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WOOD FIBRE EVALUATION OF *MORINGA OLEIFERA (LAM)* AS RAW MATERIAL FOR PULP AND PAPER PRODUCTION

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ABSRACT

Wood quality studies were carried out on the *Moringa oleifera* collected from Lafia, Nasarawa State, Nigeria to ascertain their suitability for pulp and paper making. Ten (10) sample trees collected from the 3year old *Moringa* plantation, at the Faculty of Agriculture (Shabu-Lafia Campus), Nasarawa State University Keffi. Sample discs were collected from 5%, 25%, 50%, 75% and 85%, of the whole length of each of the harvested stands (axial positions), while radial samples were collected from the core wood, middle wood, outer wood and bark. Physical properties: growth ring, ring width and fibre morphology such as fibre length, fibre diameter, lumen width, cell wall thickness, Runkel ratio, flexibility ratio and felting coefficient were studied on axial and radial directions on the ten samples. Five slivers were obtained randomly from each of the 4 radial and 5 axial sampled discs replicated on ten (10) randomly selected *Moringa* trees, totaling 1000 fibres used for this study. The wood splints of 1 x 3cm were obtained from the wood sample with the aid of a knife and placed inside test tubes and macerated with an equal volume (1:1) of 10% glacial acetic acid and 30% Hydrogen Peroxide (H_2O_2) at $100\pm2^{O}C$ and boiled until soft and bleached white as adopted by Franklin, 1945. The study was laid out in a 5 x 4 x 10 factorial experiment in a completely randomized design (CRD). Pith diameter was 9.29±4.05 mm, it increased significantly from base to top. Bark thickness was 4.75±1.67mm. Significance between-tree variation was observed for ring width with a mean of 5.27±0.68 mm, however, ring width consistently increased along the stem axis. The results of the fibre morphological characteristics showed that the fibre length was 2.28±0.49 mm, 13.77±3.13 µm lumen width, 19.54±1.95 µm fibre diameter while the cell wall thickness was 2.37±2.00µm. Fibre length, lumen width and cell wall thickness varied significantly along the stem axis at ($p<0.05$). *Moringa oleifera* fibre characteristics as reported in this study showed that, they are well suited for tissue, corrugating medium, newsprint, and writing paper. It is therefore necessary for researchers to focus more on some agricultural crop alternatives as well as lesser known wood species such as *Moringa oleifera*, by exploring their pulping potentials and thus prevents overdependence on already depleting scarce forest resources.

Keywords: Fibre length, Wall Thickness, Runkel Ratio, Flexibility ratio, Felting Coefficient

INTRODUCTION

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. The Nigerian Government in 1975 established three paper industries. They are; The Nigeria Pepper mill (NPM) at Jebba Niger State, Nigeria Newsprint Manufacturing Company (NNMC) Oku Ibokun at AkwaIbom State, and Iwopin Pulp and Paper Company (IPPC) in Ogun State to produce Paper of different grades (Sotannde, (2000). These paper Mills were established to make Nigeria a self-sufficient country in pulp and paper production. *Gmelina arborea* and *Pinus caribaea* are the prime sources of pulpwood due to their conformity with the qualities of good pulpwood owing to the fact that their pulping properties are superior to most of the other hardwood species.

Moringa oleifera as Alternative Fibre Source

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 pulps (Oluwadare and Egbewole, 2008).

Moringa Tree, also known as Horseradish treeand drumstick tree is widely cultivated in the tropics and mostly grown in parts of the world hit by malnutrition (Livestrong, 2011). *Moringa* is a fast growing perennial tree which can reach a maximum height of 7-12 m and a diameter of 20-40 cm at breast height. All parts of the tree are useful because of their pharmacological and nutritional properties (Fahey, 2005). *Moringa* is a medium sized tree that belongs to the family moringaceae of a thirteen genera (Radovich, 2012). *Moringa oleifera* is a highly valued plant that is well distributed in many countries of tropics and subtropics (Ramachandran,*et al*., 1980).

Ekhuemelo and Udo (2016) stated that, so much research work has been done on *Moringa oleifera* for its nutritional qualities, water purification, soil fertility, medicine for various ailments, oil, animal feeds, biopesticides; but no work has been done on its physical and chemical properties to ascertain its suability in pulp and papermaking. It is therefore necessary for researchers to focus more on some agricultural crop alternatives as well as lesser known wood species, exploring their pulping potentials and thus prevents overdependence on the scarce forest resources which is already depleting (Ekhuemelo and Udo, 2016).

It is also necessary for efficient fiber management and utilization. As a first step towards utilization of any raw materials, it is important that its wood quality parameters be examined especially if it is suitable for paper making (Osadare and Udohitinah, 1993), since the morphological characteristics of wood present considerable challenges in the quality and quantity of pulp produced. The overall influence these properties have on paper properties cannot be over-emphasized (Egbewole *et al.,* 2015). It is imperative that the wood quality parameters of this promising native pulpwood species be examined as such information will be useful in future tree improvement programmes and plantation management of *Moringa* for the desired purpose.

This research work intends to assess some wood quality parameters of *Moringa oleifera* especially its fibre characteristics with regards to different points both within and between stands, their pattern of variations in the radial and axial directions and there suitability as a raw material for pulp and paper production. It is on this background that this study on fibre characteristics of *Moringa oleifera* was carried out.

MATERIALS AND METHODS

Raw Materials

Samples of *Moringa oleifera* were collected from the Moringa plantation behind departmental nursery Faculty of Agriculture, Department of Forestry, Wildlife and Ecotourism Nasarawa State University, Shabu-Lafia Campus on a coordinate of (8.506^0N, 8.5227^0E), located in the Guinea Savanna Zone of North Central Nigeria at an attitude of 177m above sea level. The mean monthly maximum and minimum temperature range between 35.06^0C – 36.40^0C and 20.16^0C – 20.50^0C, respectively while the mean monthly relative humidity and rainfall are 74.67% and 168.90mm, respectively (Jayeoba, 2013).

