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EVALUATION OF FIBRE QUALITY OF *SACCHARUM OFFICINARUM* (SUGARCANE) BAGASSE AS A RAW MATERIAL FOR PULP AND PAPER PRODUCTION.

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ABSTRACT

Long fibre raw materials for pulp and paper industries have been a major setback to paper Industry in Nigeria. Therefore an alternative raw material for pulp and paper production becomes a major concern to researchers. This study assessed the fibre quality of Saccharum officinarum Bagasse as raw material for pulp and paper production. Samples of Sugarcane bagasse were collected from Doma, Lafia and Keffi in Nasarawa State. The study was laid out in a 3 x 15 x 3 factorial experiment in a completely randomized design (CRD). The treatment was analyzed with respect to 3 locations, 15 stem samples and 3 disc levels while the variable measured were:- fibre length, fibre diameter, lumen width, cell wall thickness, Runkel ratio, flexibility ratio and felting coefficient. The average fibre length was 1.63mm, 20.78µm fibre diameter, 13.30µm lumen width, 56µm cell wall thickness, 0.72 Runkel ratio, 64.0 flexibility ratio and 76.82% felting coefficient. 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 stems, while the effects of location and disc levels were not significant on the observed fibre characteristics at $p<0.05$. Sugarcane bagasse fibre characteristics as reported in this study, showed that, they are well suited for tissue, corrugating medium, newsprint, and writing paper. However, detailed analysis should be conducted on bagasse, this will enhance its suitability as a potential source of short fibre non wood pulp. Pulp and Paper industries should harness the potential in Sugar cane bagasse as it can be used to revive the Nigerian pulp and paper industry.

Keywords: Fibre length, wall thickness, Runkel Ratio, flexibility ratio, felting coefficient

INTRODUCTION

The growing demand for pulp and paper products in Nigeria has resulted to the development of multiple ranges of dependent industries ranging from pulp and paper mills, paper/paperboard conversion mill to newsprint, books and stationery industries (Oluwadare and Egbewole, 2008). Pulp and paper products are important requirements to the economic development of any nation. In the past few decades, there has been drastic increase in the consumption of pulp and paper products in Nigeria. For instance, Nigeria has imported ₦11 million and ₦150million worth of pulp and paper products between 1970 and 1988 respectively. Nigerian pulp and paper 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).

Long fibre raw materials for pulp and paper industries have been a major setback to paper Industry in Nigeria. Therefore an alternative raw material for pulp and paper production becomes a major concern to researchers. Hence to overcome this shortage and the increasing demand of paper product, the non-woody plants were attracted by researcher to use them as a source of paper production due to their several advantages such as short growth cycles, moderate irrigation and fertilization requirements and low lignin content which reduces the energy and chemicals used in pulping process (Hurter and Riccio, 1998).

In the tropics, sugarcane represents a major crop. Because of the increasing demand for sugar in last century, large areas in the tropical and subtropical countries around the world were allotted for sugar cane crops. Low level of maintenance and good productivity made sugar cane an attractive crop for farmers in these regions. Besides the main product, sugar juices and several by-products are available in the sugar extraction process, Paturau (2005) pointed out that the most important is bagasse. Actually, bagasse is a waste product from sugar cane and is often neglected by many. Bagasse fibres serve as secondary fibres and their usage therefore helps to keep the environment clean.

Production, Storage and Composition of Sugarcane Bagasse

Bagasse is the fibrous matter that remains after sugarcane is crushed to extract their juice. It is currently used as a biofuel and in the manufacture of pulp and paper products and building materials. It is often common in countries like India, Mexico, and Brazil, where it is extensively used as raw material for pulp and paper making. Fibre in bagasse consists mainly of cellulose, pentoses and lignins. Cellulose is a natural linear polymer and has polymer chains of 2000 to 3000 units (Paturau, 1989; Elsunmi, 1993).

