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Research article

Assessment of Fibre Characteristics and Suitability of Sida acuta Burm F. for Pulp and Paper Production

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Abstract. The ever-increasing demand for paper and paper products and alarming rate of global population growth necessitates research into non-wood fibre to augment the popular wood fibres in short supply. Sida acuta obtained at two locations, samples collected from 3 areas per location. Samples of dimension 10 x 10 x 20 mm macerated in equal volumes of glacial acetic acid and 30% hydrogen peroxide at 80°C in an oven. Twenty-five whole fibres in swollen condition were measured. Derivatives of fibre dimensions viz: Runkel ratio, flexibility and slenderness were also evaluated. Pooled mean fibre length was 1.04mm, pooled fibre diameter was 25.02μm, pooled fibre lumen width was 14.69μm and fibre cell wall thickness was 5.17μm. Runkel ratio was 0.73, coefficient of suppleness (flexibility) was 60.05 while felting power (slenderness) was 42. Values obtained connote that S. acuta's fibre morphology is good for pulping much more that its Runkel ratio (0.73) is less than 1, coefficient of suppleness (60.05) is greater than 50 and its felting power (42) is greater than 33. Specific Gravity ranged from 0.416–0.468. With reference to the above, S. acuta is fairly suitable for pulp and paper making.

Keywords: Fibre Dimension; Fibre Length; Runkel Ratio

Introduction

All over the world trees are being harvested for the production of paper, paper board and fibre board. Averagely, 35% of the world's trees are harvested for these purposes [1]. However, the consumption of paper and allied products have grown 400% since the last four decades [2]. In any form paper exists, its importance to human existence cannot be over emphasised. Paper has from time immemorial served and remains as a most important medium for the recording and presentation of history. Paper is extensively used in the newspaper and the print media [3] and has played a key role in the development of a nation. In the present time, it is still much relevant and it will continue to be so [4]. Meanwhile, the advancement and improvement in pulp and paper technology coupled with the worldwide shortage of paper to meet the teeming population demand has further encouraged exploitation of lesser known tropical wood species for paper production and this led to the introduction of exotic tropical species such as *Gmelina arborea and Pinus caribaea* [5], [6].

Specific gravity which has been described as a measure of the relative amount of the solid cell wall materials and extractives in the cell lumen of piece of wood [7], [8], [9] has been found to be the best single index of the quality and strength of wood [10], [9]. The specific gravity is the physical property of wood that greatly affect other physical and mechanical properties [11], [12]. [13], [9] observed that specific gravity has a direct effect on wood strength, machinability, conversion, acoustic properties, wearability and paper yield.

Sida acuta, a member of the family Malvaceae, multibranched, 1-2 metres tall from a woody rootstock [14]. It is commonly called Stubbborn grass; a perennial shrub with erect growth habit, growing up to 0.99m tall, leaves are lanceolate with toothed leaf margin (2-9cm long) (Figure 1). They are smooth or have only a few hairs. The petiole (3-7mm long) has 2 stipules of unequal size at the base. It is called *Isekotu or Isubu* in Yoruba, *Utu-wanyi or Utu-ndi* in Igbo, *Yaakawaa* in Kanuri, *Kubur* in Tiv and *Ere-aja or Kosogun* in Hausa [15]. Due to shortage of conventional raw materials for pulping and the increasing demand for paper products worldwide; non-wood plants and agricultural residues have attracted renewed interest, especially in Mediterranean countries like Spain, Italy and Greece with insufficient forest resources [2]. There is little or no information on the specific gravity or fibre characteristics of the species. Therefore, the study was carried out to evaluate the fibre characteristics and suitability of *Sida acuta* in relation to its specific gravity for pulp and paper manufacture.