Sample Preparation

Ten (10) sample trees from the 3year old *Moringa* plantation, were randomly selected and their total height, diameter at breast height, crown diameter, merchantable height, crown depth, diameter at butt, middle and top measured using destructive sampling method to study pith diameter, bark thickness, bark proportion, proportion of bast fibre and grain orientation along the stem height. From each tree, a disc of 5cm thickness were cut from base at 5%, 25%, 50%, 75% and top 85%, along stem height to study axial variation in selected properties. The results obtained were pooled together to determine how these properties varied along the stem axis.

Determination of the Physical Properties

Ring width was determined as described by Egbewole (2004). In this method, ring width was measured in the four cardinal positions on the transverse surface of the disc using a double biconcave lens super imposed over a calibrated transparent ruler. Ring width was from the first formed early wood to the last formed latewood bands of each growth ring. Mean from the four points was used for each growth ring. Bark thickness and bark proportion was computed using Wang *et al*. (1984) method as described in the equation below: (Equations 1 and 2).

$$BT = \pi \frac{(DOB)^2}{2}(DT) - \pi \frac{(DIB)^2}{2}(DT) \quad \dots\dots (1)$$

Where:

BT = Bark thickness

DOB = Diameter over bark

DIB = Diameter inside bark

TD = Average disc thickness and π = 3.142

Proportion of bast fibre from air-dried wood sample was calculated using the relationship below:

$$\text{Bast fibre (\%)} = \frac{(Wf)}{Wb + Wf} x \frac{100}{1} \dots\dots\dots (2)$$

Where:

Wf = Weight of bast fibre

Wb = Weight of bark without bast fibre

Fifty discs of *Moringa oleifera* (5 disc from each of the 10 tree stands) were collected from the same location at base 5%, 25%, 50%, 75% and top 85%, of the bole length of each *Moringa* tree. The methods of Schmidt and Smith (1961) and Saikia *et al*. (1997) used by Egbewole (2004) was modified and used to determine grain orientation. It is assumed that fibre lie in a perpendicular position along the stem. The fibre perpendicularity was inscribed using the tip of a divider, any deviation from this position was considered as grain orientation denoted or measured in degree (ϴ°) using a protractor. Each disc was oven-dried, while radial samples were collected from the core wood, middle wood, outer wood and bark. Five slivers were obtained randomly from each of the 4 radial and 5 axial sampled discs replicated on ten (10) randomly selected *Moringa oleifera* trees, totaling 1000 fibres used for this study. The wood silver of 1cm x 3cm were obtained from the wood sample with the aid of a knife and placed inside test tubes and macerated with an equal volume (1:1) of 10% glacial acetic acid and 30% Hydrogen Peroxide (H_2O_2) at 100 ± 2^0 C and boiled until soft and bleached white as adopted by Franklin, 1945. The slivers were then washed, placed in 30ml-test tubes with 20ml-distiled water and shaken vigorously to separate the fibre bundles into individual fibre. The macerated fibre suspension was carefully aligned on a slide using white tread. The resulting image on Rheichertvisopan microscope screen was measured for fibre length on magnification x20, while diameter and lumen width where on magnification x8. From the se, the derived values for slenderness ratio as fibre length/fibre diameter, flexibility coefficient as (fibre lumen diameter/fibre diameter) x 100 and Runkel ratio as (2 x fibre cell wall thickness)/lumen diameter were calculated.

Derived morphological fibre characteristics:

i. $$\text{RunkelRatio} = \frac{2(CellWall\ thickness)}{LumenWidth} \dots . (3)$$

ii. $$\text{Felting} \frac{\text{coefficient}}{\text{slenderness}} \text{ratio} = \frac{Fiber\ Length}{Fiber\ diameter} \dots\dots\dots\dots\dots . (4)$$

iii. $$\text{Flexibility Ratio/ Elasticity Coefficient} = \frac{\text{Lumen width x 100\%}}{Fibre\ diameter} \dots\dots\dots (5)$$

Source: (Saika *et al*., 1997; Ogbonnaya *et al*., 1997; Egbewole, 2004; Egbewole *et al*., 2015).

Method of data analysis

The data collected were analyzed using 5 x 4 x 10 factorial experiments in a Completely Randomized Design (CRD) replicated 5 times. The model for this type of experimental arrangement is given as

$$Y_{kijl} = \mu + A_i + B_j + C_l + AB_{ij} + AC_{il} + ABC_{ijl} + e_{kijl} \dots\dots (6)$$

Where Y_{kijl} = individual observation

μ = general mean

A_i = effect of factor A (5%, 25%, 50%, 75% and 85%: axial position along the bole) (5 levels)

B_j = effect of factor B (core wood, middle wood, outer wood and bark) (4 levels)

C_l = effect of factor C (Individual stem of *Moringa* tree) (10 levels)

AB_{ij} = effect of interaction between factor A and B

AC_{il} = effect of interaction between factor A and C

BC_{jl} = effect of interaction between factor B and C

ABC_{ijl} = effect of interaction among factors A, B and C

e_{kijl} = experimental error

i = level of factor A = 5 levels (5%, 25%, 50%, 75% and 85%)

j = level of factor B = 4 Disc levels (4 levels (5%, 25%, 50%, 75% and 85%)

l = level of factor C = 10 *Moringa* trees

k = number of observed fibre cells per slide (replicate) (5)

RESULTS AND DISCUSSION

(a) Results of physical characteristics of *Moringa oleifera*

The moisture content of *Moringa oleifera* tree showed that the percentage moisture was 44.46±7.07%. Samples obtained at 85% disc level (top) had the highest mean moisture content of 48.52±5.17%, this was followed by 48.01±5.59% at 75% disk level, 45.28±5.17% at 50% level. While the least moisture content of 40.51±11.19% was recorded in *Moringa oleifera* obtained at 5% level (base). The result also revealed that the *Moringa oleifera* collected at 5% disc level had the highest ring width of 3.52±0.53 mm, this was followed by 3.49±0.70mm at 25% disc level, 3.36±0.69mm at 50% disc level. While the least mean ring with of 1.88±0.71mm was recorded in *Moringa oleifera* collected at 85% disk level. The result revealed that the *Moringa oleifera* collected at 5% disc level had the highest mean grain orientation of 9.11±3.52^{0}; this was followed by 7.81±3.34^{0} at 25% Disk level, 7.59±2.17^{0} at 50% Disk level. While the least mean grain orientation of 5.86±2.69^{0} was recorded in *Moringa oleifera* collected at 85% Disk level (Table 1).