Processing of cane is crushed in a series of mills, each consisting of at least three heavy rollers. Due to the crushing, the stalk will break into small pieces and subsequent milling will squeeze the juice out. The juice is collected and processed for production of sugar. The resulting crushed and squeezed cane stalk, named bagasse is considered to be a by-product of milling process (Elsunmi, 1993). Bagasse is essentially a waste product from sugarcane milling process. According to Atchinson (1995) bagasse will be ahead of other crops as a source for pulp in paper industry

Saccharum officinarum as alternative fibre source

Comparatively, little use is at present being made of this material that can be grown as annual crop. Before pulpwood was used, agricultural materials and residues played an important role in the paper industry and often yielded high-quality products. Such resources today are almost always utilized exclusively in small-scale operations (Phillips, 1983). Consequently, there is need to investigate the fibre characteristics of lesser-used fibrous materials like *Saccharum officinarum*, for its pulping potential. This research work intends to assess the characteristics of bagasse fibres with regards to different points within stand and within different stems of *Saccharum officinarum*. There is now considerable evidence to show that resources whose potentials had previously been disregarded, particularly agricultural residues like bagasse have a bright future Ajuziogu, *et al* (2010). It is on this background that this study on fibre characteristics of bagasse (*Saccharum officinarum)* was carried out.

MATERIALS AND METHODS

Raw Materials

Samples of *Saccharum officinarum* sugar canes were collected at the sugar cane plantation of FADAMA III project site at Doma Local Government Area, Keffi and Lafia in Nasarawa State. In each sites, twenty (20) stands were randomly selected from each location and harvested. Samples were cut into 20cm disc collected at 25%, 50% and 75% of the total height of the sugarcane stems (Plate 1, 2 & 3).

Plate 1: Sugarcane Plantation

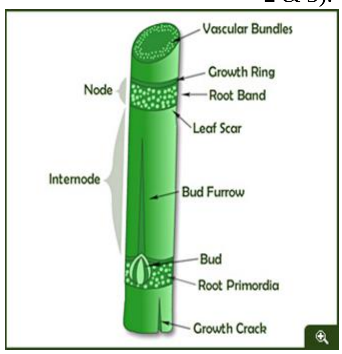

Plate 2: Annotated diagram of a Sugarcane Stem

Plate 3: Sugarcane bagasse after juice has been extracted.

Source: Sugarcane crop (2013)

Table 1: The coordinate of locations where *Saccharum officinarum* (sugar cane) samples were collected

		Co-ordinate		
S/n	Location	Longitude (θ)	Latitude (θ)	Elevation (m)
1	Doma	8º 27´	8º36´	139
2	Keffi	8.725	7.830	273
3	Lafia	8.597	8.593	160

Jayeoba (2013).

Sample Preparation

Bagasse were collected from *Saccharum officinarum* (sugar cane) cut into 20cm discs collected at 25%, 50% and 75% of the total height of the sugarcane stems. Each disc of 20cm long was crushed and sundried to remove the moisture in it. Five slivers were obtained randomly from each of the sampled disk, this amounted to fifteen randomly selected stem samples from which 45 sample discs were obtained from each cane stand, totaling 225 fibres used for this study. Bagasse slivers obtained were put into 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˚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 sheken 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 Rheichert visopan microscope screen was measured for fibre length, diameter, lumen width and cell wall thickness. From these, 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. Runkel Ratio/ Rigidity Coefficient = $\dfrac{2 \times \text{Cell wall Thickness}}{\text{Lumen width}}$

ii. Felting Coefficient/ slenderness ratio = $\dfrac{\text{Fibre Length}}{\text{Fibre Diameter}}$

iii. Flexibility Ratio/ Elasticity Coefficient = $\dfrac{\text{Lumen width} \times 100\%}{\text{Fibre Diameter}}$