Figure 1. Lanceolate leaves of Sida acuta with toothed margin

1. Materials and Method

1.1. The study Area

Study samples were collected at Federal College of Forestry, Ibadan and Asa Dam Area, Ilorin. The two locations are in Nigeria. The College is situated at Jericho Hill in Ibadan South –West Local Government Area of Oyo State. The area lies between Latitude 7°26¹N and Longitude 3°54¹E. Asa Dam, Ilorin, Kwara State is located on River Asa (8° 44 00 N; 4° 56 00 E) at approximately 5 km from the city centre.

1.2. Sample collection

From each location three (3) areas (stands) were purposely selected for collection of *Sida acuta* because of their population in such areas. Selection was based on freshness and healthiness of the plant. The roots, branches and leaves were removed while the main stem was air dried in the wood and paper laboratory of Federal College of Forestry, Ibadan for three (3) months.

1.3. Sample defibrisation

Twenty-five plants were selected per stand, dimensioned to 10 x 10 x 20 mm, chopped, macerated in glacial acetic acid (ethanoic acid) and 30% hydrogen peroxide in ratio 1:1 in an oven at 80°C and were later rinsed thoroughly in water. Twenty-five unbroken fibres were measured randomly in swollen condition using a calibrated eye-piece microscope for fibre characteristics evaluation. The fibre dimensions evaluated include the length (FL), diameter (FD), lumen width (LW) as well as fibre wall thickness (FT).

$$\mathrm{FT} = \frac{\mathrm{FD} - \mathrm{LW}}{2} \tag{1}$$

These following derivatives were also determined in accordance with [16]:

$$\text{Felting Power (Slenderness)} = \frac{\text{Fibre Length}}{\text{Fibre Diameter}} \tag{2}$$

$$\text{Coefficient of Suppleness} = \frac{\text{Lumen Width}}{\text{Fibre Diameter}} X\ 100 \tag{3}$$

$$\text{Runkel Ratio} = \frac{\text{2 X Cell Wall Thicknes}}{\text{Lumen Diameter}} \tag{4}$$

The specimens for specific gravity were obtained by removing cylinders of 10 x 10 x 20 mm from the main axis of the test specimens; they were subjected to gravimetric procedure developed by [17] in which specimens were completely saturated with water by boiling. Each cylinder was removed from water, blotted to remove excess water, weighed and oven dried to a constant weight at 80°C. Specific gravity was determined using the formula:

$$SG = \frac{1}{\frac{Wo - Ws}{Wo} + \frac{1}{1.53}} \tag{5}$$

Where:

SG=specific gravity

Ws= saturated weight of wood

Wo=oven-dried weight of wood

1.53=constant developed by [18] as actual weight of wood substance

1.4. Statistical Analysis

A 2 x 3 factorial experimental design was used for the study since 2 locations and 3 stands were considered. Effect of different factors was tested with analysis of variance but Duncan Multiple Range Test was used to assess significance in the parameters treated.

2. Results and Discussion

Fibre Dimension of *Sida acuta*

The mean fibre dimension of *Sida acuta* for locations one (Ibadan) and two (Ilorin) are presented in Table 1. Location one fibre length had mean value of 1.02mm ranging from 1.02 to 1.03mm while that of two was 1.05mm ranging from 1.02 to 1.08mm. Pooled mean was 1.04mm.

Location	Parameter	Stand 1	Stand 2	Stand 3	Mean
Ibadan	Fibre length (mm)	1.02±0.11	1.03±0.11	1.02±0.12	1.02±0.42
	Fibre Diameter (μm)	28.7±0.53	29.0±1.00	25.9±0.66	27.6±1.05
	Lumen Width (μm)	14.0±1.00	13.4±0.36	13.2±0.30	13.5±0.50
	Cell Wall Thickness (μm)	7.4±0.17	7.8±0.20	6.4±0.30	7.2±0.46
Ilorin	Fibre Length (mm)	1.08±0.02	1.05±0.48	1.02±0.43	1.05±0.04
	Fibre Diameter (μm)	22.2±0.98	21.2±1.59	22.98±0.18	22.13±0.81
	Lumen Width (μm)	15.4±0.53	16.4±0.53	15.8±1.20	15.87±1.12
	Cell Wall Thickness (μm)	3.4±0.60	2.4±0.53	3.6±3.12	3.13±1.16

Table 1. Mean Fibre Characteristics Value of Sida acuta for the two locations

The results of analysis of variance (Table 2) show that there are no significant differences in fibre length collected from the two locations, the stands as well as the interaction between the locations and the stands. Pooled mean fibre length was 1.04mm.

