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# SUITABILITY OF *Senna siamea* (LAM.) IRWIN AND BARNEBY WOOD FOR PULP AND PAPER PRODUCTION.

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## ABSTRACT

The study was carried out to determine the fibre characteristics of *Senna siamea* wood with a view to assessing its suitability for pulp and paper production. Two stands of *Senna siamea* were assessed for their fibre characteristics and suitability for pulp and paper production; both axial (base, middle and top of the merchantable height) and radial (innerwood, middlewood and outerwood) axes were sampled and the fibre derivatives of the dimensions evaluated. Slivers were obtained from each zone and macerated in equal volume of glacial acetic acid and 30% hydrogen peroxide at 80$^{o}$C in an oven. Twenty-five (25) whole fibres were randomly selected for measurement in swollen condition in each of the zones. The results of mean fibre dimensions and derivatives evaluated were as follows: fibre length (FL) was 1.29mm, while fibre diameter (FD), lumen width (LW) and fibre thickness (FT) measured 19.6, 12.2 and 4.3µm, respectively while Runkel ratio, coefficient of suppleness and felting power had 0.70, 62.24 and 65.82, respectively. The values obtained indicate the suitability of *S. siamea* as a pulping material, especially for its Runkel ratio of 0.70 which is less than 1, and a favourable coefficient of suppleness of greater than 50. It can be concluded based on this study that *S. siamea* is pulpable and suitable for pulp and paper industry.

**Keywords:** *Senna siamea*, fibre characteristics, Runkel ratio, fibre derivatives, pulpable

## Introduction

The world consumption of paper has grown four hundred percent in the last forty years (Ekhuemelo and Tor, 2013). Nearly four million trees or thirty five percent of the total trees fell around the world are used by paper industries on every continent (Ekhuemelo and Tor, 2013). Wood has traditionally been the most widely used lignocellulosic matter in the production of pulp, furniture and boards of diverse types, as well as being a source of energy. The increasing demand for these raw materials, together with economic and environmental factors, makes it necessary to research alternative sources of lignocellulosic matter (Majid *et al.*, 2011). In order to make responsible forest management the norm over the long term, markets must be developed for lesser known timber species (LKTS), even in pulp and paper industries (WWF, 2020).

Many forest concessions in the tropics can contain over 100 different tree species, but their characteristics are simply not known and there is lack of knowledge about their uses and purposes (Eddowis, 1980 and WWF, 2020). To date, *Gmelina arborea* is one of the few outstanding exotic tropical wood species planted in Nigeria for pulp and paper production (RMRDC, 2003 and Onilude, 2011). This wood species is vastly exploited in the forest for other purposes besides pulp and paper production, therefore, this demand for an intensive research into sourcing and evaluation of the properties of lesser-known Tropical Species (LKTS) since this will help in efficiently utilizing the diverse species available for us in the tropical forest thereby reducing pressure on the species primarily used for pulp and paper. Published studies have shown that there are other potential hardwood species especially, LKTS that are equally suitable for pulp production (Adejoba and Onilude, 2012; Noah *et al.*, 2015 and Ajala and Noah, 2019).

*Senna siamea*, a lesser known tropical hardwood species belongs to the family Leguminosae, a medium sized evergreen tree. It has been widely planted for erosion control, windbreak, shelterbelts, fuelwood, polewood, as ornamental tree along the road side and medicinal purposes (F/FRED, 1994; FACT, 1999 and Soladoye *et al.*, 2010). It has been cultivated worldwide and naturalized in many locations (Gutteridge, 1997) but mostly found in cultivated areas of South Western Nigeria (Keay, 1989). According to F/FRED (1994) the wood of *S. siamea* has multiple uses but, there is the need to evaluate its pulp and paper potentials. This study hence research into the potentials of *Senna siamea*, a lesser known tropical hardwood species as a suitable pulping material for pulp and paper industry.