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

RESULTS AND DISCUSSIONS

(a) Result of physical characteristics of *Saccharum officinarum*

The results of physical characteristics of *Saccharum officinarum* showed that the mean wet weight of the cane sampled was 133.89±23.85 g, average sample volume was 125.17±21.92 cm^3. The highest volume of 135±24.3 cm^3 was observed axially at 25% disc level, followed by 124±20.5 cm^3 at 50% and the least volume of 115±17.3 cm^3 was observed at 75% disc level. Samples collected from Lafia had the highest volume of 132±2.34 cm^3, followed by 128±16.5 cm^3 at Keffi while the least 115±22.8 cm^3 was recorded in *Saccharum officinarum* collected at Doma. Mean dry weight of 61.75±18.16g with a range between 79.98±6.87 g in sample 9 and 44.52±3.91 g found in sample 3. Axially, there was an increase in the dry weight 75% disc level had the least 49.03±18.74 g, followed by 66.21 g±14.64 g at 50% disc level and the highest dry weight of 70.01±14.26 g at 25% disc level (Table 2).

(b) Result of fibre characteristics of *Saccharum officinarum* bagasse

The results of the fibre characteristics of *Saccharum officinarum* bagasse showed that the mean fibre length was 1.63±0.50 mm, mean lumen width of 13.26±0.32µm, fibre diameter of 20.78 ±0.34µm and mean cell wall thickness of 7.52±0.15µm (Table 3).

Table 2: Mean Values of physical characteristics of *Saccharum officinarum*

	Wet Weight (g)	Dry Weight (g)	Girth (cm)	Length (cm)	Volume (cm³)	Density (g/cm³)
Location						
Keffi	138.15±16.55[a]	67.52±14.69[a]	12.62±0.81[a]	10.05±0.17[a]	128±16.5[a]	0.53±0.06[a]
Lafia	140.24±26.93[a]	64.30±14.92[a]	12.82±1.12[a]	10.05±0.14[a]	132±2.34[a]	0.48±0.07[a]
Doma	123.28±24.50[a]	53.43±21.94[a]	11.95±1.16[a]	10.05±0.14[a]	115±22.8[a]	0.45±0.06[a]
Sample						
1	106.03±11.21[ab]	47.15±6.19[a]	11.30±0.72[b]	10.10±0.10[a]	102±13.2[ab]	0.46±0.09[a]
2	121.57±25.79[bcde]	49.76±28.75[ab]	11.93±0.90[b]	10.00±0.17[a]	114±18.4[b]	0.43±0.06[a]
3	94.86±6.12[a]	44.52±3.91[a]	10.53±0.60[a]	10.13±0.15[a]	90.36±9.9[a]	0.49±0.07[a]
4	143.39±20.73[fg]	73.01±11.20[bcd]	12.70±0.66[d]	9.93±0.15[a]	127±13.2[cd]	0.57±0.05[a]
5	148.51±19.89[fg]	66.13±15.34[abcd]	13.15±0.98[de]	10.10±0.09[a]	139±20.0[d]	0.48±0.03[a]
6	157.10±20.13[gh]	77.71±27.72[cd]	13.47±0.61[e]	10.03±0.21[a]	145±13.6[e]	0.53±0.05[a]
7	118.52±4.46[bc]	67.91±15.38[abcd]	11.53±0.35[b]	10.00±0.10[a]	106±5.29[b]	0.64±0.10[a]
8	119.21±5.46[bcd]	49.58±33.94[ab]	11.77±0.23[b]	10.00±0.20[a]	109±4.63[b]	0.45±0.05[a]
9	169.89±14.72[g]	79.98±6.87[abcd]	14.17±0.48[f]	10.20±0.10[a]	163±10.5[f]	0.49±0.04[a]
10	135.29±30.23[cdef]	62.33±10.32[d]	12.80±0.79[de]	9.93±0.05[a]	129±16.6[d]	0.48±0.11[a]
11	141.69±6.45[efg]	60.60±5.85[abcd]	12.57±0.15[cd]	10.17±0.23[a]	127±10.9[cd]	0.48±0.05[a]
12	132.31±13.29[cdef]	54.92±15.70[abcd]	12.62±0.86[cd]	10.00±0.14[a]	127±16.6[cd]	0.43±0.08[a]
13	139.15±13.18[defg]	71.60±5.18[abcd]	12.67±0.75[d]	10.03±0.15[a]	128±16.6[cd]	0.56±0.04[a]
14	140.12±13.10[fg]	71.06±5.11[abc]	13.60±0.80[e]	9.70±0.18[a]	126±16.1[cd]	0.56±0.04[a]
15	137.22±6.43[efg]	77.02±5.01[ab]	11.00±0.18[a]	10.60±0.02[a]	129±10.2[d]	0.59±0.03[a]
Disc level						
25%	146.51±25.35[a]	70.01±14.26[b]	12.96±1.16[c]	10.04±0.15[a]	135±24.3[c]	0.51±0.08[a]
50%	134.26±21.72[b]	66.21±14.64[b]	12.43±1.05[b]	10.05±0.12[a]	124±20.5[b]	0.53±0.05[a]
75%	120.90±17.95[c]	49.03±18.74[a]	12.00±0.89[a]	10.05±0.17[a]	115±17.3[a]	0.42±0.06[a]
GM	**133.89±23.85**	**61.75±18.16**	**12.46±1.09**	**10.05±0.15**	**125.17±21.92**	**0.49±0.06**

