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TAXIMETRIC STUDY OF SOME WILD PLANT SPECIES WITH POTENTIALS FOR PULP AND PAPER MAKING

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The pulp and paper potentials of four wild plant species, namely *Jatropha curcas, J. podagrica*, *Sida acuta* and *Ricinus communis* were investigated. Pulp was produced by a soda pulping process at liquor to solid ratio 7:1 and bleached with hydrogen peroxide in basic medium. The studied species were found to be good candidates for use as raw materials for pulp and paper production due to possession of appropriate raw material features (i.e. fibre length, fibre diameter, cell wall thickness, lumen density as well as Runkel ratio, flexibility coefficient and relative fibre length). The pulp yield of *J. curcas, J. podagrica, Sida acuta* and *R. communis* were 70%, 87%, 80% and 81% respectively. Thus, short fibres needed to produce good quality pulp and paper can be generated from the 4 studied plant species and they can compete favourably with other highly rated pulp and paper making materials.

Keywords: Paper industry, *Jatropha curcas, J. podagrica*, *Sida acuta, Ricinus communis*

Paper is an important material, used daily for many purposes worldwide. The global production of paper and cardboard stood at approximately 407 million metric tons in 2014. More than half of that production was attributable to packaging paper, while almost one third was attributable to graphic paper. The world's three largest paper producing countries are China, the United States and Japan. These three countries account for half of the world's total paper production, while the leading paper importing and exporting countries are Germany and the United States. Countries with higher productions earned foreign currency from exporting pulps and papers to other countries.

In Nigeria, in the 1970s and 1980s, the pulp and paper industries were vibrant with excellent production, and in the 1980s the pulp and paper mills performed optimally (Ogunwusi 2013). But subsequently upon this, the industries gone into recess and have never recovered fully till date. According to Ogunwusi (2013), many problems were identified to have been responsible for this happening among which include scale of operation of the integrated pulp and paper mills with lowest installed capacity of 68, 000 tons per annum; production of 100 tons per day is a large capacity according to UNIDO (1978), dependence on importation of long fiber and pulping chemicals because the Nigerian forest consists of hardwoods with short fibre length of 0.8mm to 1.6mm, sub-optimal performance of *Pinus* species in plantation in Nigeria due to lack of mychorriza in the Nigerian soils (Ojo 1971, Momoh 1970, 1971, Madu 1971, Jackson 1971), inadequate funding of research and development in Nigeria (Famuyide and Adebayo 1993, FAO 2001)

Ogunwusi and Ibrahim (2014) have advocated for the use of non-wood raw materials in the production of pulps and papers. However, that notwithstanding, there is growing interest in the use of non-wood plants like annual plants and agricultural residues for this purpose (Sridach 2010). Tough, non-wood plants are used mostly in countries with little or no woody plants, King (1977) and Patil *et al*. (2011) admonished the developing nations to take the advantages of the availability of non-woody plants for production of pulp and paper in order to sustain the industries. In addition to this, Sridach (2010) and Hurter and Riccio (1998) gave some benefits accruable from the non-woody plants as fast annual growth, and smaller amount of lignin that binds fibres together resulting to reduced energy and chemicals use during pulping, moderate irrigation and fertilization requirements. Another important advantage of non-woody plants is that they can be used for production of

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on the dry surface. They were then floated on a known volume of water in a measuring cylinder to determine the volume of water displaced, representing the volume of the stem and leaf samples. The weight of the displaced water was also determined at 4^0C. the specific gravity was then expressed as the numerical ratio of the density of the stem samples to that of water at 4^0C.

Statistical analysis

For variations in the fibre dimensional characteristics between the 10 different populations, analysis of variance was conducted based on the randomized block design. The total number of observations (N) for each character was 100. Also for character variations within individual plants in a typical population, analysis of variance was conducted based on completely randomized design.

Production of pulp and paper

The already bleached pulp was set for paper making, using a manual method. 5g of the bleached pulp was soaked in a container containing water and allowed to soak for some minutes. While stirring it continuously, 2g of calcium carbonate, a little quantity of starch and the binder (top bond) were added. Thereafter, the mixture was then poured into a blender and was blended until the pulp became smooth. The blended pulp was then poured into an improvised paper formval and kept in a big bucket of water, allowing the pulp to take the shape of the improvised paper former. The water was drained from the improvised paper former and then dried for about 24 hours. The paper (Fig. 1) is gently removed after it has been dried.

RESULTS

Fibre length

The mean length of the stem xylem fibres, determined from the data obtained from the 10 populations of *Jatropha curcas, J. podagrica, Sida acuta* and *Ricinus communis* are 1.00mm, 0.73mm, 0.87mm, 1.43 respectively and that of their leaves are 0.83mm, 1.05mm, 1.06mm and 0.78mm respectively. There is a fairly wide range of variation in the xylem fibres of *J. curcas* (0.36mm-1.13mm and 0.66mm 1.05mm), *J. podagrica* (1.05mm-2.10mm- and 0.36mm-2.10mm), *S. acuta* (0.77mm-1.23mm and 0.80mm-1.90mm), and *R. communis* (0.74mm -1.01mm and 0.57mm-1.02mm) for the stem and leaf respectively. Within a plant, there is a basipetal increase in fibre length so that the longest fibres are found at the basal region of the plants (Tables 1 - 3). The differences in the fibre lengths between the segments in individual *J. curcas* and that of *S. acuta* plants and between the ten different populations of each of the plants are not significant at 5% and 1% probability levels, but are significant for *J. podagrica* and *R. communis* at 1% probability level (Tables 4 - 6).

