for the variables. This is an indication that there are variations in fibre properties of wood in both longitudinal and radial positions of these tree species. These variations played significant roles in the strength and mechanical properties of wood for different uses. This supports the report of Zobel and Van Buijtenen (1989) that variations in wood density and fiber dimensions are present in trees in the radial and longitudinal direction and within the annual rings. These variations may be due to genetic, physiological or silvicultural treatments (Muller-Landau, 2004).

Table 1: Analysis of Variance for Fibre dimensions (Fibre length, fibre diameter, lumen width and cell wall thickness) of the two species of Rizophora in Mangrove region of Delta state, Nigeria

Source of variation	df	Fibre Length (mm)	Fibre Diameter (µm)	Lumen Width (µm)	Cell Wall Thickness (µm)	F - tabulated
Species	1	2.29ns	8.24*	8.83*	0.50ns	4.26
Height	2	1.13ns	1.15ns	1.38ns	1.50ns	3.40
Radial Position	1	25.69*	3.35ns	3.89ns	0.15ns	4.26
Species*Height	2	0.14ns	1.62ns	0.46ns	0.82ns	3.40
Species*Radial Position	1	0.26ns	0.87ns	0.38ns	0.31ns	4.26
Radial Position*Height	2	0.45ns	0.99ns	0.53ns	0.50ns	3.40
Species*Radial Position*Height	2	2.26ns	3.00ns	0.26ns	2.58ns	3.40
Error	24					
Total	35					

*significant at ($p < 0.05$) probability level or Calculated F-ratio > F-table

ns = not significant at ($p < 0.05$) probability level or Calculated F-ratio < F-table

Fibre length (mm)

The mean values of fibre length obtained in the longitudinal positions as shown in Table 2 ranged from 1.62 for the top, to 1.65 for base and 1.700mm for middle for *R. racemosa*, In *R. harizonii*, the fibre length for ranged between 1.68 and 1.74 with the mean highest value in the At the radial position the mean fibre length was 1.767 for sapwood and 1.547 for the heartwood in *R. racemosa*, while the values for radial positions for *R. harizonii* were 1.794 and 1.634 for sapwood and heartwood respectively. The results showed that wood fibre length is higher for the middle portion of the wood than for the base and top for both species. In addition, the general pattern for both species in the radial direction is that the sapwood had higher fibre length than the heartwood The fibre length of these two mangrove species is within the range of 1.65 and 2.33 obtained for a 25-year old Teak in south east Nigeria (Izekor & Fuwape, 2011), 0.75 and 1.75 for 10 – 12 year old stands of Gmelina in Costa Rica (Roque & Fo, 2007) and similar to the recent mean value (1.75mm) for Gmelina in Nigeria (Ogunkunle 2010). Generally, the fibre length of the species is lower than what was reported for the tropical Pines (3.32 for *Pinus caribaea*: Ajala, 1997 and 3.80 – 4.40 for *Pinus patula* : PPI, 2011). *Gmelina* and *Pines* are acclaimed fast growing exotic species for pulp and paper production. The fibre length of these species is higher than the mean values of between 0.84 and 1.14 reported by Migneault *et al*.(2008) for Salix species in Argentina, 0.9 and1.0 for Eucalyptus spp (PPR&I, 2011) and 0.91 and 1.11mm of Ishiguri *et al* (2007) for *Paraserianthes falcataria* in Indonesia.

Table 2: Fibre length, Fibre diameter, lumen width and cell wall thickness of the two species of Rhizophora in the study area.

Species	Wood Properties	Radial Position	Sampling height (%)			
			Base-10%	Middle-50%	Top-90%	Pooled Mean(%)
R. racemosa	Fibre Length (mm)	Sapwood	1.741	1.844	1.717	1.767
		Heartwood	1.563	1.556	1.52	1.547
		Mean	1.652	1.7	1.618	1.657
R. harrisonii		Sapwood	1.897	1.739	1.776	1.794
		Heartwood	1.58	1.748	1.575	1.634
		Mean	1.738	1.743	1.675	1.719
R.racemosa	Fibre Diameter (µm)	Sapwood	37.29	38.058	35.413	36.92
		Heartwood	36.117	35.413	34.224	35.251
		Mean	36.708	36.755	34.929	36.085
R. harrisonii		Sapwood	35.285	32.533	36.074	34.307
		Heartwood	34.41	34.965	32.896	34.09
		Mean	34.247	33.749	34.485	34.245
R.racemosa	Lumen Width (µm)	Sapwood	19.264	20.352	18.944	19.52
		Heartwood	18.517	19.008	17.45	18.325
		Mean	18.89	19.68	18.197	18.922
R. harrisonii		Sapwood	17.685	17.706	18.197	17.863
		Heartwood	17.365	17.813	16.533	17.237
		Mean	17.525	17.759	17.365	17.55
R.racemosa	Cell Wall Thickness (µm)	Sapwood	9.013	8.853	8.234	8.7
		Heartwood	8.8	8.202	8.394	8.465
		Mean	8.906	8.527	8.314	8.582
R. harrisonii		Sapwood	8.8	8.902	8.394	8.465
		Heartwood	8.522	8.576	8.181	8.426
		Mean	8.861	8.739	8.287	9.445