Note: means with different alphabet on the same column were significantly different at $p<0.05$

(i) Results of fibre length of *Saccharum officinarum*

The mean fibre length was 1.63±0.50 mm. The longest fibre length of 1.69±0.86 mm was observed axially at 50% disc level, followed by 1.60±0.05 mm at 75% and the least fibre length of 1.59±0.05 mm was observed at 25% disc level. Samples collected from Doma had the highest fibre length of 1.70±0.86mm, followed by 1.59±0.04mm both at Keffi and Lafia. 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 stems, while the effects of location and disc levels were not significant on the observed fibre length, lumen width, fibre diameter and cell wall thickness of *Saccharum officinarum* at $p<0.05$ (Table 4).

The mean fibre length 1.63±0.50 mm observed in *Saccharum officinarum* was lower than 2.7-4.6 mm reported by (Atchison, 1987) on fibre lengths of selected softwoods, and close to the minimum 0.7 - 1.6 mm value for hardwood fibre sources. It is also close to 1.7 mm values reported by Noah (2009) for bagasse fibres. Ogunwusi (1997) reported a higher fibre length value of 2.41mm for naturally grown *Steculia setigera* while 2.64 mm was reported by Oluwadare and Egbewole (2008) for grown *Steculia setigera*. Fibre length is a critical factor to consider in selecting any species for the production of high quality pulp for paper making (Dinwoodie, 1965). The short fibre length of bagasse is characterized by high degree of opacity; stiffness and smoothness which are very suitable for making bank notes which can withstand rough handling (Noah, 2009).

(ii) Results of fibre diameter of *Saccharum officinarum*

The results revealed that the mean fibre diameter was 20.78±0.34 µm ranging between 17.65±0.39 µm and 22.90±0.13 µm. The fibre diameter of the cane samples collected at different locations showed an increase of fibre diameter of 20.75±0.35 µm from Doma, 20.75±0.39 µm at Lafia while the largest fibre diameter of 20.83±0.27 µm was recorded in samples from Keffi. Axial decrease was observed in fibre diameter with 20.78±0.35 µm observed at

25% and 50% disc levels while 20.77±0.33 µm was observed in fibre diameter at 50% disc level.

The mean 20.78±0.34 µm fibre diameter for *Saccharum officinarum* falls within the range of 20 – 40 µm fibre diameters for hardwood fibres as reported by (Usta and Eroghe, 1987), it is also at a close range to the 20.0µm fibre