Fibre diameter

The mean diameters of the fibres for stem and leaves of *Jatropha curcas* (15.92µm and 16.68µm), *Jatropha podagrica* is (23.60µm and 19.23µm), *S. acuta* (19.28µm and 19.57µm) and *Ricinus communis* are (16.79µm and 16.24µm) and respectively. There is no definite basipetal pattern of variation as wide fibres occur at both basal and apical regions of the plant (Tables 1 - 3). For *J curcas* and *S. acuta*, the differences in the fibre diameter both between segments within individual plants and between different population, based on the completely randomized design is not significant at 1% or 5% probability level. But for *J. podagrica* and *R. communis*, the differences in the fibre diameter between segments within individual plants, based on the completely randomized design are not significant at 1% or 5% probability level. However, with randomized block design, there are significant differences both between segments within individual plants and between different populations at 1% probability level in both plants (Tables 4 - 6).

Cell wall thickness

The mean cell wall thickness of stems and leaves of *J. curcas* (2.52µm and 2.70µm), *J. podagrica* is (3.40µm and 2.97µm), *S. acuta* all kind papers. Therefore, increase in their use has increased just within 3 years from 12,000 tons in 2003 to 850,000 tons in 2006 (FAO 2009, Lopez *et al*. 2006).

The importance of fiber dimensions and their derived values (slenderness ratio, flexibility coefficient and Runkel ratio) on pulp and paper mechanical strength is well documented. Seth and Page (1988) have shown that, under certain conditions, tearing resistance depends strongly on fiber length. Kellogg and Thykeson (1975) and Matolcsy (1975) have also pointed out the significance of fiber dimensions in predicting wood pulp mechanical properties. Researchers like Saikia *et al*. (1997) have successfully used those derived values to assess the suitability of various non-wood fiber raw materials for pulp and paper manufacture. Paper strength also depends on the lignin and cellulose content of raw plant materials; pulp mechanical strength and especially tensile strength is directly proportional to cellulose content (Madakadze *et al*, 1999), whereas lignin is an undesirable polymer and its removal during pulping requires high amounts of energy and chemicals.

This present study, therefore, investigated a possible industrial use of *J. curcas* L. (Euphorbiaceae), *J. podagrica* Hook. (Euphorbiaceae), *S. acuta* L. (Malvaceae) and *R. communis* L. (Euphorbiaceae) and is also concerned with the analysis of the fibrous elements in the stems and leaves of these plants respectively, with a view to assessing the potential of these plants as a resource for production of pulp and paper.

MATERIALS AND METHODS

Study materials

Stems and leaves of *J. curcas, J. podagrica*, *S. acuta* and *R. communis* were collected with 2.0cm basal diameter of stems and leaves collected from ten populations growing differently at Tanke Oke-Odo, Ilorin, Kwara State, Nigeria. The stems were cut into four segments of 12cm each, the basal segment being coded 1 and apical segment 4. The leaves were collected fresh.

Tissue maceration, pulping and examination

The stem segment and leaves were macerated in hot 5% potassium chlorate in concentrated nitric acid (Jane 1956, Oladele and Jaiyeola 1986). The isolated xylem fibres were rinsed thoroughly in distilled water and stained in 1% aqueous safranin. They were then mounted in dilute glycerine for microscopic examination and measurement. Four dimensional characteristics, namely fibre length, fibre diameter, cell wall thickness and lumen diameter were measured from the fibres. Ratios of some dimensions were found, namely flexibility co-efficient, which is lumen diameter/fibre diameter, Runkel Ratio which is given by 2 x cell wall thickness/lumen diameters (Ademuluyi and Okeke 1979). Flexibility co-efficient indicates flexibility and tensile strength property of the fibres, while the Relative Fibre Length expresses the slenderness and degree of resistance to tear. Runkel Ratio which is equal to or less than 1 indicates suitability for paper-making.

Pulping of 20 g samples of oven-dried stems and leaves was done in 18% sodium hydroxide at 170^{0}C for 3hours (Palmer 1982). The pulp was then beaten in a homogenizer for 1 min. The pulp yield was oven dried and the pulp expressed as percentage dry weight of stem. Re-hydrated pulp was beaten for 10 sec and screened in an Endecotts laboratory test sieve of 400 m meshwork. The fractions obtained were oven dried and weighed. The pulp purity was the dry weight of the residue on the sieve, expressed as percentage of the pulp. Characterization of fibres was done by examined samples of the fractions under the light microscope (LM) to verify the fibrous component of the pulp. Then the non-fibrous vessel parenchyma, cell fragments and crystals were screened off.

Determination of the specific gravity

Stem and leaf samples were oven dried for 24 hours at 100^{0}C, and subsequently weighed at 4^{0}C. These were carefully immersed in molten paraffin wax to build a thin, water-proof coat

(2.95µm and 2.83µm) and *R. communis* is (2.53µm and 2.63µm) respectively with a fairly wide range of variation at the high coefficient of variation. Fibres with the thickest cell walls are found at the base of the plants (Tables 1 - 3). With the completely randomized design, the variation within individual plant is significant at 5% probability level. However, for *J podagrica* and *R. communis*, with the randomized block design, the variation is significant at 1% probability level. The differences between different populations are also significant at 5% probability level. While between populations of *S. acuta* is not significant at 1% and 5% probability level while the variation within individual and between populations of *J. curcas* is not significant at 1% and 5% probability level (Tables 4 - 6).