Sources of variation	**df**	**Fibre Length**	**Fibre Diameter**	**Lumen Width**	**Cell Wall Thickness**
Location (LO)	1	0.207ns	0.000*	0.000*	0.000*
Tree Stand (TS)	2	0.538ns	0.327ns	0.713ns	0.638ns
LO * TS	2	0.601ns	0.006*	0.281ns	0.015*
Error	143				
Total	**148**				

ns-not significant ($P > 0.05$)

Table 2. Result of Analysis of Variance (ANOVA) for Fibre Dimensions of Sida acuta

In a similar work on maize husk and stalk, [2] reported a mean value of 1.39 and 1.52mm respectively. [19], [20], [21] reported fibre length values of 1.76mm, 1.29mm and 1.50mm on *Aningeria robusta*, *Senna siamea* and *Gerdenia ternifolia* respectively, all of which are lesser-known tropical species researched to be good for paper making. Observed variations could have been caused by factors which include species used, sampling intensity and geographical location among others. The average fibre length for conifers ranges from 1.18 to7.39mm while that of hardwood ranges from 0.5 to 2.6mm [7], [22]. According to [23] & [24] fibre length is the most important in selecting a particular species for paper making. The pooled mean fibre length of 1.04mm recorded in this study can then be considered to be good for paper making. Results obtained in this study clearly indicated that fibre length of *Sida acuta* fall within the range specified for hardwood [22]. High and positive correlation (0.92) exists between fibre length and specific gravity obtained from location one while high but negative correlation (-0.90) was found from location two (Figure 2). Physical and mechanical properties of wood are directly affected by fibre length while it is connected with its toughness, workability and durability [25], [26], [9], [24].

	IBFL	**ILFL**	**IBFD**	**ILFD**	**IBLW**	**ILLW**	**IBSG**	**ILSG**
IBFL	1							
ILFL	0.18	1						
IBFD	0.66	0.86	1					
ILFD	-0.97	-0.43	-0.84	1				
IBLW	-0.17	0.94	0.63	-0.10	1			
ILLW	0.88	-0.31	0.22	-0.72	-0.62	1		
IBSG	0.92	-0.23	0.31	-0.78	-0.55	1.00	1	
ILSG	-0.59	-0.90	-1.00	0.78	-0.70	-0.13	-0.22	1

IB-Ibadan, IL-Ilorin, FL-fibre length, FD-fibre diameter, LW-lumen width, SG-specific gravity

Figure 2. Correlation Matrix of Specific Gravity and Fibre Characteristics of Sida acuta.

The mean fibre diameter of *Sida acuta* is presented in Table 1. The first location had a mean value of 27.9µm; ranging from 25.9 to 29.0µm while 22.13µm was recorded for the second location but ranged from 21.2 to 22.98µm. Pooled mean was 25.02µm. Statistically, location and interaction between location and stand were significant at 5% probability level (Table 2), the follow up test carried out showed mark difference in location (Table 3). However, follow up test on interaction between location and stand showed that stands in location 2 are not different from one another but, stands 1 and 2 in location 1 are quite different from stand 3. Table 4 show that fibre diameter of samples collected from location 1 is quite different from those of 2. Pooled mean fibre diameter was 25.02µm.