Table 3: Mean values of fibre characteristics of *Saccharum officinarum* bagasse

	Fiber Length (mm)	**Fibre Diameter (µm)**	**Lumen Width (µm)**	**Cell Wall Thickness (µm)**	**Runkel Ratio**	**Flexibility Ratio**	**Felting Power (%)**
Location							
Keffi	1.59 ± 0.04^{a}	20.83 ± 0.27^{a}	13.23 ± 0.43^{a}	7.60 ± 0.16^{a}	0.57 ± 0.08^{a}	63.51 ± 2.10^{a}	76.55 ± 2.28^{a}
Lafia	1.59 ± 0.05^{a}	20.75 ± 0.39^{a}	13.27 ± 0.22^{a}	7.48 ± 0.16^{a}	0.56 ± 0.04^{a}	64.00 ± 1.50^{a}	76.84 ± 2.99^{a}
Doma	1.70 ± 0.86^{a}	20.75 ± 0.35^{a}	13.25 ± 0.24^{a}	7.50 ± 0.13^{a}	0.57 ± 0.04^{a}	63.85 ± 1.30^{a}	76.79 ± 3.34^{a}
Sample							
1	1.60 ± 0.08^{a}	20.70 ± 0.28^{a}	13.26 ± 0.11^{ab}	7.44 ± 0.12^{a}	0.56 ± 0.03^{a}	64.05 ± 1.06^{b}	77.08 ± 4.19^{a}
2	2.10 ± 1.91^{b}	20.68 ± 0.41^{a}	13.20 ± 0.29^{ab}	7.48 ± 0.15^{a}	0.57 ± 0.05^{a}	63.83 ± 1.53^{b}	76.80 ± 4.81^{a}
3	1.61 ± 0.05^{a}	20.90 ± 0.13^{a}	13.30 ± 0.08^{ab}	7.60 ± 0.06^{ab}	0.57 ± 0.02^{ab}	64.31 ± 0.52^{ab}	76.82 ± 2.27^{a}
4	1.61 ± 0.07^{a}	20.65 ± 0.39^{a}	13.19 ± 0.23^{ab}	7.46 ± 0.16^{a}	0.57 ± 0.05^{a}	63.87 ± 1.46^{b}	77.81 ± 4.04^{a}
5	1.59 ± 0.04^{a}	20.83 ± 0.45^{a}	13.35 ± 0.40^{b}	7.48 ± 0.22^{a}	0.56 ± 0.07^{a}	64.09 ± 2.36^{b}	76.44 ± 3.15^{a}
6	1.60 ± 0.05^{a}	20.67 ± 0.37^{a}	13.25 ± 0.11^{b}	7.42 ± 0.14^{a}	0.56 ± 0.04^{a}	64.10 ± 1.19^{b}	77.49 ± 2.85^{a}
7	1.61 ± 0.03^{a}	20.78 ± 0.33^{a}	13.20 ± 0.48^{ab}	7.58 ± 0.14^{ab}	0.57 ± 0.07^{ab}	63.12 ± 2.07^{ab}	77.42 ± 2.17^{a}
8	1.58 ± 0.05^{a}	20.82 ± 0.29^{a}	13.18 ± 0.48^{ab}	7.64 ± 0.21^{ab}	0.58 ± 0.09^{ab}	63.30 ± 2.54^{ab}	75.75 ± 2.71^{a}
9	1.58 ± 0.05^{a}	20.83 ± 0.36^{a}	13.31 ± 0.16^{b}	7.52 ± 0.11^{ab}	0.56 ± 0.02^{a}	63.90 ± 0.80^{b}	76.10 ± 2.38^{a}
10	1.58 ± 0.03^{a}	20.72 ± 0.50^{a}	13.26 ± 0.17^{ab}	7.46 ± 0.18^{a}	0.56 ± 0.04^{a}	64.00 ± 1.39^{b}	76.46 ± 2.39^{a}
11	1.60 ± 0.03^{a}	20.84 ± 0.35^{a}	13.24 ± 0.19^{ab}	7.60 ± 0.13^{ab}	0.57 ± 0.04^{ab}	63.53 ± 1.11^{ab}	76.73 ± 2.31^{a}
12	1.58 ± 0.04^{a}	20.83 ± 0.27^{a}	13.29 ± 0.10^{ab}	7.54 ± 0.09^{ab}	0.57 ± 0.02^{a}	63.80 ± 0.72^{b}	75.83 ± 2.11^{a}
13	1.60 ± 0.04^{a}	20.75 ± 0.34^{a}	13.29 ± 0.26^{b}	7.46 ± 0.13^{a}	0.56 ± 0.04^{a}	64.05 ± 1.38^{b}	76.87 ± 2.27^{a}
14	1.60 ± 0.04^{a}	20.89 ± 0.16^{a}	13.13 ± 0.67^{a}	7.76 ± 0.21^{b}	0.59 ± 0.12^{b}	62.85 ± 3.09^{a}	76.42 ± 2.17^{a}
15	1.63 ± 0.04^{a}	20.73 ± 0.16^{a}	13.17 ± 0.07^{a}	7.56 ± 0.19^{a}	0.57 ± 0.02^{a}	63.53 ± 3.01^{a}	75.41 ± 2.11^{a}
Disk level							
25%	1.59 ± 0.05^{a}	20.78 ± 0.35^{a}	13.30 ± 0.22^{a}	7.48 ± 0.15^{a}	0.56 ± 0.04^{a}	64.00 ± 1.46^{a}	76.89 ± 2.69^{a}
50%	1.69 ± 0.86^{a}	20.77 ± 0.33^{a}	13.23 ± 0.21^{a}	7.54 ± 0.12^{a}	0.57 ± 0.04^{a}	63.70 ± 1.18^{a}	76.46 ± 3.12^{a}
75%	1.60 ± 0.05^{a}	20.78 ± 0.35^{a}	13.22 ± 0.45^{a}	7.56 ± 0.18^{a}	0.72 ± 0.08^{a}	63.62 ± 2.22^{a}	76.82 ± 2.87^{a}
GM	$\mathbf{1.63\pm0.50^{a}}$	$\mathbf{20.78\pm0.34^{a}}$	$\mathbf{13.26\pm0.32^{a}}$	$\mathbf{7.52\pm0.15^{a}}$	$\mathbf{0.57\pm0.58^{a}}$	$\mathbf{63.81\pm1.69^{a}}$	$\mathbf{76.73\pm2.89^{a}}$