Lumen diameter

The mean lumen diameter for stem and leaves of *J. curcas* (10.91µm and 11.83µm), *J. podagrica* is (16.86µm and 13.4µm), *S. acuta* (13.21µm and 12.00µm) and *R. communis* is (11.77µm and 11.00µm) respectively, with a narrow range of variation. There is a slight tendency for a basipetal increase in the lumen diameter. Hence, the fibres with the widest lumina are found near the base of the plant (Tables 1 - 3). With the completely randomized design, the variation within individual plant is significant at 5% probability level, but it was at the 1% level with randomized block design, the

Figure 1: Sample papers produced from the studied materials (a) *Jatropha curcas*, (b) *Jatropha podagrica*, (c) *Sida acuta* and (d) *Ricinus communis*

Table 1: Variation of stem fibre dimension in 10 different populations of some wild plant species

Species	Species Population	Fibre length (µm)	Fibre diameter (µm)	Cell wall thickness (µm)	Lumen diameter (µm)	Runkel ratio (RR)	Flexibility coefficient (FC)	Relative fibre length (RFL)
Ricinus communis	1	1.01 ± 0.09	17.90 ± 1.45	2.60 ± 0.37	12.7 ± 1.43	0.41	0.71	56.42
	2	0.88 ± 0.05	15.90 ± 0.92	2.50 ± 0.38	11.1 ± 1.14	0.45	0.7	55.35
	3	0.78 ± 0.07	14.60 ± 1.13	2.40 ± 0.37	10.0 ± 1.02	0.48	0.68	53.43
	4	0.98 ± 0.07	19.30 ± 1.47	2.60 ± 0.37	14.10 ± 1.49	0.36	0.73	50.78
	5	0.96 ± 0.12	18.40 ± 1.94	2.6 ± 0.37	13.20 ± 1.61	0.39	0.72	52.22
	6	0.82 ± 0.09	16.80 ± 1.21	2.4 ± 0.37	12.00 ± 1.50	0.4	0.71	48.81
	7	0.93 ± 0.08	17.00 ± 1.17	2.5 ± 0.38	12.00 ±0.89	0.42	0.71	50.71
	8	0.74 ± 0.05	15.30 ± 0.96	2.5 ± 0.38	10.30 ± 0.96	0.49	0.67	48.37
	9	0.81 ± 0.08	16.10 ± 1.10	2.5 ± 0.38	11.10 ± 0.99	0.45	0.68	50.31
	10	0.75 ± 0.05	16.60 ± 1.40	2.7 ± 0.35	11.20 ± 1.34	0.48	0.67	47.59
	Mean ± S.E	0.87± 0.07	16.79 ± 1.03	2.53 ± 0.07	11.77 ± 0.92	0.43 ± 0.03	0.70 ± 0.02	51.40±2.11
	Coefficient of variance	8.05	6.13	2.77	7.82	7	2.86	4.1
Jatropha podagrica	1	1.01 ± 0.09	17.9 ± 1.45	2.6 ± 0.37	12.7 ± 1.43	0.41	0.71	53.92
	2	0.88 ± 0.05	15.9 ± 0.92	2.5 ± 0.38	11.1 ± 1.14	0.45	0.7	68.1
	3	0.78 ± 0.07	14.6 ± 1.13	2.4 ± 0.37	10.0 ± 1.02	0.48	0.68	70.18
	4	0.98 ± 0.07	19.3 ± 1.47	2.6 ± 0.37	14.1 ± 1.49	0.36	0.73	52.79
	5	0.96 ± 0.12	18.4 ± 1.94	2.6 ± 0.37	13.2 ± 1.61	0.39	0.72	57.92
	6	0.82 ± 0.09	16.8 ± 1.21	2.4± 0.37	12.0 ± 1.50	0.4	0.71	58.23
	7	0.93 ± 0.08	17.0 ± 1.17	2.5 ± 0.38	12.00 ± 0.89	0.42	0.71	61.74
	8	0.74 ± 0.05	15.3 ± 0.96	2.5 ± 0.38	10.3 ± 0.96	0.49	0.67	59.5
	9	0.81 ± 0.08	16.10 ± 1.10	2.5 ± 0.38	11.1 ± 0.99	0.45	0.68	56.8
	10	0.79 ± 0.05	16.60± 1.40	2.7 ± 0.34	11.2 ± 1.34	0.48	0.67	51.98
	Mean±S.E	0.87 ± 0.07	16.79 ± 1.03	2.53 ± 0.07	11.77 ± 0.92	0.43 ± 0.03	0.70 ± 0.02	59.12±4.37
	Coefficient of variation	8	6.13	2.77	7.82	7	2.86	7.39
Sida acuta	1	0.77 ± 0.08	16.60 ± 1.52	2.70 ± 0.48	11.20 ± 1.61	0.48	0.67	46.39
	2	1.04 ± 0.18	19.80 ± 2.07	2.70 ± 0.35	14.40 ± 1.88	0.38	0.73	52.53
	3	1.23 ± 0.27	21.60 ± 2.72	3.60 ± 0.61	14.40 ± 2.32	0.5	0.67	56.94
	4	0.79 ± 0.08	16.20 ± 1.25	2.40 ± 0.37	11.40 ± 1.52	0.42	0.7	48.77
	5	1.02 ± 0.09	19.70 ± 1.39	3.10 ± 0.53	13.50 ± 1.79	0.46	0.69	51.78
	6	1.02 ± 0.10	19.80 ± 1.30	3.20 ± 0.60	13.40 ± 1.40	0.48	0.68	51.51
	7	1.04 ± 0.10	18.70 ± 1.35	2.70 ± 0.59	12.40 ± 0.91	0.44	0.63	52.79
	8	0.94 ± 0.09	19.00 ± 0.89	3.00 ± 0.48	13.10 ± 0.85	0.46	0.69	49.47
	9	1.05 ± 0.10	20.10 ± 1.49	3.20 ± 0.45	13.80 ± 1.06	0.46	0.69	52.69
	10	1.11 ± 0.15	20.30 ± 1.80	2.90 ± 0.53	14.50 ± 1.52	0.41	0.71	54.68
	Mean±S.E.	1.00 ± 0.10	19.28 ± 1.19	2.95 ± 0.25	13.21 ± 0.86	0.45 ± 0.03	0.68± 0.02	51.71±2.14
	Coefficient of variation	10	6.17	8.48	6.5	6.67	2.94	4.14
Jatropha curcas	1	0.65 ± 0.08	14.90 ± 1.30	2.50 ± 0.40	10.00 ± 1.30	0.5	0.67	43.62
	2	0.36 ± 0.03	12.50 ± 0.90	2.40 ± 0.40	7.90 ± 0.90	0.61	0.63	28.8
	3	1.13 ± 0.14	20.90 ± 1.40	2.90 ± 0.40	15.10 ± 1.40	0.38	0.72	54.07
	4	0.64 ± 0.08	14.60 ± 1.23	2.50 ± 0.38	9.40 ± 1.40	0.53	0.64	43.84
	5	0.82 ± 0.20	17.20 ± 2.80	2.30 ± 0.35	12.60 ± 3.17	0.37	0.73	47.67
	6	1.01 ± 0.18	20.90 ± 3.20	3.30 ± 0.48	14.50 ± 2.80	0.46	0.69	48.33
	7	0.58 ± 0.04	13.40 ± 1.20	2.30 ± 0.30	8.80 ± 1.10	0.52	0.66	43.28
	8	0.61 ± 0.08	13.20 ± 1.60	2.40 ± 0.39	8.40 ± 1.31	0.57	0.64	46.21
	9	0.66 ± 0.18	14.90 ± 3.10	2.40 ± 0.37	10.10 ± 2.80	0.48	0.68	44.3
	10	0.80 ± 0.23	16.70 ± 3.60	2.20 ± 0.30	12.30 ± 3.50	0.36	0.74	47.9
	Mean±S. E.	0.73 ± 0.16	15.92 ± 2.15	2.52 ± 0.24	10.91 ± 1.83	0.48 ± 0.06	0.68± 0.03	44.80±4.64
	Coefficient of variation	21.92	13.55	9.52	16.77	12.5	4.41	10.36