In comparison with tropical hardwood species, the mean value in this study is higher than what were reported by Awaku (1994) for some indigenous hardwood species of tropical rainforest ecosystem. His values and the species of are *Strombosia glaucescen*, 1.57, *Terminalia ivorensis*, 1.20, *Musanga cercropioides*, 1.39, *Trip1ochiton scleroxylon*, 1.30 and *Pycnanthus angolensis*, 1.40. It is alos higher than the values of Ogunkunle (2010) for 12 Ficus species that ranged between 0.99 and 1.33mm. Izokor and Fuwape (2011) reported a decrease in fibre length from the base to the top, but in this study, an increase in fibre length was from base to the top was discovered. But the study corroborated their findings of an increase in fibre length from inner wood (heartwood) to outer wood (sapwood). The inconsistency in fibre length in the longitudinal direction also agreed with the studies of Ogunsile and Uwajeh (2009) and DeBell *et al* (2002). The inconsistency in fibre length from the base to the top and its corresponding increase from heartwood to sapwood observed in this study had earlier been reported in the wood of *Populus* stems *(*De Bell *et.al* 2002*)*. The differences in fibre length associated with increase in height could be mainly due to the differences in the juvenile and mature wood as juvenile wood is expected to increase with an increase in height. Fibre length and distribution has been reported to play important roles in the processing and mechanical performance of fiber-based products such as paper and fiberboard (Migneault *et al*., 2008). They also claimed that both wood density and fibre length will determine whether the quality of a raw material is suitable for a specific use in the paper industry or not because of its impacts on paper characteristics, such as strength, optical properties and surface quality. For pulp and paper production, species with higher lengths are preferred since a better fibre net will be achieved, resulting in a paper with high resistance. This is the reason why fibres longer than 1mm (as obtained in this study) are preferred for pulp and paper manufacturing (Monteoliva *et al*., 2002, 2005).

Fibre diameter (µm)

The results of the fibre diameter as presented in Table 2 show the same trend with fibre length for these important mangrove species. For, R. racemosa, the fibre diameter ranged between 34.22 and 38.06. However, the highest mean value (36.76) was obtained at the middle position, followed by 36.71 at the base of the tree and the least (34.93) was from wood samples collected at the top. At the radial position of the wood samples, the mean fibre diameter for the sapwood of R. racemosa (36.92) is higher than the heartwood (35.25), though there was no significant difference. This indicates that both sapwood and heartwood of the species are suitable for pulp production. In the second species, its fibre diameter was between 32.53 and 36.07, with a general mean of 34.25 (Table 2). The highest mean diameter (34.49) was from wood samples at top of the trees. This is closely followed by 34.25 from the base and the least, 33.75 from the middle. In the radial direction, the sapwood had a higher but not significant average fibre diameter of 34.31than the heartwood (34.09). Izekor and Fuwape (2011) reported a decrease in fibre diameter from the base to the top and an increase from the inner wood to outer wood for Teak stands. Even though the increase observed in the longitudinal direction in this study did not follow a specific trend, which could be attributed to the uneven pattern of tree growth in the natural forest, it corroborated the findings of Izekor and Fuwape (2011) on the increase of fibre diameter from inner to outer wood. The Increase in fiber diameter was reported to be associated with the many molecular and physiological changes that occur in the vascular cambium as well as the increase in wood cell walls during the tree growing processes (Plomion *et al*, 2001 and Roger *et al*, 2007). The mean fibre diameter of these two indigenous species is higher than what was reported for teak in Nigeria (32.83; Izekor & Fuwape, 2011), *Gmelina arborea* in Costa Rica(18.5 – 27.5; Voque & Fo , 2007), *Gmelina* in Nigeria (23.57: Ogunkunle, 2010), *Paraserianthes falcataria* in Indonesia (15.4 – 21.20; Ishiguri et al., 2009),), Eucalyptus spp (14.0-16.0; PPR&I, 2011) and *Leucoena leucocephala* (15.67; Oluwadare & Ashimiyu 2007). The fibre diameter of *Pinus patula* (36.0 – 40.0; PPR&I, 2011) is higher than the two species. For comparison with tropical hard wood species, it is higher than the range of 18.69 – 28.93 reported for 12 species of Ficus (Ogunkunle, 2010). Based on the results of the fibre diameter, it shows that these species are suitable for pulp and paper production.