Note: means with different alphabet on the same column were significantly different at $p<0.05$

Table 4: Analysis of Variance for Measured fibre characteristics of *Saccharum officinarum*

Sources of Variation		Fibre Length		Fibre Diameter		Lumen Width		Cell wall Thickness		Runkel Ratio		Felting Power		Flexibility Ratio	
	df	F	Sig.	f	Sig.	f	Sig.	f	Sig.	f	Sig.	f	Sig.	f	Sig.
Sample stem	14	1.13	0.34^{ns}	0.84	0.61^{ns}	1.32	0.21^{ns}	1.48	0.13^{ns}	1.65	0.07^{ns}	0.62	0.84^{ns}	1.57	0.10^{ns}
Disc level	2	0.99	0.37^{ns}	0.02	0.98^{ns}	2.55	0.08^{ns}	1.26	0.29^{ns}	2.39	0.10^{ns}	0.51	0.60^{ns}	2.19	0.12^{ns}
Sample disc level	28	1.04	0.41^{ns}	0.77	0.79^{ns}	0.88	0.64^{ns}	0.96	0.53^{ns}	0.91	0.60^{ns}	0.66	0.89^{ns}	0.97	0.51^{ns}
Error	108														
Total	224														
R^2			**0.192**		**0.145**		**0.195**		**0.201**		**0.211**		**0.215**		**0.212**

Note: ns = not significant

diameter in baggase as reported by Noah (2009).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 reported by Ogbonnaya, *et al.* (1992) and Pahkala (2001) (Table 5) which showed the comparism of the *Saccharum officinarum* with other non-wood fibre sources that revealed that the fibre diameter gotten was higher than the observed 15.45 µm in *Thaumatococcus danielli* (Sotande, 2000), Bamboo (15.0 µm) by Pande (1998), 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 29.85µm, *Musa sapentium* 30.16 µm and 28.53 µm in *Sterculiar oblonga*.

