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Fibre Characterisation of Gerdenia Ternifolia (Linn C.) Schumach for its Pulping Potential

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Abstract

The study was conducted to determine the fibre characteristics of *Gerdenia ternifolia* obtained at different locations in Onigambari Forest Reserve of Oyo State, Nigeria, with a view to assessing its pulping potential. Three trees of *Gerdenia ternifolia* of average age of 7 years purposively selected were felled, and wood samples collected from the stem of each tree at 10, 50 and 90% of the merchantable height corresponding to the base, middle and top positions respectively. The collected wood samples were macerated in a solution containing 10% acetic acid and 30% hydrogen peroxide in the ratio of 1: 2 by volume. Pulp samples of the softened and defiberised wood were viewed under a visopan microscope for assessment and determination of the following fibre parameters: fibre length, fibre diameter, lumen width, cell wall thickness, and Runkel ratio, coefficient of suppleness and felting power. The results obtained show that *Gerdenia ternifolia* on the average has the following dimensional characteristics: fibre length (1.38mm), fibre diameter (27.79 μm), lumen width 14.80μm), cell wall thickness (6.48 μm), Runkel ratio (0.88), coefficient of suppleness (53.70) and felting power (51.08). The values obtained indicate the suitability of *Gerdenia ternifolia* as a pulping material, especially for its Runkel ratio of 0.88 which is less than 1, and a favourable coefficient of suppleness of greater than 50. A comparison of the values for the respective parameters assessed with similar values from known pulpable wood species like *Gmelina arborea* and *Pinus caribaea,* gives encouraging results. However, the need to subject the species to conventional chemical pulping under varied process regimes will be imperative, in order to establish the screened pulp yield of the study plant for affirmative determination of its pulpability. Also, despite not having wood samples taken from the radial plane of outer, middle and core positions, to give a holistic assessment of wood, it can still be concluded that based on this study, *Gerdenia ternifolia* is pulpable and is therefore recommended as a good and suitable fibrous material for the pulp and paper industry.

Keywords: Gerdenia ternifolia; fibre characteristics; pulpability.

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1. Introduction

From time immemorial paper has played key roles in the cultural development of many nations, and there is no doubt that it would continue to have much impact on the advancement of several societies in future. Paper, however, must maintain its competitiveness through continuous products development in order to meet the ever increasing demand on its performance [1].

In its various forms, paper has been indispensable to the civilized man. As writing and printing material, paper remains the medium of recording and preserving history, besides being used extensively as a communication medium in newspaper printing and book publishing [2].

Practically, paper has no rival as base material for hygienic and sanitary conveniences. Therefore, paper and paper products are an essential part of modern living and it would be hard to imagine how our life styles would be without them [3]

Today's pulp and paper products are made from a variety of fibre types, including natural and synthetic fibres. However, the vast majority of these fibres are obtained from natural resources – plant. According to TAPPI [4], more than 90% of all paper products are derived from wood due to its unique properties of abundant availability, easy pulpability and sustainable renewability. Fibre characteristion of wood defines the dimensions of fibre and predicts the effects on quality of paper made from such fibre. Generally, fibre length, cell wall thickness and to some extent fibre width affect such paper properties as mechanical strength, sheet formation, opacity and smoothness [5].

Fundamentally, paper properties depend on fibre properties and the method of fibre preparation. The fibre characteristics of wood have been described to vary widely and thus exert varied influences on pulp and paper quality, including bulk density, fibre strength and inter-fibre bonding [6, 7]. Pulp and paper quality tend to relate closely to fibre dimensions. Hence, paper making is one advanced means of utilizing the inherent properties of wood fibres and their cellulosic components [8].

To date, *Gmelina arborea* is about the only outstanding exotic tropical wood species planted in Nigeria for pulp and paper making [9]. This wood species is vastly exploited in the forest for other purposes, besides pulp and paper production. It is therefore imperative to start searching for alternative wood species in order to meet up with process needs as insufficient supply of fibrous material on sustainable basis remains the major setback to the pulp and paper sector [10].

Published research studies have shown that there are other potential hardwood species that are equally suitable for pulp production. Hence, species like *Gerdenia ternifolia* should be given trial cultivation and be evaluated for its pulping properties [9, 11].

Gerdenia ternifolia is an evergreen small tree of the family of Rubiaceae, native to the tropical and sub-tropical regions of Africa and southern Asia. It is capable of growing to a height of about 15m on acidic soil with good drainage, and thrives well at average temperature of 25^0C [12].

According to FAO [13], it is estimated that there are currently more than 50,000 plant species worldwide, and astonishingly, only about 1000 different tree species are utilised globally. Thus, thousands of tree species are either not utilised, under-utilised or used inappropriately. Investigating therefore into some lesser known or lesser-used wood species becomes an attractive option for researchers in the pulp and paper industry. This research therefore explores the potential of *Gerdenia ternifolia* as a suitable pulping material for the pulp and paper industry.