## Materials and Method

Wood samples for the study were obtained from two (2) stands of *Senna siamea* purposely selected from Federal College of Forestry, Ibadan. The College is situated at Jericho Hill in Ibadan South –West Local Government Area of Oyo State. The area lies between Latitude $7^{o}26^{1}$N and Longitude $3^{o}54^{1}$E. The age of the trees could not be determined because the growth rings were indistinct and the trees were obtained from a free area, thereby making it impossible to determine when they were planted. Tree selection was based on absence of reaction tendencies, bole devoid of crookedness and absence of excessive knots. Samples were collected at 25%, 50% and 75% (base, middle and top) of the merchantable height. At each sampling height, cross sectional disc of about 2.5cm thick were removed, strips of 2.5cm were also removed from the centre of the discs and divided into 3 zones namely: innerwood, middlewood and outerwood based on the relative distance from the pith. Wood slivers were carefully prepared from each of the zones. The slivers were macerated in equal volume of glacial acetic acid and 30% hydrogen peroxide at $80^{o}$C and were later rinsed thoroughly in water. A total of twenty-five whole fibres were measured in swollen condition with a calibrated eye-piece microscope from each sampling zone for fibre characteristics evaluation. The fibre dimensions evaluated include fibre length (FL), fibre diameter (FD), lumen width (LW) and fibre cell wall thickness (FT).

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

Derivatives of these characteristics were also evaluated thus:

$$Runkel\ Ratio = \frac{2FD}{LW} \dots\dots\dots..2$$

$$Coefficient\ of\ Suppleness = \frac{LW\ X\ 100}{FD} \dots\dots\dots..3$$

$$Felting\ Power = \frac{FL}{FD} \dots\dots\dots..4$$

Where,

FL= Fibre length (mm), FD= Fibre diameter (µm), LW= Lumen width (µm) FT=Fibre cell wall thickness (µm).

Data obtained were analysed using descriptive statistics, analysis of variance (ANOVA) and correlation matrix. Split-plot experimental design was used.

## Results and Discussion

The mean fibre dimensions of *Senna siamea* are presented in Table 1. Fibre length had a mean value of 1.29mm; it decreased from the base to the top along the sampling height of the tree. Ogunjobi *et al.*, (2014) reported similar trend with a mean value of 1.48mm in *Vitex doniana*. This pattern of variation could be adduced to the presence of endogenous auxin in the apical region of the growing shoot which stimulates cambial division and xylem differentiation. The fibre length reduced towards the crown because of the frequent division in cells which adversely affects its maturity. The importance of this is that, better paper with higher strength properties will be produced. An inconsistent variation was reported along the same axis of *Gerdenia ternifolia* by Noah *et al.* (2015), though, a mean of 1.38mm was reported. In their own study on *Aningeria robusta*, Ajala and Noah (2019) also reported an inconsistent trend in the axial direction with a mean of 1.79mm. In a similar study on Conifers grown in Nigeria, Osadare (2001) reported a range of 1.86 to 5.74mm on *Pinus caribaea* while Ajala and Onilude (2007) reported 2.44 to 4.32mm from the same species.

In the radial plane of *Senna siamea* (Table 1), an inconsistent pattern or sinusoidal variation was observed, but, it is at variance with the findings of Ogunjobi *et al.*, (2014) and Ajala and Noah (2019) who observed a gradual increase from corewood to outerwood of *Vitex doniana* and *Aningeria robusta,* respectively. The observed variation in the findings could be attributed to geographical locations, environmental factors and sampling intensity. Ages of trees sampled could also be a factor because older trees have the tendency of having over matured fusiform initials from which the fibres evaluated were derived. There is significant difference in all the sources of variation (Table 2). According to Panshin and deZeeuw (1980), the average fibre length for cornifers ranges from 1.18 to 7.39mm while that of hardwoods ranges from 0.5 to 2.6mm. The mean fibre length of 1.29mm reported for *Senna siamea* can be considered to be good enough for paper making.

**Table 1: Mean fibre Value of different wood positions of *Senna siamea***

| | | Sampling Position | | | |
|---|---|---|---|---|---|
| Wood Property | Wood Position | Top | Middle | Base | Mean |
| Fibre Length (mm) | Corewood | 1.22±0.03 | 1.23±0.01 | 1.42±0.02 | 1.29±0.02 |
| | Middlewood | 1.25±0.07 | 1.24±0.05 | 1.26±0.04 | 1.25±0.04 |
| | Outerwood | 1.26±0.01 | 1.36±0.06 | 1.36±0.07 | 1.33±0.03 |
| | **Mean** | **1.24±0.04** | **1.28±0.08** | **1.35±0.04** | **1.29±0.10** |
| Fibre Diameter (µm) | Corewood | 18.9±1.50 | 18.9±2.80 | 18.0±3.40 | 19.0±2.29 |
| | Middlewood | 20.5±4.24 | 18.2±2.5 | 18.6±2.2 | 19.1±2.50 |
| | Outerwood | 20.2±5.35 | 21.6±4.3 | 20.2±4.77 | 20.7±4.20 |
| | **Mean** | **20.0±2.0** | **20.0±1.0** | **19.0±4.6** | **19.6±2.10** |
| Lumen Width (µm) | Corewood | 10.8±2.9 | 10.8±4.51 | 9.7±1.47 | 10.4±2.43 |
| | Middle wood | 12.0±1.73 | 20.9±0.96 | 10.5±2.0 | 14.5±0.86 |
| | Outerwood | 11.1±0.85 | 11.6±0.66 | 12.2±1.39 | 11.6±1.15 |
| | **Mean** | **11.3±0.61** | **14.5±1.32** | **10.8±2.88** | **12.2±3.30** |
| Fibre Thickness (µm) | Corewood | 4.1±1.65 | 4.0±1.3 | 4.1±1.01 | 4.1±0.85 |
| | Middle wood | 4.4±0.53 | 4.4±1.44 | 3.9±1.15 | 4.3±1.39 |
| | Outerwood | 4.1±0.85 | 4.9±0.36 | 4.3±0.61 | 4.4±0.56 |
| | **Mean** | **4.2±0.98** | **4.5±0.5** | **4.1±0.82** | **4.3±0.82** |