(iii) Results of lumen width of *Saccharum officinarum*

The results revealed that the mean lumen width was 13.26±0.32µm ranging between 12.26±0.32µm and 14.26±0.32 µm. The lumen width of the cane samples collected at different locations showed an increase of lumen width of 13.23±0.43 µm from Keffi, 13.25±0.24 µm at Doma while the highest lumen width 13.27±0.22 µm was recorded in samples from Lafia. Axial decrease was observed in lumen width with 13.30±0.22 µm observed at 25%, 13.23±0.21 µm at 50% disc level while 13.22±0.45 µm was observed in lumen width at 75% disc level. The mean value observed was 13.26±0.34 µm which is lower than the values observed on *Steculia setigera* by Oluwadare and Egbewole (2008) and higher than those reported for similar non wood fibres (Table 5).

(iv) **Results of cell wall thickness of *Saccharum officinarum***

(v) The results revealed that the mean cell wall thickness was 7.52±0.15 µm, it ranged between 7.22±0.13 µm and 7.95±0.17 µm. The cell wall thickness of the cane samples collected at different locations showed that cell wall thickness of 7.50±0.15 µm from Doma, 7.48±0.16 µm at Lafia while the highest cell wall thickness of 7.60±0.16µm was recorded in samples from Keffi. Axial increase was observed in cell wall thickness with 7.48±0.15 µm observed at 25%, 7.54±0.12 µm at 50% disc level while 7.56±0.18µm was observed in cell wall thickness at 75% 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 *Saccharum officinarum* at $p<0.05$ (Table 4).

The mean value for cell wall thickness was 7.52±0.15 µm which is lower than 8.56µm reported by Sotannde (2000) on *Thaumatococcus danielli* and higher than 2.94 µm observed in *Steculia setigera* as reported by Oluwadare and Egbewole (2008). 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 5) 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 63.81±1.69 ranging between 61.31±1.69 and 65.81±1.79. The flexibility ratio of the samples collected at different locations showed an increase of flexibility ratio of 63.51±2.10 from Keffi, 63.85±1.30 at Doma while the highest flexibility ratio 64.00±1.50 was recorded in samples from Lafia. Axial decrease was observed in flexibility ratio with 64.00±1.46 observed at 25% and 63.70±1.18 at 50% level while 63.62±2.22 was observed at 75% disc level. The mean flexibility ratio of 63.81±1.69% observed in *Saccharum officinarum* was higher compared to other non woody fibre sources as reported in (Table 5). Sotannde, (2000) reported 22% flexibility ratio on *Thaumatococcus danielli* (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), and 15% on *Musa sapentium* (bark). However, it is lower compared to 78% flexibility ratio reported by Oluwadare and Egbewole (2008) on *Steculia setigera*. Flexibility ratio is an important criteria for evaluating fibre quality. Therefore, 63.81±1.69 mean flexibility ratio of *Saccharum officinarum* bagasse falls under the second category of Osadare (1988) classifications. This implies that the fibre of *Saccharum officinarum* bagasse will collapse partially and give an elliptical cross sectional form, good surface contact and fibre to fibre bonding. However, this low flexibility shows that the pulp of sugarcane bagasse may not be suitable to produce paper with greater bursting and tensile strength which require higher flexibility. Sugarcane bagasse fibre characteristics as reported in this study, showed that, they are 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 *Saccharum officinarum* was 76.73±2.89. It ranged between 73.73±2.90 and 79.23±2.90. The Felting coefficient of the samples collected at different locations showed an increase of Felting coefficient of 76.84±2.99 from Lafia, 76.79±3.34 at Doma while the least Felting coefficient 76.55±2.29 was recorded in samples from Keffi. Felting coefficient of 76.89±2.69 observed at 25% disc level and 76.46±3.12 at 50% level while 76.82±2.87 was observed at 75% disc level. The mean value for the felting coefficient of bagasse was 76.73±2.89. This is low compared to other non woody fibre sources as reported in (Table 5). Oluwadare and Egbewole (2008) reported 101.50 felting coefficient on *Steculia 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 76.73; it is greater than ≥70 and so can be utilized by the pulp and paper industry.