2. Materials and Methods

2.1 Collection of Sample

Three standing trees of *Gerdenia ternifolia* of average age of 7 years, at different locations in Onigambari Forest Reserve of Oyo State, Nigeria, were purposively selected and felled. Wood samples were collected at 10, 50 and 90% of the merchantable height of each tree, corresponding to base, middle and top portions respectively along the bole of the tree. The wood samples were reduced to chips, and with the aid of a sharp knife, further cut into splinter-like shapes of about 2 mm long and 1 mm wide, in readiness for maceration.

2.2 Maceration and Microscopy

The wood samples were macerated in properly labelled test tubes containing a solution of 10% acetic acid and 30% hydrogen peroxide, mixed in the ratio of 1:2 by volume, as reported by Oluwadare and Sotannde [14]. All the test tubes containing the various samples were later kept in an oven for 4 hours and maintained at temperature of 101^{o}C, for the non-cellulose components to dissolve out, leaving majorly cellulosic fibres only.

At the expiration of the 4 hours, the softened and bleached pulpy mass was gently rinsed with distilled water to remove residual chemical before the test tubes were thoroughly but carefully shaken to separate the fibrous mass into liberated individual fibres.

Twenty fibres were randomly selected from each of the samples collected from the base, middle and top portions of the selected trees, making sixty samples per tree. The fibres of each sample were viewed under an electron microscope for fibre dimension assessment and determination. A total of 180 samples were selected from the three trees evaluated.

2.3 Parameters Determined

Under the electron microscope, the following fibre parameters were assessed:

- Fibre length - this was measured by aligning the pulp fibres sideways to the graduated ruler in the microscope.
- Fibre Diameter - the fibre diameter was measured by placing the graduated ruler in the microscope in a horizontal direction at the middle of the fibre.
- Lumen width - this is the cavity of the cell from the first wall side to the second wall side.

Parameters determined as derived values using appropriate formula include:

- Cell wall thickness - this was calculated by subtracting the lumen width from the fibre diameter and dividing the difference by two.

Mathematically,

$$CW = \frac{D - Lu}{2} \qquad (1)$$

Runkel ratio - this measures the amount of cell wall thickness with respect to the cavity (lumen width) of the fibre. It is a major fibre assessment index to determine the pulpability of fibrous material for paper making.

Mathematically,

$$\text{Runkel ratio} = \frac{2Cw}{Lu} \qquad (2)$$

Where,

Cw = cell wall thickness (µm)

Lu = lumen width (µm)

D = fibre diameter (µm)

- Coefficient of suppleness – commonly referred to as flexibility coefficient- gives a measure of the flexibility of the fibres, the bonding strength of individual fibres and by extension, the tensile and bursting strength values of the paper formed from the fibres.

Mathematically,

$$\text{Coefficient of suppleness} = \frac{Lu}{FD} \times 100 \qquad (3)$$

Where,

Lu = lumen width (µm)

FD = fibre diameter (µm)

- Felting power - is an indication of the collapsibility of the fibres into a mat. It shows the slenderness of the fibres (slenderness ratio), and measures the tear property of pulp fibres in paper production.

Mathematically,

$$\text{Felting power} = \frac{FL}{FD} \qquad (4)$$

Where,

FL = fibre length (mm)

FD = fibre diameter (µm)

2.4 Experimental Design and Statistical Analysis

The experimental design adopted was a 3 x 3 factorial in a completely randomized design (CRD). The mathematical model used for the design is given as

$$Yij = \mu + Ai + Bj + ABij + Eij \qquad (5)$$

Where, Yij = Individual Observation

µ = General Mean

Ai = Effect of factor A (tree)

Bj = Effect of factor B (stem portion)

ABij = Effect of interaction between A and B

Eij = Effect of interaction in error term

Analysis of variance (ANOVA) was used to interprete the various effects of factors treated, while a follow- up Duncan Multiple Range Test (DMRT) was adopted to assess, if there was any significance in the parameters treated among the trees evaluated.

3. Results and Discussion

The mean values for fibre characteristics of *Gerdenia ternifolia* are presented in Table 1

Table 1 shows that *Gerdenia ternifolia* has a pooled mean value of 1.38 mm for fibre length, though Tree A recorded the highest mean value of 1.50 mm at the stem middle potion and Tree C having the least value of 1.18 mm at the top portion of the tree stem

For fibre diameter, the mean value is 27.79 µm, with the highest value of 31.0 µm obtained in Tree B at the base portion of the bole while Tree A recorded the least value of 22.80 µm at the stem top portion.