Table1: Mean Values of physical characteristics of *Moringa oleifera*

Source of variation (Disc)	Ring width (mm)	Disc Diameter (cm)	Bark Thickness (mm)	Wet Weight (g)	Dry Weight (g)	Grain Orientation (°)	Pith Diameter (mm)	Moisture Content (%)
5%	3.52±0.53^{a}	7.49±2.37^{b}	6.19±1.56^{c}	252.91±27.39^{a}	147.82±19.41^{a}	9.11±3.52^{a}	9.57±4.61^{c}	40.51±11.19^{a}
25%	3.49±0.70^{a}	6.53±2.41^{ab}	5.38±1.71^{bc}	226.31±17.46^{a}	118.71±11.39^{a}	7.81±3.34^{a}	9.03±3.46^{bc}	44.00±8.23^{a}
50%	3.36±0.69^{a}	5.69±1.76^{ab}	4.37±1.68^{ab}	178.31±13.57^{a}	102.42±4.27^{a}	7.59±2.17^{a}	9.68±4.31^{ab}	45.28±5.17^{a}
75%	2.09±0.76^{a}	5.00±2.01^{a}	4.21±1.72^{a}	145.40±11.59^{a}	87.43±7.41^{a}	6.09±2.77a	9.15±3.41^{a}	48.01±5.59^{a}
85%	1.88±0.71^{a}	4.42±1.79^{a}	3.61±1.67^{a}	103.08±8.16^{a}	68.51±5.36^{a}	5.86±2.69a	9.00±4.44^{bc}	48.52±5.17^{a}
Grand Total	**5.27±0.68**	**5.83±2.10**	**4.75±1.67**	**185.20±15.63**	**100.98±9.57**	**7.29±2.20**	**9.29±4.05**	**44.46±7.07**

Note: Mean with the same letter(s) on the same column are not significantly different 6.09±2.77a

(b) Result of fibre morphological characteristics of *Moringa oleifera*

The results of the fibre morphological characteristics of *Moringa oleifera* showed that the mean fibre length was 2.28 ± 0.49mm, mean lumen width of 13.77 ±3 .13μm, fibre diameter of 19.54 ± 1.95μm and mean cell wall thickness of 2.37 ± 2.00μm (Table 2).

Table 2: Mean values of fibre characteristics of *Moringa oleifera*

Source of Variation	Item	Fibre Length (mm)	Fibre Diameter (μm)	Lumen Width (μm)	Wall Thickness (μm)	Runkel Ratio	Suppleness	Flexibility ratio
Tree	Tree 1.	2.25±0.45^{a}	19.52±1.84^{a}	14.56±1.90^{ab}	2.33±0.54^{a}	0.32±0.57^{b}	121.0±27.67^{a}	74.59±5.3^{ab}
	Tree 2.	2.28±0.42^{a}	19.79±1.89^{ab}	15.11±1.81^{b}	2.31±0.48^{a}	0.31±0.53^{ab}	119.0±24.24^{a}	76.7±5.32^{b}
	Tree 3.	2.26±0.43^{a}	19.19±2.07^{a}	13.45±8.09^{a}	2.87±0.57^{a}	0.43±0.14^{a}	119.0±23.06^{a}	70.1±37.50^{a}
	Tree 4.	2.30±0.60^{a}	19.72±1.91^{c}	15.16±1.79^{b}	2.37±0.53^{a}	0.31±0.59^{b}	116.0±32.07^{a}	76.88±5.38^{ab}
	Tree 5.	2.29±0.46^{c}	19.68±1.77^{bc}	13.44±8.72^{a}	3.06±4.50^{b}	0.46±1.03^{a}	123.0±26.43^{c}	68.29± 40.8^{a}
	Tree 6.	2.18±0.64^{a}	19.47±1.96^{ab}	14.89±1.61^{b}	2.97±0.58^{a}	0.39±0.72^{ab}	114.0±34.54^{a}	76.48± 4.85^{b}
	Tree 7.	2.3 ±0.45^{b}	19.30±1.81^{a}	14.63±1.02^{a}	2.31±0.43^{a}	0.32±0.84^{a}	124.02±25.07^{bc}	75.80±4.98^{b}
	Tree 8.	2.14±0.59^{a}	19.67±2.05^{a}	15.11±1.72^{a}	2.29±0.51^{a}	0.30±0.59^{a}	109.6±32.02^{a}	76.82±5.02^{b}
	Tree 9.	2.27±0.49^{a}	19.49±1.82^{a}	14.38±1.99^{ab}	2.31±0.46^{a}	0.32±0.46^{b}	121.0±27.67^{a}	73.78±5.30^{ab}
	Tree 10.	2.28±0.59^{a}	19.51±1.86^{a}	14.51±1.98^{ab}	2.30±0.59^{a}	0.31±0.59^{b}	121.0±27.67^{a}	74.37±5.31^{ab}
Disc level	Disc at 5%	2.39±0.46^{abc}	19.12±2.03^{a}	14.36±1.89^{ab}	2.44±0.51^{a}	0.33±0.54^{b}	123.8±25.34^{c}	75.10±5.39^{b}
	Disc at 25%	2.31±0.41^{bc}	20.10±1.81^{c}	15.04±1.82^{b}	2.43±0.49^{ab}	0.32±0.54^{b}	118.13±22.73^{ab}	74.83±5.08^{b}
	Disc at 50%	2.31±0.42^{ab}	19.51±1.94^{ab}	14.86±1.90^{b}	2.32± 0.57^{a}	0.31±0.6^{ab}	116.0±23.02^{ab}	76.17±5.30^{b}
	Disc at 75%	2.29±0.46^{c}	19.54±1.83^{bc}	13.57±8.73^{a}	3.17±4.49^{b}	0.47±1.03^{a}	123.0±26.43^{c}	69.45±40.8^{a}
	Disc at 85%	2.21±0.64^{a}	19.45±1.81^{b}	14.82±1.56^{b}	2.21±0.47^{a}	0.29±0.6^{ab}	114.0±34.54^{a}	76.20± 4.85^{b}
Radial position	Core wood	2.29± 0.41^{b}	19.76±1.73^{a}	13.87±8.04^{a}	2.44± 4.67^{b}	0.32±1.16^{a}	117.7±22.06^{b}	70.19±37.5^{a}
	Middle wood	2.38±0.41^{b}	19.44±2.00^{a}	14.71±2.02^{a}	2.43±0.49^{a}	0.33±0.49^{a}	125.8±25.02^{c}	75.67±5.65^{b}
	Outer wood	2.32 ±0 .40^{b}	19.39 ± 1.87^{a}	14.67±1.09^{a}	2.39±0.55^{a}	0.34±1.01^{a}	124.02±25.07^{bc}	75.66± 4.98^{b}
	Bark	2.26±0.59^{a}	19.60±2.03^{a}	15.09±1.75^{a}	2.36±0.51^{a}	0.3±0.58^{a}	109.6±32.02^{a}	76.20±5.02^{b}
Grand mean		**2.28±0.491**	**19.0±1.89**	**13.77±3 .13**	**2.59±2.00**	**0.35± 0.66**	**119.30±26.96**	**66.76±19.40**

