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PULPING POTENTIAL OF *Thaumatococcus daniellii* (Benn) Benth. IN OMO AND OBAN FOREST RESERVES OF NIGERIA

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ABSTRACT
This study investigated the potential of the stalk of *Thaumatococcus daniellii* for pulp production in Omo and Oban forest reserves located in Ogun and Cross River States of Nigeria respectively. Stalks' samples of *Thaumatococcus daniellii* were obtained from three sites (plantation, natural forest and farmland fallow) within each of the two locations. The stalks' samples collected were reduced to sliver form and macerated separately in a well labelled test tube with 10ml in an equal volume mixture of 30% Hydrogen Peroxide and 10% acetic acid and cook in a water bath at $100^o \pm 2^o$ C for 45 minutes. The following fibre characteristics namely; fibre length, diameter, lumen width, and cell wall thickness were measured in swollen condition and its associated derived indices; Runkel ratio, slenderness ratio and coefficient of flexibility were evaluated. Data obtained were subjected to Analysis of variance (ANOVA) and T-test., The results showed there were no significant differences in fibre characteristics among the sites in Omo forest reserve (location one) while those in Oban forest reserve (location two) were significant ($p< 0.05$). The T-test result showed there were no significant differences in fibre characteristics between the two locations. Appreciable fibre mean length of 2.5mm and pulp yield of 56.2% obtained in farmland site of location one with less drastic conditions for pulping make it suitable as a alternative source of fibrous material to wood.

KEYWORDS: Derived indices, fibre characteristics, pulping, *Thaumatococcus daniellii.*

INTRODUCTION

Nigeria is blessed with huge amount of bio-resources such as non-woody plants like sisal, abaca, straws, hemp, jute, kenaf ,alfalfa, flax, bamboo, reeds, sabai-grass, esparto-grass etc for paper production. The large amount quantity of these co-products produced each year must be developed into value-added products that would allow the utilization of these resources as part of sustainable development (Onilude, 2011). With an average of annual world pulp and paper consumption growth rate of 3.2% and woody pulp plants production growth rate less than 1%, Foresters as well as other environmentalists are already confronted with the problem of providing pulp and paper without undermining the environment for a population that continues to grow at alarming rate. This situation is believed to be worse in most African, Asian and Latin American countries where pulp production is in a deficit and population consumption growth rate is as high as 4.0%. In Nigeria, where the population is estimated to increase at 3.3% annually the story is even the worst, currently all the pulp and paper consumptions are imported yet the primary and secondary forests are continually cleared at a huge environmental cost.

The recent renewed interest in non-woody plants as paper-making fibres originated from a strong environmental motive (Matthew, 2000). Many non-woody fibres used for paper-making are available as by-products/waste of agriculture and thus can be potentially cheaper than wood (Matthew, 2000). Plants of this type can be grown in areas that will not support trees, often with very limited water and low soil quality. Apart from the above, non-woody plants offer other several advantages including high annual yield per hectare, short growth cycle, moderate fertilization requirement, ease harvesting and transportation, and lower lignin content resulting to reduce energy and chemical used during pulping (Ververis *et al*.,2003). *Thaumatococcus daniellii* stalks are by-products/wastes which also possess all these sterling advantages over wood, also scanty attention has been given to its pulping potentials comparison in different ecological zones of Nigeria. It is on these backgrounds that the authors investigated and compared the potentials of *Thaumatococcus daniellii* stalks as a reasonable alternative/replacement of wood fibre in Omo and Oban reserves – predominantly Lowland rainforest and Mangrove forest vegetation zones respectively and made recommendations for the management practices for sustainable non-woody plants production and utilization with the ultimate aim for a sustainable development of Nigeria.

MATERIALS AND METHODS

Raw materials

A total of one hundred and fifty (150) stalks of *Thaumatococcus daniellii* were obtained randomly from three different selected sites (natural forest, plantation forest and farmland), twenty-five (25) from each site within the two locations (Omo and Oban forest reserves) for the study. All the selected stalks have no blemish and shown good adaptability to the areas climatic conditions with satisfactory foliage production and stalks length ranging from 64.4cm to 81.6cm. They were cleaned, air and oven-dried to desirable moisture content before subjected to laboratory test.