Fibre lumen width (µm)

The mean value of the fibre lumen width for R. racemosa ranged from 18.20 – 19.68. Although there was no difference in lumen width according to the sample position, the highest was found to exist at the middle position of the samples while the least value was at the top position. The pooled mean width therefore is 18.92. In the radial direction, the width is higher for the sapwood (19.52) than in the heart wood (18.33). This followed the same pattern with other anatomical characteristics. A mean that varied between 17.36 and 17.76 were obtained for fbre lumen with in *R. harrisonii*. Also in this species, a highest value (17.76) was obtained from the samples that were taken at the middle and the least for sample from the top. The sapwood also had a mean width that is higher than the heartwood. The mean values are 17.86 and 18.33 for sapwood and heartwood respectively. Generally, the variation in lumen width in both at the radial and longitudinal directions for the two species could be attributed to the increase in cell size and physiological development of the wood as the tree grows in girth. Roger *et al* (2007) reported a positive relationship in lumen width and cambium age in their study. It was also observed that fibre lumen width decreased from outer wood to inner wood. The average fibre width of this study is higher than 15.94 reported by Izekor & Fuwape (2011) for Teak and 17.42 reported by Ogunkunle (2010) for Gmelina, within the range (14,80 -20.99) reported for ficus species, 9.87 reported for *Lecaena leucocephala* and 13.0 reported for Gmelina by Ajala (1997). In addition, the lumen width is also greater than the range (2.47 – 4.94) with a mean of 3.31 reported for some indigenous hardwood species in the tropical rainforest ecosystem (Awuku, 1994).The lumen compared favorably with the species prominent in pulp and paper manufacturing.

Cell wall thickness (µm)

The thickness of the cell wall of these species ranged from 8.31 and 8.91 with a mean value of 8.58 along the sample height for *R. racemosa*. The thickness for the sapwood of this species is 8.70 while it is 8.47 for the heartwood. Highest thickest of the cell walls was observed at the base position while the least was at top. For *R. harrisonii*, the thickness ranged from 8.86 to 8.29 ith a pooled mean of 8.45 along the height. The value for the sapwood (8.47) is also higher than heartwood (8.43) like other properties. Even though the mean value of these species is higher than what were reported for *Gmelina* (2.82) and *Ficus* species (1.94 – 4.99) by Oguntoke (2010), *Leucaena* (2.90) by Oluwadare & Ashimiyu (2010) and Teak by Izekor & Fuwape (2011), it is within the range (5.0 – 10.0) reported for Pine, a reputed long fibre pulp species by PPR&I (2011). The thicker cell walls of these species could be a setback to the production of good quality paper, but comparison with Pines confirmed the suitability of this genus as raw material for pulp and paper industries.

Derived Fibre qualities

The ANOVA results for verifying the presence of significant differences in derived wood properties according to position of sample and speies is presented in Table 3. From this table, there was no significant difference in most of the variables and all interactions. However, there was a significant difference in the coefficient of flexibility and relative fibre length of the two species. Also, a significant difference also existed in relative fibre length when results from the samples from the sapwood and heartwood were compared. This shows that the fibre qualities of these two species are similar and both are good raw material for pulping. These findings are in agreement with the works of Izekor & Fuwape (2010), Oguntoke (2010) and Oluwadare & Ashimiyu (2007) who also obtained non-significant differences in fibre derived properties. This is an indication that every part and wood component of these species are very suitable for pulp and paper manufacturing.