Locations	Tree Stand (TS)	Fibre Parameters	Mean (SE)
Ibadan	TS 1	Fibre Diameter	28.7(0.046)c
	TS 2		29.0(0.047)c
	TS 3		25.9(0.033)b
Ilorin	TS 1		22.2(0.028)a
	TS 2		21.2(0.026)a
	TS 3		22.8(0.037)a
Ibadan	TS 1	Fibre Thickness	0.073(0.032)bc
	TS 2		0.08(0.264)c
	TS 3		0.064(0.016)b
Ilorin	TS 1		0.034(0.239)a
	TS 2		0.024(0.017)a
	TS 3		0.035(0.022)a

Mean (SE), number carrying the different alphabets in column are significantly different (P≤0.05) Numbers in parenthesis are Standard Error

Table 3. Follow-Up Test on effect of interaction between location and stand on fibre dimensions of Sida acuta

Locations	Parameters	Mean (SE)
Ibadan	Fibre Diameter	27.8(0.043)a
Ilorin		22.1(0.031)b
Ibadan	Lumen Width	13.5(0.024)b
Ilorin		15.9(0.028)a
Ibadan	Cell Wall thickness	0.072(0.027)a
Ilorin		0.031(0.021)b

Mean (SE), number carrying the same alphabet in column are not significantly different (P>0.05). Numbers in parenthesis are Standard Error

Table 4.Follow-Up Test on effect of location on fibre dimensions of Sida acuta

The values obtained in this study are at variance with reports of previous studies on popular conifers like pine which are used for paper production. For instance, [27] reported a range of 33.00 to 47.00µm from *Pinus caribaea* grown in Nigeria while [28] reported 60.00 to 62.00µm from the same conifer species grown in Malaysia. Variation in results could have been due to environmental effect, geographical location, sampling intensity and even age of trees used.

The mean lumen width values are presented in Table 1. Location 1 (Ibadan) had a mean value of 13.5µm ranging from 13.2 to14.0µm while location 2 (Ilorin) had a mean value of 15.87µm ranging from 15.4 to 16.4µm. Pooled mean was 14.69µm. Location is significant at 5% probability level (Table 2). Follow up test on lumen width showed that the two locations are independent of each other (Table 4). Pooled mean lumen width was 14.69µm.

These values disagree with reported researches of [29], [31] who reported 26.19µm and 23.8µm on *Gmelina arborea* and *Ficus mucoso* respectively. Differences in species used, age of species, genetic variation and geographical location could be adduced for differences in results obtained.

The mean fibre wall thickness is presented in Table 1; location 1 had a mean thickness value of 7.2µm which ranged from 6.4 to 7.8µm. The second location had a mean thickness value of 3.13µm but ranged from 2.4 to 3.6µm. Location of study as well as the interaction between location of study and tree stand had significant effect on fibre wall thickness at 5% probability level (Table 2). Follow up test on effect of location on cell wall thickness revealed that the locations were independent of one another (Table 4). Tree stands in location 2 are not different from one another while those in location 1 were different (Table 3). Pooled mean cell wall thickness was 5.17µm. Wide margin in results obtained from the two locations could be traced to species used, age of species, genetic variation, stand composition, topography and geographical location. [32] in their study on three-year old green Paulownia reported 3.89µm for cell wall thickness.

[33] opined that fibre with Runkel ratio that is greater than 1 is said to have thick wall while cellulose realised from such is not fit for paper manufacture and will possess a stiff fibre with less flexibility and poor bonding ability [34] thus producing bulkier paper than fibre with low Runkel ratio. However, fibre with Runkel ratio equal to 1 has cell wall that is said to have medium thickness and cellulose realised from such is fit for paper manufacture, unlike when the ratio is less than 1, hence having thin cell wall but cellulose realised from such fibre produces high pulp yield and is most suitable for paper making. Location 1 (Ibadan) recorded Runkel ratio of 1.07 while location 2 (Ilorin) had 0.39. [35] reported that species with low fibre width, lumen diameter as well higher Runkel ratio were recommended for higher quality in terms of paper strength and this is strongly in favour of location 1 fibres. Pulled Runkel ratio for the two locations was 0.73. From this morphological characteristic, *S. acuta* can be pulped and is fit for paper manufacture. The values obtained in this study compare favourably well with *Pinus caribaea* and *Gmelina arborea* that have been studied for fibre characteristics (Table 5).