Note: Means with the same letter(s) on the same column are not significantly different

Results of fibre length of *Moringa oleifera*

The mean fibre length was 2.28 ± 0.49 mm. The longest fibre length of 2.39± 0.46mmwas observed axially at 5% level, followed by 2.31 ± 0.4mm at 25% and 50% and the least fibre length of 2.21 ± 0.64mm was observed at 85% disc level. samples collected at the middle wood had the highest fibre length of 2.38 ± 0.41mm, followed by 2.32 ±0 .41mm at the outer wood, while the least 2.26 ± 0.50mm was recorded in *Moringa oleifera* collected from the wood back (Table 2). However the analysis of variance showed that there was a significant difference observed in the fibre length, lumen width, fibre diameter and cell wall thickness both within and between sample disc, while the effects of trees and radial positions were not significant on the observed fibre length, lumen width, fibre diameter and cell wall thickness of *Moringa oleifera* $p<0.05$ (Table 3).

The mean fibre length of 2.28 ± 0.496 mm observed in *Moringa oleifera* was lower than 2.31±0.49 mm in *Newbouldia laevis* as reported by Egbewole *et al.* (2016) 2.88±0.78 mm in *Bambusa vulgaris* as reported by Egbewole *et al.* (2015), but it was higher than 1.63±0.50 mm in *Saccharum officinarum as* reported by Egbewole *et al.* (2015). It is also higher compared to the minimum 0.7 -1.6mm value for hardwood fibre sources and to 1.7 mm values reported by Noah (2009) for bagasse fibres. Ogunwusi (1997) reported a close fibre length value of 2.41 mm for naturally grown *Sterculia setigera* while 2.64 mm was reported by Oluwadare and Egbewole (2008) for plantation grown *Sterculia setigera* (Table 5). Dinwoodie (1965) opined that fibre length is a critical factor to be considered in selecting any species for the production of high quality pulp for paper making. Thus, the long fibre length of *Moringa oleifera* may be characterized by high degree of opacity; stiffness and smoothness which are very suitable for making bank notes that can withstand rough handling (Noah, 2009).

(i) Results of fibre diameter of *Moringa oleifera*

The results revealed that the mean fibre diameter was 19.00 ± 1.89µm. The fibre diameter of the *Moringa* samples showed an increase of fibre diameter of

Table 3: Analysis of Variance for Measured fibre characteristics of *Moringa oleifera*

Sources of Variation		Fibre Length		Fibre Diameter		Lumen Width		Ce1llwall Thickness		Runkel Ratio		Felting Power		Flexibility Ratio	
	df	F	Sig.	F	Sig.	F	Sig.	F	Sig.	f	Sig.	f	Sig.	F	Sig.
Disk level (D)	4	10.50	0.00**	1.41	0.22 ns	3.937	0.020*	1.21	0.28 ns	264.41	0.00**	1.21	0.28 ns	25.00	0.00**
Radial Positiion(R)	3	2.72	0.02 *	0.63	0.54 ns	1.00	0.403 ns	0.46	0.721 ns	16.89	0.00**	0.26	0.85 ns	17.83	0.00**
Tree (T)	9	0.51	0.45 ns	0.35	0.71 ns	0.299	0.821 ns	1.01	0.373 ns	13.86	0.00**	1.26	0.26 ns	14.54	0.00**
D *R	12	1.46	0.06 ns	3.41	0.00**	4.34	0.000**	3.03	0.002*	77.71	0.00**	3.42	0.00**	83.58	0.00**
D* T	36	2.23	0.01*	0.29	0.89 ns	0.286	0.940 ns	0.56	0.699 ns	13.24	0.00**	0.59	0.65 ns	13.50	0.00**
R *T	27	1.51	0.05 *	0.85	0.54 ns	0.741	0.693 ns	1.51	0.096 ns	21.58	0.00**	1.09	0.31 ns	20.52	0.00**
D *R *T	108	1.10	0.24 ns	1.16	0.21ns	1.269	0.176 ns	1.37	0.086 ns	18.12	0.00**	1.01	0.41 ns	17.00	0.00**
Error	800														
Total	999														
R^2			**0.546**		**0.247**		**0.327**		**0.274**		**0.869**		**0.243**		**0.864**

Note: **= highly significant at 1% probability level, * = significant at p<0.05, ns = not significant