Table 3: Analysis of Variance for derived fibre qualities (runkel ratio, coefficient of flexibility and relative Fibre length) of the two Rizophora species in Mangrove region of Delta state, Nigeria

Source of variation	df	Runkel ratio	Coefficient flexibility (%)	Relative fibre length (µm)	F - tabulated
Species	1	3.34ns	1.45*	7.75*	4.26
Height	2	1.44ns	1.42ns	1.27ns	3.40
Radial Position	1	0.77ns	0.94ns	16.41*	4.26
Species*Height	2	0.28ns	0.18ns	0.94ns	3.40
Species*Radial Position	1	0.01ns	0.00ns	0.12ns	4.26
Radial Position*Height	2	0.24ns	0.30ns	0.21ns	3.40
Species*Radial Position*Height	2	0.75ns	0.42ns	0.60ns	3.40
Error	24				
Total	35				

*significant at ($p < 0.05$) probability level or Calculated F-ratio > F-table
ns = not significant at ($p < 0.05$) probability level or Calculated F-ratio < F-table

Runkel ratio

The runkel ratuo of wood fibre is one of the properties of wood that have been recognized as important traits for pulp and paper properties (Ohshima *et al*. 2005). It is related to paper conformity and pulp yield. It should be less than 1 for a wood with good quality for pulp production (Kpikpi, 1992). The runkel ratio of these species are less than 1 in both longitudinal (height along tree bole) and radial directions (direction from outer to inner wood represented by sapwood and heartwood as shown in Table 4. In the radial direction, the runkel ratio of *R. racemosa* is between 0.91 - 0.98 with a mean value of 0.94 for the sapwood and 0.94 – 0.98 for the heartwood with a mean of 0.96. But according to sample height, the highest runkel ratio of 0.98 was obtained at the base. This is followed by 0.95 for the top and the least ratio (0.92) at the middle. For *R. harisonnii*, the value is similar *to R. racemosa*. A runkel ratio that ranged between 0.86 – 0.99 was for the sapwood while 0.97-0.99 was for the heartwood. High ratio (0.99) was also observed at the base and the top of the samples while the least was at the middle (0.92). The mean runkel ratio for this species is 0.97. The runkel ratio of these two species correspond with the 0.99 reported for *Anthonatha macrophylia* and *Dalium guinensis* hardwood species in Nigerian rainforest ecosystem (Ezeibekwe, et al., 2009) but higher than an average of 0.75 reported by Awuku (1994) for some tropical hardwood species, the 0.25 and the range (0.28 and 0.68) reported for Gmelina and some ficus spp respectively

(Ogunkunle, 2010), 0.59 for *Leucaena leucocephala* (Oluwadare & Ahimiyu, 2007), 0.79 for tropical Pine species (Ajala, 1997) and the 0.70 for *Dacryodes edulis* (Ajuziogu et al., 2010). These authors claimed that these species are suitable for pulp production since their runkel values are <1. In the same vein, these Rhizophora species are also suitable as raw material pulp and paper production.

Table 4: Runkel ratio, coefficient of flexibility and relative fibre length of the two species of Rhizophora in the study area.

Species	Wood Properties	Radial Position	Sampling Height(%)			
			Base (10%)	Middle (50%)	Top (90%)	Pooled Mean (%)
R racemosa	Runkel Ratio (µm)	Sapwood	0.975	0.922	0.912	0.936
		Heartwood	0.981	0.924	0.982	0.962
		Pooled mean	0.978	0.923	0.947	0.949
R. harrisonii		Sapwood	0.992	0.863	1.000	0.957
		Heartwood	0.990	0.974	0.987	0.987
		Pooled mean	0.991	0.919	0.993	0.972
R. racemosa	Coefficient of flexibility (%)	Sapwood	52.023	53.409	53.574	53.002
		Heartwood	51.38	52.077	51.034	51.797
		Pooled mean	51.701	52.743	52.304	53.340
R. harrisonii		Sapwood	49.521	54.498	50.500	51.506
		Heartwood	50.439	50.929	49.664	50.344
		Pooled mean	49.980	52.714	50.082	50.925
R. racemosa	Relative Fibre Length (µm)	Sapwood	47.845	49.861	50.022	49.247
		Heartwood	44.300	45.198	44.999	44.832
		Pooled mean	46.073	47.530	47.511	47.053
R. harrisonii		Sapwood	53.54	55.488	49.849	52.959
		Heartwood	46.237	49.587	47.387	47.737
		Pooled mean	49.889	52.538	48.618	50.348

