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FIBRE CHARACTERISTICS OF *Agave sisalana* FOR PULP AND PAPER PRODUCTION

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Abstract:

With the increase in demand for wood and wood products, there is need to find alternative sources for the production of pulp and paper. Non wood plants have attracted interest due to their short growth cycles, moderate irrigation and fertilizer requirements and low lignin content. This study aimed at investigating the fibre characteristics of Agave sisalana for pulp and paper production.

Leaves were collected from three sisal plant stands in Oyo State, Nigeria. The plant whorl was divided systematically into bottom, middle and top from which five leaves were randomly collected from each whorl position. The fibres of the leaves were extracted from which 2cm of fibres were taken from three positions on the leaf (top, middle and base). Extracted fibres were macerated and 3375 fibres were measured.

The result shows that the fibre length of sisal increased with increasing length of the leaves from base to top with a mean value of 1.68mm. The fibre diameter and cell wall thickness averaged 16.98µm and 2.32µm respectively decreasing from the stem base to the top. The slenderness ratio averaged 99.4 while the coefficient of flexibility averaged 72.61. The highest value of the runkel ratio of Agave sisalana was 0.42. The fibres from sisal (Agave sisalana) leaves possess good fibre dimensions and derived values which will make it suitable for the production of high quality paper.

Key words*: fibre dimensions; Agave sisalana; fibre length; cell wall thickness.*

INTRODUCTION

Consumption of paper and paper products is increasing in Nigeria daily due to increasing technological awareness and advancement in education (Oluwadare 2007). Sharma *et al*. (2013) projected world paper consumption by 2020 to be 500 million tons.

The fibers of wood from angiosperm (hardwood) and gymnosperm (softwood) have desirable fiber characteristics for pulp and paper production, but over exploitation of the forest over the years have resulted in continuous decline in their supply for pulp and paper production (Ashori 2006). In view of the shortage of conventional raw materials for pulping and the increasing demand for paper products worldwide, it is therefore evident that new sources of pulp and paper raw materials should be sourced (Ververis *et al*. 2004). This seems to be a positive step towards meeting the demand for pulp (Ogunleye *et al*. 2016). Non-wood plants and agricultural residues have attracted renewed interest for pulp production. Some of these include cereal straw and bagasse, or plants grown specifically for the fiber, such as bamboo, reeds, and some other grass plants such as flax, hemp, kenaf, jute, sisal, or abaca (Marques *et al*. 2010, Shakes *et al*. 2011). Some of the advantages of using non-wood plants include short growth cycles, moderate irrigation and fertilization requirements and low lignin content resulting to reduced energy and chemicals use during pulping (Hurter and Riccio 1998).

However, before recommending any species for pulp production, the detail anatomical (fibre) properties is necessary in order to be well furnished with adequate information on how these properties will affect its paper performance as the quality of paper to a majorly depends on the quality of its fibres (Ogunleye *et al*. 2016). Understanding of the fibre characteristics has been considered to be the most important factor for determining the degree of efficiency of wood species in pulping (Ogunwusi 2001). The morphological characteristics of a fibre, such as fibre length and width, are important parameters in estimating the qualities of pulp (Marques *et al*. 2010).

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OBJECTIVES

The objective of this study is to investigate the fibre morphological properties of *Agave sisalana* as a potential fibrous raw material for pulp and paper production.

MATERIALS AND METHODS

Agave sisalana used for this study was harvested from Awotan area of Ido Local Government Area, Oyo State, Nigeria. The leaf was the plant part used for this study was collected from three sisal plant stands. The plant whorl was divided systematically into bottom, middle and top from which five leaves were randomly collected from each whorl position. The fibres of the leaves were extracted by mechanical means through beating of the leaves, scrapping and washing. Extracted fibres were dried from which 2cm of fibres were taken from three positions on the leaf (top, middle and base). For fibre characteristics determination, extracted fibres were macerated with 30% hydrogen peroxide and 10% glacial acetic acid in a 1:1 ratio and placed in a boiling water for 2hrs (Oluwadare 2007). After boiling, the fibres were decanted and rinsed with water. Fibres were then separated into individual fibres by vigorously shaking the solution. The resultant fibre suspension was place on a slide and stained with safranin solution. The fibre length (mm), lumen width (µm), fibre diameter (µm) and cell wall thickness (µm) were then measured using a calibrated microscope. 25 randomly selected fibres were measured giving a total of 3375 fibres (3 plants x 3 positions on the branch x 3 positions on the leaf x 5 leaves x 25 fibres). Derived values were obtained using the values obtained from measured fibre dimensions according to Ververis *et al*. (2004).

$$Slenderness\ ratio = \frac{FL}{FD} \quad (1)$$

$$Flexibility\ coefficient = \frac{\frac{LW}{FD}}{100} \quad (2)$$

$$Runkel\ ratio = \frac{2 \times CWT}{LW} \quad (3)$$

$$F - factor = \frac{FL}{CWT} \quad (4)$$

$$Muhlsteph\ ratio = \frac{FD^2 - LW^2}{FD \times 100} \quad (5)$$

where: FL = Fibre length;
FD = Fibre diameter;
LW = Lumen width;
CWT = Cell wall thickness.