Pulp yield determination

Samples of 100g of chips were obtained from ten stalks crushed each from the three sites in the study locations. They were cook in a mixture ratio 2:1 of sodium hydroxide and sodium sulphide in a prototype pulp digester for 2hours at 105^{o}C. Cooking liquor was separated from the pulp and pulp properly washed with cold water till non-slippery pulp obtained. Thereafter, the pulp was air dried for two days and oven-dried for 6hours at 80^{o}c and finally weighed to determine the pulp yield in percentages.

Fibre treatment and measurement

Samples selected were reduced to sliver forms and macerated separately in a well-labelled test tube with 10ml in an equal volume mixture of 30% Hydrogen Peroxide and 10% acetic acid and cook in a water bath at 100^{o} ± 2^{o} C for 45 minutes as used by Ogunsanwo and Onilude (2000) and Ojo *et al*. (2008). Hydrogen Peroxide (H_20_2) was used as oxidizing agent to bleach the silvers. The chemical used was decanted and the silvers were then washed, placed in small flasks with 50ml distilled water and the fibre bundles were seperated into individuals fibres using small mixer with a plastic end to prevent fibre breaking. Ten macerated fibre suspension samples from each site of the two locations were finally placed on a slide (standard, 7.5cm x 2.5cm) by means of a medicine dropper (Ververis *et al.,* 2003). For fibre diameter, lumen diameter and cell-wall thickness determination, cross-sections were made from the same length as above and stained with 1:1 aniline sulphate-glycerine mixture to enhance cell-wall visibility (cell walls retain a characteristic yellowish colour). All tested fibre samples were viewed and measured under a calibrated Rheichart Viscopan microscope. Data obtained were tested using analysis of variance (ANOVA) among the sites in the two locations and mean values derived were used to compare the potentials of pulping in the two locations using t-test.

Derived valued (indices)

Three derived values were also evaluated using primary fibre characteristics or dimensions: 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 (Shatalov and Pereira, 2002). The values were then compared with those of soft and hardwoods to assess its suitability as reasonable alternative raw material for paper production.

Statistical analysis

Data collected were subjected to analysis of variance (ANOVA, P< 0.05) for each location separately using appropriate statistical software (SPSS). Sources of variation were different sites: Natural forest (NF), plantation forest (PF), farmland (FL) as well as the prevailing environmental conditions. T-test was used to compare the two locations using mean values and pulp yield presented in bar-chart.

RESULTS AND DISCUSSION

Pulp yield

Table 1 and Fig.1 show the pulp yield. It is clearly obvious that yield in location 1 (Omo forest reserve in Ogun State) on average is about 15% higher than that of location 2 (Oban forest reserve in Cross-river State). On individual site account natural forest has lowest yield, followed by plantation forest in both locations with 20.2% and24.3% higher in location 1 over location 2 respectively. The highest was obtained in farmland site with insignificant difference of 1.9% higher in location 2 over location 1. The reason for the higher variations in natural and plantation forest sites between the two locations could be adduced to differences in ecological factors especially hydrological cycle which usually remain nearly intact and level of soil colloids. Unfavourable hydrological cycle prevailing in location 2 might have hindered the availability and uptake of essentials nutrients needed for higher production and storage of carbohydrate. Appreciable amount of pulp yield obtained in farmland sites in both locations as seen in Table 1 could be ascribed to the extent to which the plants are exposed to sunlight and enjoyed some silvicultural/agricultural practices favouring higher formation and storage of carbohydrate. Other sources of variations might be the age and genetics make up. Age at harvest affects the organic matter quantity because it is general knowledge that at onset and during flowering stage most of the soluble carbohydrate would be mobilized for fruiting and thus reduce pulp yield of stalks. The result obtained in location 1 is in agreement with the range of pulp yield of wheat straws reported by (Onilude, 2011, EPA, 2002, Casey, 1980) using the same pulp processing. Obtaining higher values in location 1 is an indication that the vegetation zone (lowland rainforest) is better suited for production and utilization of *Thaumatococcus daniellii* stalks as fibrous raw material for pulp and paper production than location 2 (mangrove/coastal forest zone) in Nigeria.