Table 4: Correlation coefficient matrix for ring width and fibre morphology

		Ring Width (mm)	Fibre Length (mm)	Fibre diameter (mm)	Lumen Width (µm)	Wall Thickness (µm)	Runkel Ratio	Felting Power	Flexibility ratio
1	Ring Width (mm)	1							
2	Fibre Length (mm)	0.250	1						
3	Fibre diameter (mm)	0.700**	0.711**	1					
4	Lumen Width (µm)	0.292	0.393	0.621**	1				
5	Wall Thickness (µm)	0.534*	0.529**	-0.850	0.514**	1			
6	Runkel Ratio	0.442*	0.446*	-0.439*	0.442*	0.735**	1		
7	Suppleness	0.429*	0.792	-0.81**	0.561**	0.947**	0.547**	1	
8	Flexibility ratio	0.634*	0.531**	-0.054	0.517**	0.432*	0.530**	0.536**	1

**Correlation is significant at the 0.01 probability level, *Correlation is significant at the 0.05 probability level

19.76±1.73 µm at the core wood, 19.60 ± 2.03 µm at the wood bark while the least fibre diameter of 19.39 ± 1.87 µm was recorded at the outer wood samples. Axial decrease was observed in fibre diameter with 20.10 ± 1.81µm at 25%, 19.54± 1.83 µm at 75% and the least 19.45±1.81µm was observed in fibre diameter at 850% disc levels (Table 2).The mean 19.00±1.89 µm fibre diameter of *Moringa oleifera* was slightly below the range of 20- 40µm fibre diameter for hardwood fibres as reported by (Usta and Eroghe, 1987), it was in a close range of 19.54 ±1.95 in *Newbouldia laevis* as reported by Egbewole *et al.* (2016) and to 20.0 µm fibre diameter in baggase as reported by Noah (2009) and 20.78±0.34µm byEgbewole*et al.* (2015) for *Saccharum officinarum*. This is lower than the observed trend reported by Ogunsanwo and Onilude (2000) on *Triplochiton scleroxylon.* However, The observed trend is lower compared to some non-wood materials for paper making as reported by Ogbonnaya, *et al.,* (1992) and Pahkala (2001) which showed the comparison of the *Moringa oleifera* with other wood and non-wood fibre sources that revealed that the fibre diameter gotten was to the observed 15.45µm in *Thaumatococcus daniellii* (Sotande, 2000), Bamboo (15.0µm) by Pande (1998) and 14.80±4.88 µm by Egbewole *et al.* (2015) same with *Hibiscus cannabinus* by Pande (1998) but lower than 34.87µm fibre diameter observed by Osadare and Udohitinah (1993) on *Abelmoschus esculentus,* 28.16µm in *Hibiscus cannabinus*, *Bombax buonopozense* 29.85 µm, *Musa sapentium* 30.16 µm and 28.53 µm in *Sterculia oblonga* (Table 5).

(iii) Results of lumen width of *Moringa oleifera*

The results revealed that the mean lumen width was 13.77 ±3 .13µm. The lumen width of the *Moringa* samples showed an increase of lumen width of 15.09±1.75 µm at the bark wood, 14.71±2.02µm at the middle wood while the least lumen width of 13.87±8.04 µm was recorded at the core wood samples. Axial decrease was observed in lumen width with 15.04±1.82 µm at 25%, 14.86±1.90µm at 50%, and the least 14.36±1.89 µm was observed at 5% disc level (Table 2). The mean lumen width of 13.77±3.13 µm observed was lower than the values observed on *Sterculia setigera* by Oluwadare and Egbewole (2008) and 14.57±4.36 µm in *Newbouldia laevis* by Egbewole *et al.* (2016) and higher than those reported for similar non wood fibres (Table 5).

(iv) Results of cell wall thickness of *Moringa oleifera*

The results revealed that the mean cell wall thickness was 2.59 ± 2.00 µm. The cell wall thickness of the *Moringa oleifera* samples showed that cell wall thickness of 2.44±4.67µm at a core wood of the wood samples, 2.43±0.49µm at the middle wood while the least cell wall thickness of 2.36±0.5µm was recorded at the bark samples of the wood. Axial increase was observed in cell wall thickness with 2.44 ± 0.50µm observed at 5%, 2.43±0.49 µm at 25% disc level, 2.32±0.57 µm at 50%, 3.17±4.49 µm at 75% while 2.27±0.54 µm was observed in cell wall thickness at 85% disc level (Table 3). However, the analysis of variance showed that there was a significant difference in the cell wall thickness observed within and between sample stems, while the effects of location and disc levels were not significant on the cell wall thickness of *Moringa oleifera* at $p<0.05$ (Table 2). The mean value for cell wall thickness was 2.59 ± 2.00µm which is lower than 8.56µm reported by Sotannde (2000) for *Thaumatococcus daniellii,* 2.94 µm for *Sterculia setigera* reported by Oluwadare and Egbewole (2008), 2.52±0.88µm for Bamboo by Rotowa (2014) but higher than 2.48±2.14µm reported for *Newbouldia laevis* by Egbewole *et al.* (2016). It is however considered that the fibre is fairly thin compared to Eucalyptus and Pine species (Hicks and Clark, 2001; Osadare, 2001) and as reported in Table 4 for other non-wood fibre sources. Colley (1973) reported that cell wall thickness affects specific gravity of fibrous raw materials which in turn has a marked effect on the pulp sheet properties.

(c) Results of Derived fibre Morphological Indices

(i) **Result of Flexibility Ratio (FR)**

The mean flexibility ratio was 66.76 ± 19.40%. The flexibility ratio of the samples showed an increase of flexibility ratio of 76.20 ± 5.02% at the bark wood, 75.66 ± 4.98% at the outer and middle parts of the wood while the least flexibility ratio 70.19 ± 37.50% was recorded at the core wood (Table 3).The mean flexibility ratio of 66.76 ± 19.40% observed in *Moringa oleifera* was higher compared to other woody and non woody fibre sources as reported in Sotannde, (2000) reported 22% flexibility ratio on *Thaumatococcus daniellii* (Sweet Prayers Plant), Osadare and Udohitinah, (1993) reported 22% flexibility ratio on *Abelmoschus esculentus* (okra bark), 21% on *Hibiscus cannabinus* (Kenaf), 20% on *Bombax buonopozense* (Gold coast bombax), Egbewole, *et al.* (2015) reported 63.81% on *Saccharum officinarum* (sugarcane bagasse). Rotowa (2014) reported 64.62% for *Bambusa vulgaris* (Bamboo) and 15% on *Musa sapentium* (bark). However, it is lower compared to 74.70±19.34% in *Newbouldia laevis* reported by Egbewole *et al.* (2015) and 78% reported by Oluwadare and Egbewole (2008) on *Sterculia setigera*. Flexibility ratio is another important criterion for evaluating fibre quality. This value falls under the second category of Osadare (1988) classifications (Table 4). This implies that the fibre will collapse partially and give an elliptical cross sectional form, good surface contact and fibre to fibre bonding. However, this high flexibility shows that the pulp of *Moringa oleifera* may be suitable to produce paper with greater burst and tensile which require high flexibility. This characteristics in *Moringa oleifera* may make it well suited for tissue, corrugating medium, newsprint, and writing paper as stated by Kellomäki (1998) and Covey *et al*. (2006).