Coefficient of flexibility

For wood to be eligible for pulping, its fibre must have adequate flexibility (Idu & Ijeomah, 2000). The values, as shown in Table 4, ranged from 0.57 – 0.53 along the tree height for *R. racemosa*, with the highest from the samples at the middle of tree height and the least at the base of the tree samples. The mean values of 0.53 and 0.54 were obtained for the sap and heartwood respectively. For *R. harisonii*, the coefficient of flexibility ranged from 0.50 to 0.53 along the tree height and 0.52 and 0.50 were got for the sapwood and heartwood respectively. The mean flexibility coefficient of these species is similar with the 0.51 obtained for *D. olivera* by Idu & Ijeomah (2000) and the 0.57 reported for *D. edulis* by Ajuziogu, et al (2010). Even though, the value is less than the 0.63 that was reported for L. leuucocephala by Oluwadare & Ashimiyu (2007), 0.79 reported for Gmelina and the range of 0.63- 0.79 for some Nigerian Ficus species (Ogunkule & Oladele, 2008; Ogunkunle, 2010), it is higher than the 0.24, 0.16 and 0.12 reported by Ezeibekwe et al (2009) for *D. bateri, A. macrophylla* and *D. guinensis* respectively and the 0.37 reported for *A. occidentale* (Ajuziogu, et al., 2010). So the mean coefficient of flexibility derived for these species (table 4) qualified them to be a good source of raw material for pulp and paper as it compared very well with some reported species for pulp manufacturing.

Relative fibre length

Relative fibre length of wood is the ration of its length to its diameter. It gives a paper its ability to resist tearing. The values for this species are 49.25 for the base, 52.71 for the middle and 50.08 for the top samples for R. racemosa. The RFL of the sap wood is 51.51 while 50.34 were obtained for its heartwood. A pooled mean of 47.05 was derived for this species. Similarly, the values for *R . harisonii* are 49.89 (base wood), 49.89 (middle wood) and 49.62 (top wood). At the sapwood, the RFL is 52.96 while the amount for the heartwood stood at 47.79. In the work of Ogunkunle (2010), Gmelina had a higher RFL than the two species but the mean value for these species is within the range of 42.38 – 55.34 he reported for some hardwood Ficus species and higher than the range (32.63 – 46.37) reported for some indigenous fruit species of rainforest ecosystem, Nigeria (Ezebekwe, et al 2009).

By comparison, *R.racemosa* has the highest mean fibre diameter (36.08), Lumen width (18.92), cell wall thickness (8.58) coefficient flexibility (0.52) while, *R.harrisonii* has the lowest mean fibre diameter (34.36), Lumen width (17.55), cell wall thickness (8.41) and co-efficient flexibility (50.92). In addition, *R. racemosa* had the highest mean runkel ratio (0.97), relative fibre length (50.35) while *R.harrisonii* has the lowest mean runkel ratio (0.95), and relative fibre length of (47.04) as shown in Table 5. But when these characteristics were compared and DMRT adopted for mean separation where significant differences occurred, the result shows that there was no significant difference in the variables. So it indicates that the quality of the fibres from these species will be uniform adequate for utilization. the fact that the properties of these species were discovered to be closed to what were obtained for other wood species especially the temperate species like Pines, and hardwood species like Eucalypyus and Gmelina species adjudged the best for pulp and paper manufacturing further buttressed the importance of these mangrove species for puling. According to the criteria of PPR&I (2011), these species are in the category of medium fibre (1.4 – 10.0mm). These criteria stipulated that wood with fibre length of >10mm could be regarded as long fibre as in *Pinus species*, 2-10mm as medium fibre and < 2mm as short fibre wood.

Table 5: Comparison of Fibre characteristics of the two Rhizophora species in the study area.

Anatomical properties	*R.racemosa*	*R.Harrisonii*	Remark
Fibre length (mm)	1.6573	1.717	ns
Fibre diameter (µm)	36.0889	34.3609	ns
Lumen width (µm)	18.9227	17.5502	ns
Cell wall thickness (µm)	8.5831	8.4053	ns
Runkel ratio	0.9497	0.9686	ns
Co-efficient flexibility (%)	52.3999	50.9255	ns
Relative fibre length (µm)	47.0378	50.3485	ns

Ns - ns = not significant at 95% probability level (p < 0.05)

Conclusion and recommendation

From the result of the analysis, *Rhizophora racemosa* and *Rhizophora harrisonii* can be used for pulp and paper production. It compared favourably with *G.arborea P.caribaea, and Tectona grandis* which are known to be the prime source of pulpwood in Nigeria. Based on its appreciable fibre lengths and runke ratio, the species is pulpable and can therefore be used in pulp and paper production. The trees of *R.racemosa* and *R.harrisonii* is recommended as a good material for pulp and paper making due to its appreciable fibre length and runkel ratio that is less than one (1) on the average. However, the utilization potentials of *R.racemosa* and *R.harrisonii* will be enhanced if its pulp is blended with other pulpable wood species like *Gmelina* and *Pinus caribaea* to achieve desirable pulp and paper yield.

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