The fibre length and fibre diameter were in the main increasing from base to middle of the tree before decreasing towards the top portion. Axial reduction in fibre length and fibre diameter towards the top portion of the stem is similar to the findings by Ajala and Onulide [15] in their works on Nigeria grown *Pinus caribaea*, as well as the outcome of researched study by Okon [16] on fibre dimension characteristics of 25 year old *Gmelina arborea* in Oluwa forest reserve, southwest Nigeria.

Table 1: Mean values for fibre characteristics of *Gerdenia ternifolia*

Tree	Stem portion	Fibre length (mm)	Fibre diameter (µm)	Lumen width (µm)	Cell wall thickness (µm)	Runkel ratio	Coefficient of suppleness	Felting power
Tree A	Base	1.48±0.13	30.0±6.86	16.1±4.41	6.93±0.13	0.86±0.13	53.7±3.81	51.4±11.70
	Middle	1.50±0.12	29.0±4.00	15.5±2.30	6.96±0.35	0.90±0.08	52.6±2.17	52.0±8.03
	Top	1.25±0.14	22.8±5.84	12.7±3.98	5.70±1.38	0.80±0.15	55.6±4.81	55.0±13.57
Tree B	Base	1.41±0.18	31.0±5.90	16.3±3.18	7.36±1.72	0.91±0.22	52.7±5.32	47.0±10.90
	Middle	1.42±0.14	29.4±4.41	15.4±3.33	7.00±0.78	0.86±0.17	51.9±4.78	49.0±8.77
	Top	1.22±0.31	23.3±3.67	12.8±3.67	5.21±1.72	0.82±0.15	54.9±4.66	50.9±14.51
Tree C	Base	1.49±0.17	28.8±6.89	16.2±3.40	7.45±1.35	1.04±0.47	54.6±5.84	48.5±5.61
	Middle	1.43±0.05	30.8±2.65	16.2±2.08	6.75±0.85	0.88±0.12	52.2±2.60	51.5±6.95
	Top	1.18±0.15	24.3±4.94	13.5±2.76	5.51±1.07	0.82±0.10	54.6±2.17	53.7±11.10
Pooled Mean		1.38	27.79	14.80	6.48	0.88	53.70	51.08

As shown in Table 1, the pooled mean value of cell wall thickness for *Gerdenia ternifolia* is 6.48 µm. The highest mean value of 7.45 µm and least value of 5.21 µm were recorded by Tree C at the base portion and Tree B at the top portion of the stem, respectively. This is in consonance with the auxin gradient theory that in the apical region of the growing shoot, high production of early wood near the crown predominates with thin-walled cells at the top [17].

According to Oluwadare and Sotannde [14], the thinner the cell wall thickness, the more flexible and collapsible the fibres are during web conformability. This is exemplified in the highest mean values for coefficient of suppleness, CS (55.6, 54.9 and 54.6) and felting power (55.0, 50.9 and 53.7) recorded by Tree A, B and C respectively at the top portion of the stem. CS ≥ 50 are necessary for paper making because paper strength tends to improve with increasing CS [8].

From the results in Table 1, *G. ternifolia* possesses CS > 50; hence, its fibres are flexible and will produce good surface contact for increased fibre-to-fibre bonding. Thus, the wood of *G. ternifolia* is suitable for paper making irrespective of stem portions.

Runkel ratio of less than 1, averaging 0.88 was obtained for *Gerdenia ternifolia*. This is a good fibre morphological index, indicating that *G. ternifolia* is pulpable and very suitable for paper making [3].

Table 2: Analysis of variance (ANOVA) for fibre characteristics of *Gerdenia ternifolia*

Source of variation	Degree of freedom	Sum of squares	Mean Square	F.cal	Sig.
Fibre length (mm)					
Tree	2	0.065	0.033	1.152	0.321 ns
Portion	2	1.154	0.577	20.448	0.000*
Tree & Portion	4	0.048	0.012	0.422	0.792ns
Fibre diameter (µm)					
Tree	2	5.249	2.624	0.085	0.919ns
Portion	2	833.394	411.697	13.309	0.000*
Tree & Portion	4	44.403	11.101	0.359	0.837ns
Lumen width (µm)					
Tree	2	4.166	2.083	0.199	0.820 ns
Portion	2	178.007	89.004	8.486	0.000*
Tree & Portion	4	2.936	0.734	0.070	0.991 ns
Cell wall thickness (µm)					
Tree	2	1.190	0.555	0.328	0.721ns
Portion	2	67.692	33.846	20.041	0.000*
Tree & Portion	4	1.681	0.420	0.249	0.910 ns
Runkel ratio					
Tree	2	0.049	0.024	0.568	0.569ns
Portion	2	0.221	0.110	2.571	0.083ns
Tree & Portion	4	0.115	0.029	0.671	0.614ns
Coefficient of suppleness					
Tree	2	10.259	5.130	0.282	0.755ns
Portion	2	116.158	58.079	3.196	0.046*

Tree & Portion	4	15.598	3.899	0.215	0.930ns
Felting power					
Tree	2	203.975	101.987	0.921	0.042*
Portion	2	270.373	135.186	1.221	0.030*
Tree & Portion	4	19.461	4.865	0.044	0.996ns

ns= not significant at 0.05 level of probability

*significant at 0.05 level of probability

The results of ANOVA in Table 2 show that at 0.05 level of probability the effect of tree is not significant while stem portion is of significant effect on the fibre characteristics of *Gerdenia ternifolia* assessed, except for Runkel ratio that is independent of tree and stem portion, and felting power which is significantly affected by both tree and stem portion.