Table 2: Variation of stem fibre dimension within individuals in a population of *Jatropha curcas*

Species	Stem segments (diameter in parenthesis) (cm)	Fibre length (µm)	Fibre diameter (µm)	Wall thickness (µm)	Lumen diameter (µm)	Relative fibre length (rfl)	Flexibility coefficient (fc)	Runkel ratio (rr)
Jatropha curcas	1 (2.0)	0.83±0.32	17.50±3.30	2.70±0.48	12.30±2.72	47.43	0.70	0.44
	2 (1.5)	0.93±0.22	19.20±3.61	2.70±0.48	13.80±3.51	48.44	0.72	0.40
	3 (1.0)	0.88±0.14	18.00±2.05	2.60±0.37	12.80±2.33	48.89	0.71	0.41
	4 (0.5)	0.84±0.15	16.00±1.40	2.80±0.31	10.70±1.75	44.38	0.67	0.52
	Mean± S.E.	0.84±0.15	17.68±2.11	2.70±0.13	12.40±2.06	47.27±3.22	0.70±0.03	0.44±0.09
	Coefficient of variation	17.86	11.93	4.82	16.61	6.80	4.29	20.46
Jatropha podagrica	1 (2.0)	1.52±0.43	24.80±4.25	3.60±0.51	17.90±3.40	61.29	0.72	0.40
	2 (1.5)	1.17±0.42	20.10±3.06	3.10±0.53	14.40±2.37	58.21	0.72	0.43
	3 (1.0)	1.57±0.51	25.20±5.49	3.80±0.74	17.60±4.25	63.30	0.69	0.43
	4 (0.5)	1.05±0.09	19.90±1.04	2.80±0.57	14.20±1.39	52.76	0.71	0.39
	Mean ± S.E	1.33±0.41	22.50±4.60	3.33±0.63	16.03±3.18	58.89±7.31	0.71±0.02	0.41 ± 0.03
	Coefficient of variance	30.83	20.44	18.91	19.84	12.41	2.82	7.82
Sida acuta	1 (2.0)	1.02±0.24	19.40±2.27	3.00±0.67	13.40±1.30	52.58	0.69	0.45
	2 (1.5)	1.02±0.15	19.40±1.76	3.00±0.48	13.50±1.91	52.58	0.70	0.44
	3 (1.0)	0.99±0.08	19.60±1.27	3.00±0.58	13.60±0.83	50.51	0.69	0.44
	4 (0.5)	0.89±0.07	18.10±1.00	2.80±0.56	12.50±1.40	49.17	0.69	0.45
	Mean ± S. E.	0.98±0.09	19.13±1.10	2.95±0.16	13.25±0.81	51.21±2.66	0.69±0.01	0.45± 0.02
	Coefficient of variation	9.19	5.75	5.42	6.11	5.19	1.45	4.44
Ricinus communis	1 (2.0)	0.96±0.076	17.40±1.27	2.70±0.35	12.00±0.67	0.69	0.45	55.17
	2 (1.5)	1.41 ± 0.49	22.70±4.84	3.40±0.60	15.90±3.90	0.70	0.43	62.12
	3 (1.0)	0.85 ± 0.77	17.2 ± 1.96	2.50±0.38	12.20±1.70	0.71	0.41	49.42
	4 (0.5)	0.98 ± 0.09	17.70±1.50	2.60±0.37	12.50±1.66	0.71	0.42	55.37
	Mean ± S.E	1.05 ± 0.40	18.83±4.13	2.80±0.65	13.15±2.94	0.70 ± 0.01	0.43± 0.03	55.52±8.26
	Coefficient of variance	38.09	21.93	23.21	22.36	1.43	6.98	22.36