Fibre Characteristics	***Sida acuta***	****Pinus caribaea***	*****Gmelina arborea***
Fibre Length (mm)	1.04	NA	1.24-1.38
Fibre Diameter (µm)	25.02	60-62	21.47-22.76
Lumen Width (µm)	14.69	46-47	25.66-26.19
Cell Wall Thickness (µm)	5.17	0.06-0.08	2.43-2.91
Runkel Ratio	0.73	0.74-0.88	0.80-1.03
Coefficient of Suppleness (Flexibility)	60.05	0.74-0.77	NA
Felting Power (Slenderness)	42	40-59	57.75-60.63

*Current study

**[3]

***[29]

NA-Not Available

Table 5. Mean fibre dimension of Sida acuta in comparison with popular species for pulp and paper production

According to [36], Coefficient of suppleness (flexibility) can be classified into four groups of fibres: i) High elastic fibres having elasticity coefficient greater than 75. ii) Elastic fibres having elasticity ratio of 50 to 75. iii) Rigid fibres having elasticity ratio of 30 to 50. iv), Highly rigid fibres having elasticity ratio less than 30. Location 1 had a value of 48.39, while location 2 had a value of 71.71; pulled value was 60.05. According to this classification, flexibility ratio of *Sida acuta* fibres fall within elastic fibres which ranges between 50 -70. [37] disclosed that flexibility of =50 are necessary for paper manufacture since paper strength increases as flexibility increases. Therefore, with flexibility of 60.05 (Table 5) recorded for *S. acuta*, its fibres are supple and will therefore enhance good surface contact. With this, *S. acuta* can be said to possess good fibre characteristics fit for paper manufacture.

The recommended Felting power (Slenderness) value for paper manufacture is 33 and above. Slenderness ratio for location 1 was 37 while that of location 2 was 47; pulled value was 42 (Table 5). Since the value recorded for *S. acuta* was more than the recommended value for paper making, its fibres are suitable for paper making.

The mean specific gravity for location one was 0.44 (Table 6) while that of location two was 0.43 (Table 6); ranging from 0.419 to 0.468. This range tallies with the findings of **[37], and [19]** who reported 0.40-0.48 on *Aningeria robusta,* a lesser known tropical species. [39] also reported 0.44 - 0.54 on *Boscia anguistifolia,* a lesser known tropical species. Though, *S. acuta* is not a tree but the value obtained for its specific gravity is very close to those of lesser known tropical trees. [11], & [12], noted that specific gravity has direct relationship with the paper yield. This, also confirms the possibility of considering *S. acuta* for paper making.

Location	Tree Stands	Mean Specific gravity
Ibadan	Stand 1	0.416 ±0.02
	Stand 2	0.468 ±0.1
	Stand 3	0.432 ±0.001
	Mean	**0.439±0.03**
Ilorin	Stand 1	0.419 ±0.02
	Stand 2	0.419 ±0.05
	Stand 3	0.455±0.02
	Mean	**0.431±0.02**

Table 6. Mean Specific gravity for the two locations

Conclusion

The increasing demands for paper and environmental concerns have increased the need for non-wood pulp as a low-cost raw material for papermaking. This has also led to the developing of alternative pulping technologies that are environmentally friendly. This study successfully investigated paper related properties of *Sida acuta,* one of the commonest perennial plants that grow in Nigeria and established its suitability for pulp and paper production. It was observed that none of the sources of

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variance of fibre length was significant at 5% probability level. Considering its Runkel ratio (0.73) that is less than 1, flexibility that is greater than 50, slenderness that is more than 33, specific gravity of 0.43 and 0.44, *Sida acuta* is fairly suitable as alternative to pulp and paper production. Despite this, conventional chemical pulping of the wood should be carried out to confirm its pulping ability. Moreover, blending its pulp with that of traditional species such as pine is highly recommended.

Conflicts of Interest

The authors declare no conflicts of interest.

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