(ii) Slenderness ratio/ Felting coefficient

The average Felting coefficient of *Moringa oleifera* was 119.30±26.96. The Felting coefficient of the samples ranged from 125.80±25.02 at the middle wood, followed by 124.02±25.07 at the outer wood while the least Felting coefficient of 109.60±32.02 was recorded at the bark of the wood samples. Felting coefficient of 123.80±25.34 was observed at 5% disc level, 123.00±26.43 at 75%, 118.13±22.73 at 25%, 116.00±23.02 at 50% and 114.00 ± 34.54at was observed at 85% disc level (Table 2).The mean 119.30±26.96 felting coefficient of Moringa was high compared to other woody and non woody fibre sources as reported in (Table 4). Egbewole *et al.* (2015) reported 76.73 on *Saccharum officinarum,* and 119.30 ± 26.96 on *Newbouldia laevis,* Rotowa (2014) reported 112.55 for *Bambusa vulgaris* (Bamboo) Oluwadare and Egbewole (2008) reported 101.50 felting coefficient on *Sterculia setigera*. According to Young (1998) and Bektas *et al*. (1999) if the slenderness ratio is lower than 70, it is invaluable for pulp and paper production. The slenderness ratio was found to be 109.60 it is greater than

≥70 and so can be utilized by the pulp and paper industry.

Table 5: Comparative assessment of Fibre Characteristics of *Moringa oleifera* and other woody and fibrous materials

S/no	Non wood fibre	Fibre Length (mm)	Fibre Diameter (µm)	Lumen Width (µm)	Cellwall Thickness (µm)	Runkel Ratio 2 x CW/LW	Felting Coefficient FL/FD	Flexibility Ratio LW/FDx100 (%)
1	< :***Moringa oleifera***	**2.28**	**19.54**	**13.77**	**2.37**	**0.35**	**119.30**	**66.76**
	Newbouldia laevis **Egbewole, *et al,*., 2016)**	2.31	19.54	14.57	2.48	0.31	119.30	74.70
	: *Bambusa vulgaris* (Bamboo) **(Egbewole, *et al,* 2015)**	2.88	14.80	9.55	2.52	0.55	112.55	64.62
4	*: *Saccharun officinarum* (Sugarcane bagasse) **(Egbewole *et al.,* 2015)**	1.62	20.78	13.26	7.52	0.57	76.73	63.81
5	***Thaumatococcus danielli*** (Sweet Prayers Plant) (**Sotannde, 2000)**	2.54	15.45	3.45	8.56	0.81	165.48	22
6	**Xx:** Bamboo **(Pande, 1998)**	2.7	15.0	-	-	-	180	-
7	**X:** Kenaf bastfibre (*Hibiscus cannabinus*) **(Pande, 1998)**	2.6	20.0	-	-	-	130	-
8	**Zz:** Jute (*Chorchorus capsularis*) **(Pande, 1998)**	2.5	20.0	-	-	-	135	-
9	**Z:** *Abelmoschus esculentus* (okra bark) (**Osadare and Udohitinah, 1993**)	3.49	34.87	7.63	19.62	0.78	100	22
10	**Kk:** *Hibiscus cannabinus* (Kenaf) (**Osadare and Udohitinah, 1993**)	2.90	28.16	6.08	16.0	0.76	105.1	21
11	**K:** *Bombax buonopozense* (Gold coast Bombax)	3.83	29.85	5.80	18.25	0.68	114.1	20
12	**Rr:** *Musa sapentium* (bark)	4.48	30.16	4.34	21.44	0.42	149.1	15
13	**R:** *Steculia roblonga* (yellow steculia bark)	3.27	28.53	8.49	11.54	1.77	115.1	30
14	**U:** Reed (*Arundo donax*) **(Pande, (1998)**	1.8	20	-	-	-	90.0	-

<=Currenr work, **+ =***Newbouldialaevis*(Egbewole, *et al.,* 2016) **=**, ++ = Bamboo (Egbewole, *et al.,* 2015), * = sugarcane bagasse (Egbewole*et al,* 2015), ** sweet prayer plant (Sotande, 2000), xx=Bamboo (Pande, 1998), x = Kenafbast, (Pande, 1998), zz =Jute (Pande, 1998), z = okra bark (Osadare and Udohitnah 1993),kk = Hibiscus **(**Osadare and Udohitnah 1993**),** u = Reed (Pande)