TABLE1: Pulp Yield of *Thaumatococcus daniellii*

Location1 (Omo)	Pulp Yield	Location2 (Oban)	Pulp Yield
Natural forest	45.0%	Natural Forest	24.2%
Plantation forest	49.9%	Plantation Forest	25.6%
Farmland	56.2%	Farmland	58.1%
Average	50%		36%

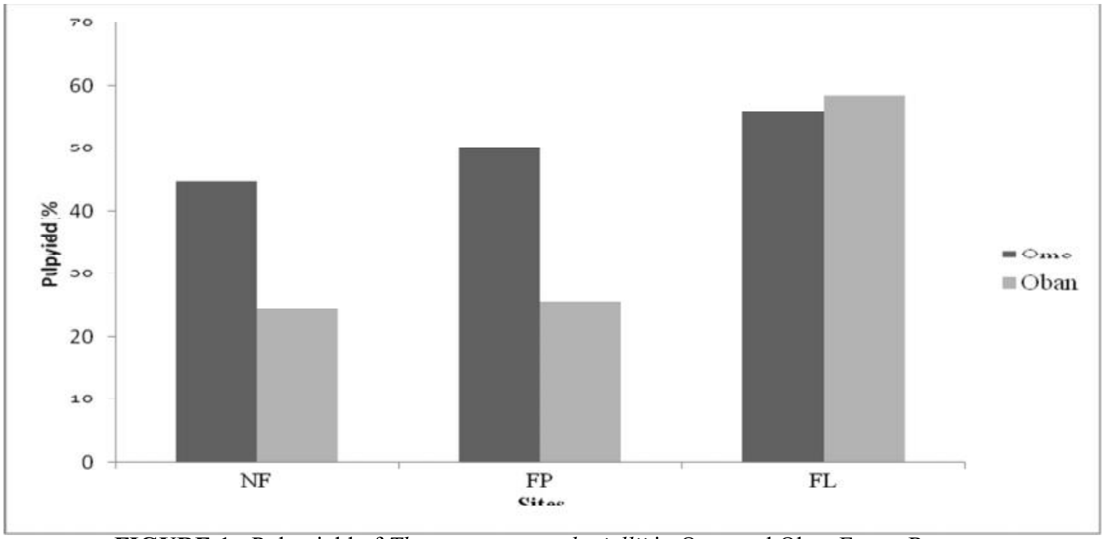

FIGURE 1: Pulp yield of *Thaumatococcus daniellii* in Omo and Oban Forest Reserve

Fibre characteristics and derived values (indices)

Fibre characteristics and their associated derived indices are shown in Table 2,3,4,5,6 and 7. The obtained results indicated that location 1 has higher favourable values for pulp and paper production than location 2 as seen in Table 2 and 6. For fibre length, though not statistically significant in location 1 as shown in Table 3, the highest fibre length of 2.50mm obtained in farmland site placed it on long fibre status. Followed by 2.19mm in plantation forest and 2.07mm in natural forest. The longer the fibres, the better the quality the final paper products (Onilude,2011). On the other, location 2 shows significant difference in fibre length as shown in Table 4. Plantation forest has longest of 2.38mm which make it statistically different from the 1.81mm and 1.70mm obtained in farmland and natural forest respectively. On average, location 1 has 2.25mm while location 2 has 1.7mm as shown in table 6. The average length of 2.25mm still placed fibres produced in location 1 within the long fibre range of 2.10-5.0mm as reported by Oluwadare (1998). The variation in the fibre length could be due to the differences in hydrological cycle pattern, shade management as well as water stress. Water stress/starvation usually limits growth and improves strength property. Good shade management hardens plants stems and also improves strength property. Good shade management and stress factors of water and nutrients are assumed to make the fibre longest in farmland site of location 1 and longer in plantation forest of location 2.