Data collected was subjected to analysis of variance (ANOVA, $p<0.05$) with the sources of variation being the position on the whorl/stem and position on the leaves.

RESULTS AND DISCUSSION

The fibre dimensions of *Agave sisalana* are presented in Table 1 and 2 showing values obtained for fibre length, fibre diameter, lumen width and cell wall thickness. The fibre length of sisal increased with increasing length of the leaves from base to top with values ranging from 1.27-2.08mm and an average value of 1.68mm. Similar pattern of variation was observed by Ververis *et al.* (2004) for fibre length of kenaf stalk. The longest fibres were found at the top of the leaf while it was shorter at the base of the leaf. It was however different at the stem position as the longest fibre was obtained at the middle with the leaves collected from the top of the stem having the shortest fibres. The fibre length was lower than that reported by Marques *et al*. (2010) who reported a value of 3.03mm but higher than 0.85-1mm reported by Dungani *et al*. (2016). There was no significant difference in the fibre length of leaves collected at various positions of the stem however, significant difference was observed in the length of fibres collected at different position in the leaf stalk at $p>0.05$ (Table 3).

The fibre diameter reported by Marques *et al*. (2010) to be 17µm was within the range of value from this study but lower than 100-300 reported by Dungani *et al*. (2016). The fibre diameter and cell wall thickness was found to be decreasing from the stem base to the top following the general pattern with values ranging from 15.12-20.64µm and 1.93-2.56µm and averages of 16.98µm and 2.32µm respectively. This goes to show that fibre diameter is highly correlated with the cell wall thickness. This can be explained by the fact that cell wall growth is dependent on the accumulation of metabolism products which increases with maturity (Vallet *et al*. 1996, Ververis *et al*. 2004). This also supports the report of Ververis *et al*. (2004) who stated that reduction in fibre diameter from bottom to top was due to a similar decrease in the cell wall thickness. Fibre diameter and cell wall thickness had a similar pattern of variation as they decreased from base to top along the stem and this follows the general pattern of variation. The fibre diameter and cell wall thickness was however inconsistent along the leaf as it decreased from base to middle and later increased to the top. There was no significant difference in the diameter and cell wall thickness of fibres collected at different positions of the leaf stalk. Significant difference was observed in the cell wall thickness of leaf fibres collected at different positions of sisal stem at p>0.05 (Table 3).

Table 1

Fibre dimensions of leaves of Agave sisalana

SP	LP(%)	FL (mm)	FD (µm)	LW (µm)	CWT (µm)
	10	1.29	17.95	13.11	2.42
Base	50	1.70	16.99	12.17	2.50
	90	2.06	17.77	12.96	2.41
	10	1.31	16.98	12.31	2.33
Middle	50	1.72	16.15	11.60	2.28
	90	2.08	17.07	12.43	2.32
	10	1.27	16.33	11.82	2.26
Top	50	1.67	16.37	12.03	2.17
	90	2.05	17.20	12.58	2.31

where: SP= Stem position, LP= Leaf position, FL= Fibre length, FD= Fibre diameter, LW= Lumen width, CWT= Cell wall thickness

Table 2

Summary of fibre characteristics

	FL (mm)	FD (µm)	LW (µm)	CWT (µm)
Stem Base	1.68^{a}	17.57^{a}	12.75^{a}	2.41^{a}
Stem Middle	1.70^{a}	16.73^{a}	12.12^{a}	2.31^{ab}
Stem Top	1.66^{a}	16.64^{a}	12.14^{a}	2.25^{b}
Leaf Base	1.29^{a}	17.09^{a}	12.41^{a}	2.34^{a}
Leaf Middle	1.70^{b}	16.50^{a}	11.93^{a}	2.29^{a}
Leaf Top	2.06^{c}	17.35^{a}	12.66^{a}	2.35^{a}

Means with the same superscript are not significantly different at p<0.05

Table 3

ANOVA for fibre characteristics

Sources of variation	DF	FL	FD	LW	CWT
Stem	2	0.406531^{ns}	0.179906^{ns}	0.308636^{ns}	0.048348*
LP	2	0.000000*	0.284977^{ns}	0.283187^{ns}	0.578538^{ns}
Stem*LP	4	0.996664^{ns}	0.913270^{ns}	0.850357^{ns}	0.896448^{ns}
Error	18				
Total	26				

"*" denotes "significant at (p<0.05)"; "ns" denotes "not significant at (p>0.05)"

The derived fibre dimensions of *Agave sisalana* are presented in Table 4 and 5. The slenderness ratio otherwise called felting power ranged from 62.40-133.33 with a mean value of 99.4. The average slenderness ratio is lower than that of 105 for kenaf (bast) (Udohitinah and Oluwadare 2011) and 174.1 for miraculous berry stalk (Sotannde 2015) but higher than 50.34 for maize stalk (Ekhuemelo and Tor 2013), 53.13 for Wheat straw (Deniz *et al*. 2004), 60.13 for rice straw (Tutus *et al*. 2004) and 50.9 for tobacco stalk (Shakes *et al*. 2011).