differences between different populations are also significant at 5% probability level. With the completely randomized design, the differences within individual and between different populations of *J. curcas* and *S. acuta* plants respectively are not significant at both 1% and 5% probability levels (Tables 4 - 6).

Flexibility coefficient

The mean flexibility coefficient of the xylem fibres in *J. curcas* (0.70), *J. podagrica* (0.71), *S. acuta* (0.69) and *R. communis* (0.70) all of which are relatively higher. Although, there is no definite basipetal pattern of variation in the flexibility coefficient, the fibres at the lower two-thirds (segments 2-4) of *R. communis* and (segments 1-2) of *J. podagrica* two-third (segments 1-3) of *J. curcas* and *S. acuta* are highly flexible (Tables 1 – 6).

Relative fibre length

The mean relative fibre length of *J. curcas* (44.80µm), *J. podagrica* is 59.12, *S. acuta* (51.71µm), *R. communis* (51.40) which are high, indicating that the fibres are generally slender and resistant to tear (Tables 1 - 3). The fibres near the base of the plants are slightly slender than those near the apex.

Runkel ratio

The mean Runkel ratio for all plants is less than 1; *J. curcas* 1(0.48µm), *J. podagrica* 1(0.41), *S. acuta* 1(0.45µm) and *R. communis* 1(0.43) indicating that the fibres are generally suitable and good for paper making. The fibres at the base of the plant have lower Runkel ratio values than those near the apex in *J. podagrica* and *R. communis* (Tables 1 - 3). There is no

Table 3: Variation of leaves fibre dimensions in 10 populations of *Jatropha curcas*

Species	Populations	Fibre length (mm)	Fibre diameter (µm)	Wall thickness (µm)	Lumen diameter (µm)
Jatropha curcas	1	1.01±0.18	20.90 ± 3.20	3.30 ± 0.48	14.50 ± 2.80
	2	0.77±0.08	16.60 ± 1.52	2.70 ± 0.48	11.20 ± 1.61
	3	0.79±0.05	16.60 ± 1.40	2.70 ± 0.35	11.20 ± 1.34
	4	0.66±0.18	14.90 ± 3.10	2.40 ± 0.31	10.10 ± 2.80
	5	1.04±0.11	19.70 ± 1.07	2.90 ± 0.63	13.90 ± 1.45
	6	1.05±0.14	20.20 ± 1.65	3.30 ± 0.48	14.10 ± 1.45
	7	0.74±0.09	16.00 ± 1.62	2.70 ± 0.35	10.80 ± 1.34
	8	0.71±0.12	10.60 ± 1.82	2.60 ± 0.37	11.40 ± 1.48
	9	0.74±0.06	15.30 ± 1.35	2.40 ± 0.37	10.50 ± 1.63
	10	0.79±0.08	16.00 ± 1.55	2.60 ± 0.51	10.60 ± 1.22
	Mean±S.E.	0.83±0.10	16.68 ± 2.16	2.70 ± 0.20	11.83 ± 1.19
	Coefficient of variation	12.05	12.95	7.41	10.06
Jatropha podagrica	1	0.61 ± 0.08	13.20 ± 1.60	2.40 ± 0.39	8.40 ± 1.31
	2	0.36 ± 0.03	12.50 ± 0.90	2.40 ± 0.40	7.90 ± 0.90
	3	0.74 ± 0.06	15.30 ± 1.35	2.40 ± 0.37	10.50 ± 1.63
	4	0.71 ± 0.05	15.10 ±0.63	2.40 ± 0.37	10.30 ± 0.90
	5	0.88 ± 0.08	17.0 ± 1.69	3.00 ± 0.48	11.20 ± 1.68
	6	1.05 ± 0.14	20.20 ± 1.65	3.30 ± 0.48	14.10 ± 1.41
	7	2.10 ± 0.29	31.00 ± 3.05	4.20 ± 0.58	22.60 ± 2.32
	8	2.00 ± 0.40	28.50 ± 3.06	3.80 ± 0.45	21.10 ± 2.69
	9	1.02 ± 0.09	19.70 ± 1.39	3.10 ± 0.53	13.50 ± 1.79
	10	1.04 ± 0.18	19.80 ± 2.07	2.70 ± 0.35	14.40 ± 1.88
	Mean ± S.E	1.05 ± 0.41	19.23 ± 4.43	2.97 ± 0.46	13.4 ± 3.57
	Coefficient of variation	39.05	23.04	15.49	26.64
Sida acuta	1	1.04 ± 0.10	19.70 ± 1.35	2.70 ± 0.59	12.40 ± 0.91
	2	1.05 ± 0.10	20.10 ± 1.49	3.20 ± 0.45	13.80 ± 1.06
	3	0.98 ± 0.07	19.30 ± 1.47	2.60 ± 0.37	14.10 ± 1.49
	4	0.81 ± 0.08	16.10 ± 1.10	2.50 ± 0.38	11.10 ± 0.99
	5	1.01 ± 0.09	17.90 ± 1.45	2.60 ± 0.37	12.70 ± 1.43
	6	0.80 ± 0.23	16.70 ± 3.60	2.20 ± 0.30	12.30 ± 3.50
	7	0.82 ± 0.20	17.20 ± 2.80	2.30 ± 0.35	12.60 ± 3.17
	8	1.90 ± 0.27	27.90 ± 2.73	3.70 ± 0.59	20.50 ± 1.91
	9	1.05 ± 0.14	20.20 ± 1.65	3.30 ± 0.48	14.10 ± 1.41
	10	1.17 ± 0.26	20.60 ± 1.76	3.20 ± 0.45	14.40 ± 2.48
	Mean ± S. E.	1.06 ± 0.22	19.57 ± 2.38	2.83 ± 0.35	12.00 ± 2.50
	Coefficient of variation	20.76	12.16	12.37	20.83
Ricinus communis	1	0.61 ± 0.09	14.20 ± 1.57	2.60 ± 2.23	9.00 ± 1.69
	2	0.57 ± 0.15	13.80 ± 1.99	2.70 ± 0.35	8.60 ± 1.56
	3	0.67 ± 0.04	14.20 ± 0.88	2.60 ± 0.37	9.00 ± 0.96
	4	0.96 ± 0.12	18.40 ± 1.94	2.60 ± 0.37	13.20 ± 1.61
	5	0.74 ± 0.05	15.30 ± 0.96	2.50 ± 0.38	10.30 ± 0.96
	6	0.79 ± 0.05	16.60 ± 1.40	2.70 ± 0.35	11.20 ± 1.34
	7	1.02 ± 0.10	19.80 ± 1.30	3.20 ± 0.60	13.40 ± 1.40
	8	0.79 ± 0.08	16.20 ± 1.25	2.40 ±0.37	11.40 ± 1.52
	9	0.97 ± 0.04	18.80 ± 1.21	2.60 ± 0.51	13.60 ± 1.40
	10	0.71 ±0.05	15.1 ± 0.63	2.40 ± 0.37	10.3 ± 0.9
	Mean ± S.E	0.78 ± 0.11	16.24 ± 1.52	2.63 ± 0.16	11.00 ±1.36
	Coefficient of variation.	14.10	9.36	6.08	12.36