As to the derived indices, although, *Thaumatococcus daniellii* stalk cells are smaller than softwoods cells they have favourable slenderness ratio. Stalks fibres have good derived values in both locations (especially slenderness ratio) compared to those of some softwoods and certainly to most hardwoods as shown in Table 7. Slenderness ratio is statistically significant with the least value higher than those of hardwoods. Therefore papers made from the *Thaumatococcus daniellii* stalks fibres are expected to have increased mechanical strength and be suitable for writing, printing, wrapping and packaging purposes. On individual site account short fibres obtained in natural forest and farmland of location 2 however highly flexible with good Runkel ratio and low felting power and can thus complement the higher mechanical strength of the stalk fibres of location 1. In terms of yield, location 1 yielded 50% on average while location 2 yielded 36%, fibres dimensions and derived values location 1 still has an edge, though t-test shows no significant difference as shown in Table 5

TABLE 2: Mean values of the Fibre Characteristics of *Thaumatococcus daniellii* stalks and their derived indices from the two locations

LOCATIONS	SITES	FL (mm)	FD (μm)	LU (μm)	CW (μm)	RR	FC	SR
	NATURAL FOREST	2.07	15.42	9.28	3.07	0.72	59.20	142.68
OMO	PLANTATION FOREST	2.19	18.18	10.82	3.68	0.71	59.35	126.36
	FARMLAND FALLOW	2.50	19.90	12.03	3.94	0.67	60.46	131.51
	NATURAL FOREST	1.70	17.73	11.46	3.14	0.60	63.48	99.72
OBAN	PLANTATION FOREST	2.38	15.10	8.64	3.23	0.81	56.38	160.15
	FARMLAND FALLOW	1.81	20.48	12.29	4.10	0.73	58.86	91.69

TABLE 3: ANOVA for Fibre Characteristics of *Thaumatococcus daniellii* in Omo Reserve

SV	DF	SS	MS	F-value	P-value
Fibre Length					
Among Sample Groups	2	1.003	0.501	2.575	0.532
Within Sample Groups	27	5.255	0.195		
Total	29	6.258			
Fibre Diameter					
Among Sample Groups	2	101.275	50.637	2.721	0.673
Within Sample Groups	27	502.467	18.610		
Total	29	603.741			
Lumen Width					
Among Sample Groups	2	30.038	19.019	2.079	0.447
Within Sample Groups	27	246.989	9.148		
Total	29	285.027			
Cell Wall Thickness					
Among Sample Groups	2	3.939	1.969	1.990	1.008
Within Sample Groups	27	26.726	0.990		
Total	29	30.665			
Runkel Ratio					
Among Sample Groups	2	2.756	1.378	1.009	0.543
Within Sample Groups	27	36.867	1.365		
Total	29	39.623			
Flexibility Coefficient					
Among Sample Groups	2	9.356	4.678	0.096	0.921
Within Sample Groups	27	1313.494	48.848		
Total	29	1322.850			
Slenderness Ratio					
Among Sample Groups	2	41.182	1.280	15.049	0.003*
Within Sample Groups	27	143.413	28.683		
Total	29	184.595			

* F-ratio is significantly different at $\alpha = 0.05$

TABLE 4: ANOVA for Fibre Charactertistics of *Thaumatococcus danielli* in Oban Reserve