The coefficient of flexibility ranged from 70.42-75.23 having an average of 72.61. The coefficient of flexibility was however higher than 57 for kenaf (bast) (Udohitinah and Oluwadare 2011), 64.54 for miraculous berry stalk (Sotannde 2015) 45.3 for maize stalk (Ekhuemelo and Tor 2013), 33.04 for Wheat straw (Deniz *et al*. 2004), 43.24 for rice straw (Tutus *et al*. 2004) and 63.28 for tobacco stalk (Shakes *et al*. 2011).

The highest value of the runkel ratio of *Agave sisalana* was 0.42 which is far below the recommended value of 1. When compared to other non-wood biomass, the average runkel ratio (0.38) was lower as Udohitinah and Oluwadare (2011) reported 0.76 for kenaf (bast), Sotannde (2015) reported 0.57 for miraculous berry stalk, Ekhuemelo and Tor (2013) reported 1.23 for maize stalk, Deniz *et al*. (2004) reported 2.23 for Wheat straw, Tutus *et al*. (2004) reported 1.98 for rice straw and Shakes *et al*. (2011) reported 1.16 for tobacco stalk.

The F-factor and Mulsteph ratio had average values of 727.55 and 47.26 respectively. No particular variation was observed in the derived indices except for the slenderness coefficient that increased from the base to top of the leaf thus the top of the leaf will produce a better surface contact and fibre to fibre bonding than the base of the leaf.

Statistical analysis revealed that no significan difference was observed in the derived characteristics of fibres from Agave leaf collected from different positions on the stem (Table 6). However, significant difference was only recorded in the slenderness ratio and F factor of the fibres collected from different positions of the leaf stalk.

Table 4

Derived fibre indices of leaves of Agave sisalana

SP	LP	SR	CoF	RR	Ff	MR
	10	72.42	72.84	0.37	532.20	46.91
Base	50	100.74	71.57	0.40	707.74	48.77
	90	115.69	72.96	0.37	856.06	46.77
	10	77.59	72.43	0.38	562.50	47.52
Middle	50	106.88	71.83	0.39	758.98	48.40
	90	122.19	72.88	0.37	905.95	46.86
	10	77.83	72.32	0.38	562.53	47.68
Top	50	102.12	73.52	0.36	775.59	45.93
	90	119.15	73.11	0.37	886.25	46.55

where: SP= Stem position, LP= Leaf position, SR= Slenderness ratio, CoF= Coefficient of flexibility, RR= Runkel ratio, Ff= F-factor, MR= Mulsteph ratio

Table 5

Summary of derived fibre characteristics

	SR	CoF	RR	Ff	MR
Stem Base	96.29^a	72.46^a	0.38^a	698.67^a	47.48^a
Stem Middle	102.22^a	72.38^a	0.38^a	742.51^a	47.59^a
Stem Top	99.70^a	72.99^a	0.37^a	741.46^a	46.72^a
Leaf Base	75.95^a	72.53^a	0.38^a	552.41^a	47.37^a
Leaf Middle	103.25^b	72.31^a	0.38^a	747.44^b	47.70^a
Leaf Top	119.01^c	72.99^a	0.37^a	882.79^c	46.73^a

Means with the same superscript are not significantly different at p<0.05

Table 6

ANOVA for derived fibre characteristics

Sources of Variation	DF	SR	CoF	RR	Ff	MR
Stem	2	0.256213^{ns}	0.572487^{ns}	0.782560^{ns}	0.286223^{ns}	0.577042^{ns}
LP	2	0.000000*	0.541459^{ns}	0.441650^{ns}	0.000000*	0.551361^{ns}
Stem*LP	4	0.980722^{ns}	0.550849^{ns}	0.688188^{ns}	0.976607^{ns}	0.546355^{ns}
Error	18					
Total	26					

"*" denotes "significant at (p<0.05)"; "ns" denotes "not significant at (p>0.05)"

The leaf of sisal have a good fibre characteristics as well as derived characteristics when compared in line with the report of Dewi and Supartini (2011) shown in table 7 thus sisal fibres fall within the grade 2 fibres. Sisal fibres are expected to have increased mechanical strength due to their good derived values and thus suitable for writing, printing, wrapping and packaging purposes. (Ververis *et al.* 2004).