definite basipetal pattern of variation in the Runkel ratio of other two species.

Pulp yield and purity

The pulp yield and purity of *J. curcas* are 70% and 57%, *J. podagrica* are 74.7% and 87%, *S. acuta* 80% and 60% and *R. communis* stem are 81% and 70.1% respectively.

Specific gravity

The specific gravities of stems are *J. curcas* (0.55g/cm^3), *J. podagrica* (0.68g/cm^3), *S. acuta* (0.58g/cm^3) and *R. communis* (0.62g/cm^3). The qualities possessed by the studied plant species (Tables 1 - 3) as described above are required

Table 4: Analysis of variance for 4 characteristics of stem xylem fibres in studied plant species

Species	Source	Degree of freedom (df)	Fibre length (mm)	Fibre diameter (µm)	Cell wall thickness (µm)	Lumen diameter (µm)
Jatropha curcas	Segments	3	13.48	17.54	0.06	0.12
	Sites	9	38.41	8.02	0.19	7.26
	Error	87	89.04	18.13	0.38	15.50
	F-ratio (segment)		0.15	0.97	0.16	0.01
	F- ratio (sites)		0.43	0.44	0.50	0.47
Jatropha podagrica	Segments	3	12.00	7.07	0.08	5.62
	Sites	9	21.68	12.73	0.40	8.86
	Error	87	32.11	31.63	0.76	20.50
	F-ratio (segment)		0.37	0.22	0.10	0.28
	F- ratio (sites)		0.68	0.40	0.52	0.43
Sida acuta	Segments	3	12.50	2.75	0.40	0.07
	Sites	9	52.40	7.92	0.64	7.95
	Error	87	50.66	7.41	0.56	5.33
	F-ratio (segment)		0.25	0.37	0.71	0.01
	F- ratio (sites)		1.03	1.07	1.13	1.50
Ricinus communis	Segments	3	13.89	6.71	0.34	4.04
	sites	9	20.82	5.93	0.18	5.11
	Error	87	18.10	4.72	0.26	4.29
	F-ratio (segments)		0.77	1.42	1.32	0.94
	F-ratio (sites)		1.15	1.26	0.68	1.19

Segments: $F_{0.05}(3, 87) = 2.76$ $F_{0.01}(3, 87) = 4.13$

Sites: $F_{0.05}(9, 87) = 2.04$ $F_{0.01}(9, 87) = 2.56$

Table 5: Analysis of variance for 4 characteristics of stem xylem fibres in a population of studied species

Species	Source	Degree of freedom (df)	Fibre length (mm)	Fibre diameter (µm)	Cell wall thickness (µm)	Lumen diameter (µm)
Jatropha curcas	Segments	3	3.99	5.42	0.33	6.87
	Error	36	94.87	15.74	0.32	14.58
	F-ratio		0.40	0.35	1.05	0.47
Jatropha podagrica	Segment	3	221.99	12.87	0.63	4.89
	Error	36	344.09	34.54	0.86	21.06
	F-ratio		0.65	0.37	0.73	0.23
Sida acuta	Segments	3	34.39	4.96	1.70	1.70
	Error	36	45.21	3.32	0.52	3.84
	F-ratio		0.76	0.93	3.25	0.44
Ricinus communis	Segments	3	83.03	14.70	1.00	4.03
	Error	36	169.67	19.76	0.43	13.03
	F-ratio		0.49	0.74	2.34	0.31