By implication, stem portion of trees has significant effect on fibre diameter, lumen width, cell wall thickness, coefficient of suppleness and felting power. Secondly, the effect of tree on fibre characteristics except for felting power is the same for other trees evaluated. Hence, tree samples from the same location will exhibit similar fibre characteristics. In addition, the interaction between tree and stem portion is not significant, implying that the fibre characteristics of *Gerdenia ternifolia* remains the same irrespective of the location of the species, provided the biotic conditions of climate and soil are the same.

Table 3: Duncan multiple range test on fibre characteristics of *Gerdenia ternifolia*

Stem portion	Fibre length (mm)	Fibre diameter (μm)	Lumen width (μm)	Cell wall thickness (μm)	Runkel ratio	Coefficient of suppleness	Felting power
Base	1.46^{b}	29.97^{b}	16.21^{b}	$7 .25^{b}$	0.94^{b}	53.72^{ab}	$48.98\ ^{b}$
Middle	1.45^{b}	29.89^{b}	15.73^{b}	6.91^{b}	0.88^{b}	52.30^{b}	51.04^{b}
Top	1.22^{a}	23.52^{a}	13.02^{a}	5.27^{a}	0.82^{b}	55.09^{a}	53.23^{b}

Mean values followed by the same superscripts in the same column are not significantly different from each other at 0.05 level of probability, using DMRT.

Table 3 shows that there is no significant difference between the base and middle portions of the tree stem for fibre length , fibre diameter, lumen width and cell wall thickness, while the top portion is significantly different for these parameters. This implies that the base and middle stem portions are likely to produce pulp with no variation compared to the top stem portion. For coefficient of suppleness, the base and middle portions will have no significant effect on the quality of pulp produced from either portion while the difference between the top and middle portions on pulp quality is significant. With regard to Runkel ratio and felting power, there is no significant effect on the pulp made from top, middle and base portions of the tree stem.

As shown in Table 4, the values obtained for fibre dimensions from *Gerdenia ternifolia*, though different from those of *Pinus caribaea* and *Gmelina arborea*, are however, favourably comparable with the values from these known pulpwood species. Thus, confirming that *Gerdenia ternifolia* is a good and suitable pulpwood for the paper industry.

Table 4: Mean fibre characteristics of *Gerdenia ternifolia* in comparison with *Pinus caribaea* and *Gmelina arborea*.

Fibre characteristics	*Gerdenia ternifolia*	*Pinus caribaea*[18]*	*Gmelina arborea**[19]*
Fibre length (mm)	1.18 - 1.50	2.32 - 3.53	1.24 -1.38
Fibre diameter (µm)	22.80 - 31.00	24.00 - 28.00	21.47 - 22.76
Lumen width (µm)	12.70 - 16.30	13.00 - 14.00	25.66 - 26.19
Cell wall thickness (µm)	5.70 - 7.36	6.00 - 7.60	2.43 - 2.91
Runkel ratio	0.80 - 1.04	0.92 - 1.09	0.80 - 1.03
Coefficient of suppleness	51.90 - 55.60	50.00 - 54.00	
Felting power	47.00 - 55.00	46.00 - 54.70	

4. Conclusion and Recommendations

The study has shown that *Gerdenia ternifolia* compares favourably well in fibre dimensional characteristics with *Pinus caribaea* and *Gmelina arborea* which are standard and known fibrous materials for pulp and paper production. Based on its appreciable fibre length for a typical hardwood species, coupled with a good Runkel ratio of less 1 and coefficient of suppleness greater than 50, *Gerdenia ternifolia* is satisfactorily pulpable and can therefore be used in pulp and paper making. However, for holistic assessment of the plant, wood samples from the outer, middle and core positions on the radial plane of the wood should be investigated, and conventional chemical pulping of the wood under varied process regimes carried out to determine the screened pulp yield, for its affirmative pulpability. Furthermore, plantation cultivation of *Gerdenia ternifolia* should be encouraged, and to boost the utilization potential of *G. ternifolia*, blending its pulp with fibrous stock from other wood species like pines is recommended in a bid to enhance the desired finished paper properties.

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