(iii) **Runkel Ratio**

The average Runkel Ratio of *Saccharum officinarum* was 0.57±0.08. It ranged between 0.52±0.01 and 0.68±0.05. The Runkel Ratio of the samples collected at different locations showed Runkel Ratio of 0.57±0.08 from Keffi and 0.57±0.04 from Doma, while the least Runkel Ratio 0.56±0.04 was recorded in samples from Lafia. Axial increase was observed in Runkel Ratio with 0.56±0.04 observed at 25% disc level and 0.57±0.04 at 50% level while 0.72±0.08 was observed in Runkel Ratio at 75% disc level. 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 no significant difference in the Runkel Ratio observed within and between sample stems and at various locations at $p<0.05$ (Table 4).

However, the average of 0.57 Runkel ratio observed in *Saccharum officinarum* was lower compared with the observation made by Oluwadare (1998) on non wood species like 0.78 in *Musa texilis*, 0.95 in the bast of *Adansonia digitata* and 0.76 in *Hibiscus cannabinus.* The runkel ratio of the sugarcane samples is also lower than 0.79 for tropical Pine species (Ajala, 1997), 0.99 reported for both *Anthonatha macrophylia* 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). The value is lower than 0.59 as reported for *Leucaena leucocephala* (Oluwadare & Sotannde, 2007), and the 0.70 for *Dacryodes edulis*

(Ajuziogu *et al*., 2010). 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 and 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 0.57 Runkel ratio observed in *Saccharum officinarum* bagasse established its suitability as a raw material for pulp and paper making.

Table 5: Comparative assessment of Fibre Characteristics of *Saccharum officinarum* and other 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	+ *Saccharun officinarum* (Sugarcane)	1.62	20.78	13.26	7.52	0.57	76.73	63.81
2	*Thaumatococcus danielli* (Sweet Prayers Plant) (**Sotannde, 2000)**	2.54	15.45	3.45	8.56	0.81	165.48	22
3	Bamboo **(Pande, 1998)**	2.7	15.0	-	-	-	180	-
4	Kenaf bast fibre(*Hibiscus cannabinus*) **(Pande, 1998)**	2.6	20.0	-	-	-	130	-
5	Jute (*Chorchorus capsularis*) **(Pande, 1998)**	2.5	20.0	-	-	-	135	-
6	**Abelmoschus esculentus* (okra) (bark) (**Osadare and Udohitinah, 1993**)	3.49	34.87	7.63	19.62	0.78	100	22
7	**Hibiscus cannabinus* (Kenaf) (**Osadare and Udohitinah, 1993**)	2.90	28.16	6.08	16.0	0.76	105.1	21
8	**Bombax buonopozense(* Gold coast Bombax)	3.83	29.85	5.80	18.25	0.68	114.1	20
9	**Musa sapentium* (bark)	4.48	30.16	4.34	21.44	0.42	149.1	15
10	**Steculiar oblonga* (yellow steculia)(bark)	3.27	28.53	8.49	11.54	1.77	115.1	30
11	Reed (*Arundo donax*) **(Pande, (1998)**	1.8	20	-	-	-	90.0	-

+ - current work, β –data from Sotannde, (2000), α -data from Pande, (1998), * -data from Osadare and Udohitinah, (1993).

CONCLUSION AND RECOMMENDATION

Conclusion

From the results of the study on the Fibre characteristics of *Saccharum officinarum* bagasse as a material for pulp and paper production, the following conclusions were reached:

1. The fibre length of *Saccharum officinarum* fall within short fibre cellulosic materials
2. Axial sampling showed no significant differences in the fibre qualities at any height on the cane stem indicating that bagasse possesses good pulping qualities suitable for pulp and paper production.
3. Sugarcane bagasse fibre characteristics as reported in this study, showed that, they are well suited for tissue, corrugating medium, newsprint, and writing paper.

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 which should include it bark. This will enhance its suitability as a potential source of short fibre non wood pulp.
3. Pulp and Paper industries should harness the potential in Sugar cane bagasse as it can be used to revive the Nigerian pulp and paper industry.

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