Ricinus communis: $F_{0.01}(3, 36) = 2.92$ $F_{0.05}(3, 36) = 4.51$
Jatropha podagrica: $F_{0.05}(3, 87) = 2.76$ $F_{0.01}(3, 87) = 4.13$
Jatropha curcas: $F_{0.05}(3, 36) = 2.92$ $F_{0.01}(3, 36) = 4.51$
Sida acuta $F_{0.05}(3, 36) = 2.92$ $F_{0.01}(3, 36) = 4.51$

ones for the production of pulp and papers. In line with this, the species are good candidates for pulp and paper industries, especially in places where there are no forest trees and where the desertification is on increase due to incessant tree felling.

DISCUSSION

The xylem fibres of *J. curcas* (0.73µm), *J. podagrica* (1.43µm), *S. acuta* (1.00µm) and *R. communis* (0.87µm) fall into the short fibre category. *Gmelina arborea* a principal source of fibre for paper making also belongs to this category (Ademiluyi and Okeke, 1979). By virtue of the herbaceous nature of the studied

Table 6: Analysis of variance for 4 characteristics of leaf fibres in a population of studied species

Species	Population	Degree of freedom (df)	Fibre length (mm)	Fibre diameter (µm)	Cell wall thickness (µm)	Lumen diameter (µm)
Jatropha curcas	Site	9	46.95	7.82	0.52	3.02
	Error	90	43.97	11.31	0.44	8.81
	F-ratio		1.07	0.69	1.17	0.34
Jatropha podagrica	Site	9	37.40	8.73	0.57	3.35
	Error	90	39.57	8.55	0.36	7.84
	F-ratio		0.95	1.02	1.58	0.43
Sida acuta	Site	9	52.45	13.02	0.38	10.78
	Error	90	154.05	19.44	0.59	13.68
	F-ratio		0.34	0.67	1.58	0.79
Ricinus communis	Site	9	37.40	8.73	0.57	3.35
	Error	90	39.57	8.55	0.36	7.84
	F-ratio		0.95	1.02	1.58	0.43

Segments: F 0.05 (9, 90) = 2.04 F 0.01 (9, 90) = 2.72

non-woody plants, with a relatively soft tissue, the pulped stems and leaves would probably require less mechanical beating to separate and fibrillate the fibres than usually required for woody stems of tree species. The advantage of less beating time is the low chance of transverse trading of the fibres into fragments of shorter length. Hence, the fibres of the four studied species can serve as suitable complement to the long slender tracheids of the *Pinus* pulp wood.

Other important dimensional characteristics of the fibres of these plants are large lumen diameter and thin cell wall. The plants possess a recommendable fibre diameter, and therefore can form better pulp. The fiber diameter of the studied plants range is between 15.92µm and 22.50µm. This is comparable with 13.2µm obtained for wheat straw (Esa 1998), 14.8µm for rice straw (Tutus *et al.* 2004), 20.96µm for bagasse (Hemmasi *et al.,* 2011) and 29.89µm for kenaf core (Villar *et al*. 2001). These characteristics usually ensures that the fibres are flattened during the paper making operations to ribbons with large areas of fibre to fibre contact, which result in a good strength development and high flexibility. The degree to which the derived pulp or paper develops and expresses strength would however, depend on the method of pulping and refining.

The relative fibre lengths possessed by these plants, expressing slenderness fibres, high flexibility and high degree of resistance to tear, have parallel in terms of pulp and paper making with those of bagasse and cereal straw (commonly used non-woody plants for pulp and paper making) (Patil *et al*. 2011, Sridach 2010, Pande and Roy 1996). They also have Runkel ratio value of less than 1 which is an indication for suitability for paper production (Oladele and Jaiyeola 1986). These properties collectively recommend the fibres as good for paper making. Subsequent to paper making trials, they may therefore serve not only as a supplement but are alternate to fibres from timbre sources. The fibres in the basal parts of plants having greater flexibility and resistant to tear, are probably better for paper making by virtue of the value of Runkel ratio than those in the apical region where the tissues are young and tender. The relatively high pulp yield and pulp purity also indicates that the xylem fibre in the species can be brought into economic use in paper making.

This study established the fact that short fibres needed to produce good quality pulp and paper can be generated from the studied plants and can compete favorably with other highly rated pulp and paper making raw materials.

In many countries, wood is not available in sufficient quantities to meet the rising demand for pulp and paper (Atchison 1987). More so, sourcing for raw materials for pulp and paper from woody plants encourages desert encroachment, greenhouse effect and other environmental hazards as a result of deforestation. Therefore, non-woody plants can serve as alternative source of short fibres for paper making. This research has really shown the potentials exhibited by *J. curcas, J. podagrica, S. acuta* and *R. communis* as good source of short fibres for paper making. The most important fibre characteristics that need more attention when determining plants to be used for pulp and paper making are relative fibre length, flexibility coefficient and Runkel ratio.

CONCLUSION

The degree of variability in the fibre dimensions within plants and between populations of a plant in the wild, especially of the studied species, may necessitate selection and breeding for improved variants with more consistent fibre characteristics. Additionally, the quality of pulp and paper produced from these plants can be improved by employing some of the modern techniques available for pulp and paper production such as organosolv pulping methods, total chlorine free bleaching and introduction of nanotechnology.