(iii)Runkel Ratio

The average Runkel Ratio of *Moringa oleifera* was 0.35 ± 0.66. 0.34± 0.49 in the outer wood, 0.33±1.01 at the middle wood while the least Runkel Ratio 0.31± 0.58 was recorded from the back wood samples. Axial increase was observed in Runkel Ratio with 0.33± 0.54observed at 5%, disc level, 0.32± 0.54 at 25%, 0.31±0.6was observed at 50% level and 0.47 ± 1.03 at 75% disc level while 0.29±0.60 was observed in Runkel Ratio at 85% disc level (Table 3). However the analysis of variance showed that there was no significant difference in the Runkel Ratio, slenderness ratio and flexibility ratio observed within and between sample stems and at various disk levels, also, there was significant difference in the Runkel Ratio observed within and between disc samples at $p<0.05$ (Table 2). However, the average of 0.35 Runkel ratio observed in *Moringa oleifera* was lower compared with the observation made by Oluwadare (1998) on non-wood species like 0.78 in *Musa ttextilis*, 0.95 in the bast of *Adansonia digitata* and 0.76 in *Hibiscus cannabinus.* The Runkel Ratio of the *Newbouldia laevis* samples is also lower than 0.79 for tropical Pine species (Ajala, 1997) 0.99 reported for both *Anthonathama crophylia* and *Dalium guinensis* hardwood species in Nigerian Rainforest Ecosystem (Ezeibekwe *et al*., 2009), 0.75 was reported by Awuku (1994) for some tropical hardwood species but the value was higher than the 0.25 and the range (0.28 and 0.68) reported for *Gmelina arborea* and some *Ficus* spp. respectively (Ogunkunle, 2010) and in a close range with 0.57 reported by Egbewole *et al.* (2015) on *Saccharum officinarum*. The value is lower than 0.59 as reported for *Leucaena leucocephala* (Oluwadare and Sotannde, 2007), and the 0.70 for *Dacryodes edulis* (Ajuziogu *et al*., 2010) and higher than 0.31 on *Newbouldia laevis* reported by Egbewole *et al.* (2016) (Table 4).

Dinwoodie (1965) stated that, the basis for establishing the suitability of raw material for pulp and paper making is that the Runkel ratio must be less than one. Volkomer, 1969 in agreement stated that, if the Runkel ratio is less than one, such fibre source is suitable for paper production. In the same vein, Bektas *et al*. (1999) stated that higher Runkel ratio gives lower paper strength properties especially lower burst, tear and tensile indexes, this was corroborated by Oluwadare and Egbewole (2008) who stated that Runkel ratio is closely associated with cell wall thickness and it influences paper strength properties. Therefore, the average of 0.35 Runkel ratio observed in *Moringa* established its suitability as a raw material for pulp and paper making.

Correlation Between Ring Width and Fibre Morphology

The simple correlation coefficients which elucidate the extent of linear relationships among ring width and fibre dimensions and their derived values are shown in Table

5. Ring width had low and insignificant relationship with all the selected properties. However, fibre diameter was significantly ($p<0.01$) correlated with lumen width (r = 0.96**), cell wall thickness (r = -0.99**), coefficient of flexibility (r = 0.92**) and Runkel ratio (r = -0.98**). Similarly lumen width had significant relationship with coefficient of flexibility (r = 0.95**) and Runkel ratio (r = -0.99**), while cell wall thickness had significant correlatio[illegible] and Runk[illegible] significantly correlated with Runkel ratio (r = -0.94**) (Table 5). These relationships show the dependence of the derived values on the fibre morphology. Therefore, the flexibility of the fibre is a function of the degree of cell wall thickness, lumen width and fibre diameter which affects pulp yield as well as response of the fibre to refining operations.

CONCLUSION AND RECOMMENDATION

Conclusion

Base on the results of the study on the Fibre [illegible] r pulp [illegible] were reached:

1. The fibre length of *Moringa oleifera* falls within short fibre cellulosic materials
2. Axial sampling showed no significant differences in the fibre qualities at any height on the stem indicating that *Moringa oleifera* trees possesses uniform pulping qualities suitable for pulp and paper production along it stem.
3. It is imperative that more detailed work on the wood quality parameters of this potentially promising pulpwood be examined as such information will be useful in future tree improvement programmes and plantation management of this species for the desired purpose.

Recommendations

The following recommendations should be considered:

1. Samples from different ecological zones should be looked into in order to assess the variations in the properties of the species from various regions
2. Detailed analysis should be conducted on *Moringa oleifera*. This will enhance its suitability as a potential source of short fibre wood pulp.
3. Pulp and Paper industries should harness the potential in *Moringa oleifera* as it can add to raw material stocks for pulp and paper industry in Nigeria.

REFERENCES

Adegbehin, J. O and Omijeh, J.E (1989). Raw materials for pulp and paper industry in Nigeria. Commonwealth Forestry Review 6(1): 35-45.

Ajala, O. O (1997). Evaluation of wood and fibre characteristics of Nigerian grown *Pinus carribaea*. M.Sc. Research Dissertation submitted to Department of Forest Resources Management, University of Ibadan, Nigeria, pp. 15- 49.

Atchison, J. E. (1995). Twenty-five years of global progress in nonwood plant fiber pulping; Historical Highlights, Present Status and Future Prospects. TAPPI Nonwood Plant Fiber Progress Report No. 22, pp. 111-130.

Awaku, F. A. (1994). Anatomical Properties of Afina [*Strombosia glaucescens*, var Lucida (J. Leonard)]. *Ghana Journal of Forestry*, Vol.1, 30-33.

Bektas, I., Tutus, A. and Eroglu, H. (1999). A Study of the Suitability of Calabrian Pine for Pulp and Paper Manufacture. *Turk. J. Agri. For.* 23 (3): 589-597.

Colley, E. (1973). African Timbers: The Properties, Uses and Characteristics of 700 Species. Division of Building Research, C.S.I.R.O. Melbourne, Australia. 723 p.

Dinwoodie, J. M. (1965). The Relationship between Fibre Morphology and Paper Properties: A Review of Literature. *Tappi*. pp. 440-447.

Ekhuemelo, D. O., and Udo, A. M (2016). Investigation of Variations in the Fibre Characteristics of *Moringa oleifera* (Lam) Stem for Pulp and Paper Production. *International Journal of Science and Technology*, 5(1): 19-25.

Egbewole, Z.T (2004): Investigation into selected wood quality indices of plantation grown *Sterculia sterigera.* M.Sc. Research Dissertation, Submitted to the Department of Forest Resource Management, University of Ibadan. 178 p.

Egbewole, Z. T., Omoake, P. O. and Rotowa O. J. (2015). Evaluation of Fibre Quality of *Saccharum officinarum* (Sugarcane) Bagasse as a Raw Material for Pulp and Paper Production. *NSUK Journal of Science and Technology,* 5(2): 142-149.