Table 7

Quality criteria of fibres as raw material for pulp and paper

	Class 1		Class 11		Class 111	
Parameter	Requirement	Score	Requirement	Score	Requirement	Score
Fibre length	>2000	100	1000-2000	50	<1000	25
Runkel ratio	<0.25	100	0.25-0.5	50	0.5-1.0	25
Slenderness ratio	>90	100	50-90	50	<50	25
Flexibility ratio	>0.8	100	0.5-0.8	50	<0.5	25
Coefficient of rigidity	<0.10	100	0.1-0.5	50	>0.5	25
Mulsteph ratio	<30	100	30-60	50	60-80	25
Interval	450-600		225-449		<225	

Source: Dewi and supartini (2011)

CONCLUSION

The investigation of fibre characteristics of the leaf of sisal (*Agave sisalana*) shows that it possesses good fibre dimensions and derived values which will make it suitable for the production of high quality paper. The fibre dimensions and derived values are similar to those of hardwoods and softwoods. The fibres from sisal can be mixed with conventional softwood pulps whose fibre lengths are generally higher than both hardwood and other non-wood fibres to make a wide range of paper grades.

REFERENCES

Ashori A (2006) Non-wood fibers- potentials source of raw materials in papermaking. *Polymer Plastic Technical Engineering Journal,* 45(10):1133-1136.

Deniz I, Kirci H, Ates S (2004) Optimisation of wheat straw triticum drum kraft pulping. *Industrial crops and products* 19:237-247.

Dewi LM, Supartini (2011) Anatomical properties of *Shorea mujongensis*. A critically endangered species of Dipterocarps from Kalimantan. *Journal of Forestry Research,* Vol 8(2):91-100.

Dungani R, Karina M, Subyakto, Sulaeman A, Hermawan D, Hadiyane A (2016) Agricultural Waste Fibers Towards Sustainability and Advanced Utilization: A Review. *Asian Journal of Plant Sciences,* 15:42-55.

Ekhuemelo DO, Tor K (2013) Assessment of fibre characteristics and suitability of maize husk and stalk for pulp and paper production. *Journal of research in forestry, wildlife and environmental volume* 5(1).

Hurter RW, Riccio FA (1998) Why CEOS don't want to hear about nonwoods or should they? In: TAPPI Proceedings, NA Nonwood Fiber Symposium, Atlanta, GA, USA, pp. 1–11.

Marques G, Rencoret J, Gutiérrez A, del Río JC (2010) Evaluation of the chemical composition of different non-woody plant fibers used for pulp and paper manufacturing *The Open Agriculture Journal*, 4:93-101.

Ogunleye BM, Fuwape JA, Oluyege AO, Ajayi B, Fabiyi JS (2016) Evaluation of fibre characteristics of *Ricinodedron heudelotii* (Baill, Pierre Ex Pax) for pulp and paper making. *International Journal of Science and Technology* Volume 5(12):634-641.

Ogunwusi AA (2011) Variation in pulp characteristics of *Pinus carribaea*. Department of Forest Resources Management, University of Ibadan.

Oluwadare AO (2007) 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):359-363.

Shakes J, Marandi MAB, Zeinaly F, Saraian A, Saghafi T (2011) Tobacco residuals as a promising lignocellulosic materials for pulp and paper industry. *BioResources* 6(4):4481-4493.

Sharma M, Sharma CL, Kumar YB (2013) Evaluation of fiber characteristics in some weeds of Arunachal Pradesh, India for pulp and paper making. *Research Journal of Agriculture and Forestry Sciences,* 1(3):15-21.

Sotannde AO (2015) Suitability of stalks of miraculous berry (*Thaumatococcus daniellii* Benth) as an alternative non-wood fibre for pulp and paper making. PhD Diss. University of Ibadan, Nigeria.

Tutus A, Deniz I, Eroglu H (2004) Rice straw pulping with oxide added soda oxygen anthraquinone. *Pakistan journal of Biological Science* 7(8):1350-1354.

Udohitina JS, Oluwadare AO (2011) Pulping properties of kraft pulp of Nigeriaan grown henaf (Hibiscus cannabinus L) *BioResources* 6(1):751-761.

Vallet C, Chabbert B, Czaniski Y, Monties B (1996) Histochemistry of lignin deposition during schlerenchyma differentiation in alfalfa stems. *Ann. Bot*. 78:625–632.

Ververis C, Georghiou K, Christodoulakis N, Santas P, Santas P (2004) Fibre dimensions, lignin and cellulose content of various plant materials and their suitability for paper production. *Industrial Crops and Products*, 19:245–254.