REFERENCES

Ademiluyi E O and Okeke R E 1979. Studies on specific gravity and fibre characteristics of *Gmelina arborea* in some Nigerian plantations. *Nigerian Journal of Science* **13** 232-242.

Atchison J E 1987 Data on non wood plant fibers in pulp and paper making. In: Hamilton, F., Leopold, B. and Kocurek, M. J.(eds.) *Pulp and Paper Manufacture Secondary Fibres and Non-wood Pulping* **3(8)**12

Clark T F 1965. Plant fibres in paper industry. *Economic Botany* **36** 129-146.

El-Sakhawy M, Fahmy Y, Ibrahim A A and Lonnberg B 1995 Organosolv pulping: 1. alcohol of bagasse. *Cellul Chem Technol* **29(6)** 615 -629.

Esa T 1998 Fiber dimension characteristics effect on paper quality. *Finnish Pulp and Paper Resources* **5** 21-52.

FAO 2001 The Forestry Revenue System and Government Expenditure on the Forestry Sector in Nigeria. Working Paper FSFM/WP/02. p. 60.

FAO 2009 Faosat-Forestry. Available online at www.fao.org accessed on October 12, 2016.

Hemmasi A H, Samariha A, Tabei A, Nemati M and Khakifirooz A 2011. Study of morphological and chemical composition of fibers from Iranian sugarcane bagasse. *American-Eurasian Journal of Agricultural and Environmental Sciences,* **11(4):** 478-481.

Hurter R W and Riccio F A 1998 Why CEOS don't want to hear about non-woods or should they? In: TAPPI Proceedings, NA Non-wood Fiber Symposium, Atlanta, GA, USA, pp 1-11.

Jackson J K 1971 Nursery techniques in the savanna region of Nigeria. In S. Kolade Adeytoju and M. O. Odeyinde (eds.) *Proceeding of the Second Annual Conference of the Forestry Association of Nigeria,* Zaria 17 -20th August, 1971. pp. 60 -71.

Jane J W 1956 The structure of wood. Macmillan, New York p. 198.

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

King K F S 1977. Political economy of pulp and paper. *Unasylva*, **29(19)** 6 -9.

Lopez F, Alfaro A, Jimenez L and Rodriguez A 2006 Alcohols as organic solvents for the obtainment of cellulose pulp. *Afinidad* **63(523)** 174-182.

Madakadze I C, Radiotis T J, Goel K and Smith D L 1999 Kraft pulping characteristics and pulp properties of warm season grasses. *Biological Resource Technology* **69** 75-85.

Madu A S 1971 *Nurseries and Plantations Diseases*. FAO Report No. 1823.

Momoh Z O 1970 The problem of mycorrhiza establishment in the savanna zone in Nigeria.

Paper Presented at the Inaugural Conference of the Forestry Association of Nigeria, 1970.

Momoh Z O 1971 Pathological Considerations in the Economics of Plantation Establishments. In S. Kolade Adeytoju and M. O. Odeyinde (eds.) *Proceeding of the Second Annual Conference of the Forestry Association of Nigeria,* Zaria 17-20th August, 1971. pp. 9 -14.

Ojo G O A 1971 Thoughts on tree improvement programme for some savanna plantation species. In S. Kolade Adeytoju and M. O. Odeyinde (eds.) *Proceeding of the Second Annual Conference of the Forestry Association of Nigeria,* Zaria 17- 20th August, 1971. pp. 146 -150.

Ogunwusi A A 2013 Towards optimizing pulp and paper production capacity in Nigeria. A*n International Journal of Science and Technology* **2(1)** 27- 44.

Ogunwusi A A and Ibrahim H D 2014 Advances in pulp and paper technology and implication for the paper industry in Nigeria. *Industrial Engineering Letters* **4(10)** 3-11.

Oladele F A and Jaiyeola F T 1986 Fibre dimension in the xylem of *Amaranthus spinosus* L. *Nigerian Journal of Biological Sciences* **1(1)** 25-32.

Palmer E R 1982 The use of abaca for pulp and paper making. *Tropical Science* **24** 1-16.

Pande H W and Roy D N 1996 Delignification kinetics of soda pulping of kenaf. *Journal of Wood Chemical Technology* **16(3)** 311 - 325.

Patil J V, Chari A, Rao S V, Maththur R M, Vimelesh B and Lal P S 2011 High biomass sorghum (*Sorghum bicolor*)- an alternative raw material for pulp and paper making in India. *IPPTA J* **23(2)** 161 -165.

Saikia S N, Goswami T and Ali F 1997 Evaluation of pulp and paper making characteristics of certain fast growing plants. *Wood Science Technology* **31** 467-475.

Seth R S and Page D H 1988 Fiber properties and tearing resistance. *Wood Science and Technology* **71(2)** 103-107.

Smook G A 1992 Handbook For Pulp and Paper Technologist. Angustwilde Publications, Vancouver, Canada. 210p.

Tutus A, Comlekcio N, Karaman S, and Alma M H 2010. Chemical composition and fiber properties of *Crambe* oriental and *Crambe* tatar. *International Journal of Agriculture and Biology* **12** 286-290.

UNIDO 1978 Paper Presented at UNIDO International Experts Group Meeting on Pulp and Paper Technology, Manila, Philipines, 1992. UNIDO/ID/WG/352/1-37.

Villar J C, Poveda P, and Tagle J L 2001 Comparative study of Kenaf varieties and growing conditions and their effect on Kraft pulp quality. *Wood Science and Technology* **34(6)** 543-552.