SV	DF	SS	MS	F-value	P-value
Fibre Length					
Among Sample Groups	2	2.678	1.339	25.833	0.027*
Within Sample Groups	27	1.400	0.052		
Total	29	4.078			
Fibre Diameter					
Among Sample Groups	2	144.534	72.267	5.175	0.001*
Within Sample Groups	27	377.037	13.964		
Total	29	521.571			
Lumen Width					
Among Sample Groups	2	73.100	36.550	2.710	0.678
Within Sample Groups	27	364.134	13.486		
Total	29	285.027			
Cell Wall Thickness					
Among Sample Groups	2	5.585	2.792	8.567	0.041*
Within Sample Groups	27	8.801	0.326		
Total	29	14.385			
Runkel Ratio					
Among Sample Groups	2	0.241	0.122	2.194	0.762
Within Sample Groups	27	1.486	0.055		
Total	29	39.623			
Flexibility Coefficient					
Among Sample Groups	2	9.356	4.678	0.096	0.078
Within Sample Groups	27	1313.494	48.848		
Total	29	1322.850			
Slenderness Ratio					
Among Sample Groups	2	41.182	1.280	15.049	0.005*
Within Sample Groups	27	143.413	28.683		
Total	29	184.595			

* F-ratio is significantly different at $\alpha = 0.05$

TABLE 5: T-test comparing the mean of the Fibre Characteristics of the Stalk of *Thaumatococcus danielli* in the two locations (Omo & Oban**)**

Fibre characteristics						95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Length	1.176	4	.305	.29000	.24662	-.39473	.97473
Diameter	.031	4	.977	.06333	2.02855	-5.56882	5.69549
Lumen Width	-.064	4	.952	-.08667	1.36141	-3.86655	3.69322
Cell Wall	.183	4	.864	.07333	.40022	-1.03786	1.18453
Runkel Ratio	-.211	4	.843	-.01333	.06307	-.18844	.16178
Flex of Coeff.	.046	4	.966	.09667	2.11800	-5.78386	5.97719
Slenderness R	.738	4	.502	16.33000	22.13679	-45.13157	77.79157

TABLE 6: Mean values fibre characteristics of *Thaumatococcus danielli* stalk in the two location

LOCATIONS	FL(mm)	FD (µm)	LW(µm)	CW(µm)
OMO	2.25	17.83	10.71	3.56
OBAN	1.96	17.77	10.79	3.49

TABLE 7: comparing derived mean values of *Thaumatococcus daniellii* stalk fibres in the two locations with those of soft and hardwoods

Plant materials	Derived values		
	Slenderness ratio	Flexibility coefficient	Runkel ratio
Thaumatococcus daniellii (Omo) *	133.52	59.70	0.70
Thaumatococcus daniellii (Oban) *	117.19	59.57	0.71
Almond tree**	58.7	32.8	2.0
Softwoods**	95-120	75	0.35
Hardwoods**	55-75	55-70	0.4-0.7

* Present findings
** From Ververis *et al*., (2003)

CONCLUSION AND RECOMMENDATIONS

Conclusion

The investigation of *Thaumatococcus daniellii* stalk pulp yield and fibre characteristics with its associated indices showed that the non-woody plant is suitable for producing paper of various grades. There is potential to take the comparative advantage pulp strength in lowland rainforest zone of Nigeria over mangrove/coastal rainforest since its cultivation will enhance sustainable development in paper production. The higher biomass output of non-woody plants could provide large amounts of non-woody fibres which could substitute for most of the imported in Nigeria. The vegetation and other climatic conditions of the country favour the establishment of both long and short fibre non-woody plant species that may be selected for propagation with less cost implication characterised by minimum tillage as a sure way of attaining sustainability in pulp and paper production. Once our paper sector becomes fully functional and sustainable, Nigeria is on the path to sustainable development. This study offers valuable information that will lead to a better industrial utilization of this non-woody plant species of high socioeconomic interest.

RECOMMENDATIONS

- With the abundance of non-woody plants growing naturally in the country, there is need for the government to popularize their propagation by rural farmers. Such fibres can be produced locally and supplied to the existing wastepaper recycling plants that are growing in number.
- Government should provide enabling environment for research.
- There is still be need however, for further investigation into comparison of many more vegetation zones in order to draw more reliable and conclusive statement in view of the two vegetation zones compared out of eight broad vegetation zones in Nigeria.
- There will also be the need to harness and combine indigenous knowledge in the use of non-woody plants with modern technology to solving many environmental problems globally.

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