Egbewole, Z. T.,Rotowa O. J., Omoake, P. O. (2015). Evaluation of Fibre Quality of *Bambusa vulgaris* (Bamboo) as a Raw Material for Pulp and Paper Production. *Production Agriculture and Technology Journal,* 11(2): 189- 202.

Egbewole, Z. T., Rotowa O. J. and Suleiman A. I. (2016). Evaluation of fibre quality of *Newbouldia laevis (p. beav)* as raw material for pulp and paper production. *Journal of Forest Science and Environment,* 5: 21-30.

Ezeibekwe, I. O., Okeke, S.E, Unamba, C. I. N. and Ohaeri, J. C. (2009): An Investigation into the Potentials of *Dactyladenia bacteri*; *Dialum guineense*; and *Anthonotama crophylia* for Paper Pulp Production. *Report and Opinion*, 1(4): 18-25.

Fahey, J. W. (2005). *Moringa oleifera*: A Review of the Medical Evidence for Its Nutritional, Therapeutic, and Prophylactic Properties. Part1. Trees for Life Journal. www.TFLJournal.org

Hicks, C. C. and Clark, N. B. (2001). Pulp Wood Quality of 13 *Eucalyptus* Species with Potential for Farm Forestry. A Report for the RIRDC/Land and Water Australia/FWPRDC No.00/164. 38 p.

Jayeoba, O. J. (2013). Land suitability evaluation for arable agriculture in Nasarawa State using Geo-information. A Ph.D. Thesis, Department of Geography, Nasarawa State University Keffi, 247 p.

Ogunkunle, A. T. J. (2010). A Quantitative Modeling of Pulp and Paper Making: Suitability of Nigerian

Hardwood Species, *Advances in Natural and Applied Sciences*, 4(1): 14-21.

Kellomäki, S. (1998). Forest Resources and Sustainable Management. *Paper making Science and Technology*. Helsinki, Finland. 179 p.

Noah, S. A. (2009). *Fundamentals of Pulp and Paper Manufacture*. Fasco Publishers. Ibadan. pp. 11-12.

Oluwadare, A. O. (1998). Evaluation of the Fibre and Chemical Properties of some selected Nigerian Wood and Non-wood species for pulp production. *Journal of Tropical Forest Research,* 14: 110-119.

Oluwadare A. O. and Egbewole, Z. T. (2008). Wood quality studies in Plantation-grown (*Sterculia setigera* Del.) in the Guinea Savanna, Nigeria. *Research Journal of Forestry,* 2(1): 22-33.

Oluwadare, A. O. and Sotande, A. O. (2007). The Relationship Between Fibre Characteristics and Pulp-sheet Properties of *Leucaena leucocephala* (Lam.) DeWit. *Middle-East Journal of Scientific Research*, 2(2): 63-68.

Ogbonnaya, C ... (1992 ... *Gmelina arborea* Seedlings Grown under Five Soil Moisture Regimes. *Am. J. Bot*., 79(2): 128-132

Ogunkunle, A. T. J. (2010). A Quantitative Modelling of Pulp and Paper Making Suitability of Nigerian Hardwood Species. *Advances in Natural and Applied Sciences*. 4(1): 14-21.

Ogunsanwo, O.Y., Onilude, M. A. (2000). Radial and Vertical Variation in Fibre Characteristics of Plantation Grown *Obeche*: *Nig. J. For.,* 30(2): 33-37.

Ogunwusi, A. A. (1997): Wood Properties of *Sterculia setigera* Grown in the Savannah Belt of Nigeria. *Nig. J. For.* 27(1): 11-14.

Osadare, A. O. (2001). Basic Wood and Pulp Properties of Nigerian-Grown Caribbean Pine (*Pinuscaribaea)* and their Relationships with Tree Growth Indices. Ph.D. Thesis, Department of Agricultural Engineering, University of Ibadan, pp. 36-97.

Osadare, A. O. and Udohitinah, J. S. (1993). Fibre Characteristics of some Nigerian Raw Materials for Long Fibre Pulp Production. In: Oduwaiye, E. A. (Ed). Forestry for Urban and Rural Development in Nigeria, *FAN 23rd Conference*, pp. 132-138.

Pahkala, L. (2001). Non Wood Plants as raw materials for Pulp and Paper. *Agric. FoodSci*., 10(1): 1-101. Finland Supplement.

Pande, H. (1998). Non Wood Fibre and Global FibreSupply. *Unasylva*, 193(46): pp 44-50.

Radovich, T. (2012). Farm and Forestry Production and Marketing Profile for Moringa (*Moringa oleifera*). In: Elevitch, C. R. (Ed.). Specialty Crops for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Holualoa, Hawai‘i. http://agroforestry.net/scps. Accessed on 16/5/2013

Ramachandran, C., Peter, K. V. and Gopalakrishnan, P. K. (1980). Drumstick (*Moringa oleifera*): a multipurpose Indian vegetable. *Economic Bot.*, 34: 276–283.

Rotowa, O. J. (2014). Assessment of fibre characteristics of *Bambusa vulgaris* Schrad (Bamboo) from ... Forestry, Wildlife and Fisheries, Nasarawa State University Keffi, Nigeria for the award of B. Forestry and Wildlife Degree. 54 p.

Saikia, C., Goswani, T. and Ali, F. (1997). Evaluation of Pulp and Paper Making Characteristics of Certain Fast Growing Plants. *Wood Science Technology*, 31: 467-475.

Sotannde, A. O. (2000): Preliminary Investigation into the Fibre Characteristics of *Thaumatococcus danielli*. A dissertation submitted to the Department of Forest Resource Management for the award of Bachelor of Forestry Degree, University of Ibadan. 59 p.

Usta, M. and Eroglu, H. (1987): Soda - Oxygen Pulping Rye Straw. In: *Non wood Plant Fibre Pulping Conference.* Washington DC. TAPPI Press, Progress Report. No.18, pp. 113-118.

Volkomer, P. J. (1969): Wood Raw Materials for Pulp and Paper in Tropical Countries. In: *FAO International Review of Forestry and Forest Products*. Unasylva, 23 No. 3.