The mean fibre diameter was 19.6µm; it increased slightly from the base towards the top of the tree. This trend is similar to the findings of Adejoba and Onilude (2012) in their work on *Ficus mucoso* though, a mean of 28.6µm was reported while Noah *et al.*, (2015) reported a reduction along tree of *Gerdenia ternifolia* with a mean of 27.79µm. Axial reduction in fibre diameter towards the top of the tree was also reported by Ajala and Onilude (2007) in their work on Nigerian grown *Pinus caribaea* as well as in the findings of Okon (2014) on fibre dimension characteristics of 25 year old *Gmelina arborea* in Oluwa Forest Reserve, South West Nigeria. Ajala and Noah (2019) reported a mean of 29.47µm with an inconsistent variation along the length of *Aningeria robusta* also LKTS as the aforementioned species. The values obtained in this study are at variance with values from popular conifers like pine (Table 5) which are used for paper production. Ajala and Onilude (2007) reported a range of 33.00 to 47.00µm from *Pinus caribaea* grown in Nigeria while FAO (1975) reported 60.00 to 62.00µm from the same conifer species grown in Malaysia. In the radial plane, fibre diameter increased from the corewood to outerwood. This pattern whereby fibre diameter increased from the base to the top is in consonant with the studies of Osadare and Udolitinah (1993) on *Ceiba pentandra* but disagrees with some previous studies on LKTS. For instance, Adejoba and Onilude (2012) and Ajala and Noah (2019) reported a decrease in fibre diameter from the pith to the bark of *Ficus mucoso* and *Aningeria robusta*, respectively. There is significant difference along the sampling height at 5% probability level (Table 2), the follow up test carried out showed mark difference among the radial position (Table 3). The mean lumen width was 12.2µm; an inconsistent variation was noticed in the axial plane. The trend is in agreement with Ajala and Noah (2019) in their work on *Aningeria robusta* though, they reported a mean value of 16.14µm. However, this disagree with the view of Adejoba and Onilude (2012) and Noah *et al.*, (2015) who reported a decreasing trend along the length of *Ficus mucoso* and *Gerdenia ternifolia*, respectively. In the radial direction, inconsistent variation was also observed, but this was at variance with the findings of Adejoba and Onilude (2012) who reported an increase from the corewood to the outerwood of *Ficus mucoso,* while Ajala and Noah (2019) reported a decreasing trend from the corewood outwardly in their work on *Aningeria robusta.* The variation in cellwall thickness may be responsible for the change in lumen width. No source of variance is significant at 5% probability level (Table 2). The mean fibre thickness was 4.3µm; an inconsistent variation was noticed in the axial plane while slight increment was observed from the corewood to the outerwood. This pattern of variation along the bole is at variance with some documented reports on LKTS. For instance, Adejoba and Onilude (2012) on *Ficus mucoso,* Noah *et al.*, (2015) on *Gerdenia ternifolia* and Ajala and Noah (2019) on *Aningeria robusta* reported a decreasing trend. The increasing pattern observed across the radial plane disagree with the report of Adejoba and Onilude (2012) who reported a decreasing trend on *Ficus mucoso* while Ajala and Noah (2019) reported an inconsistent variation on *Aningeria robusta.* The observed variations could be a function of age of tree, sampling intensity and environmental factor. No source of variance is significant at 5% probability level.

**Table 2: Result of F-values of Analysis of Variance (ANOVA) for Fibre Dimension of *Senna siamea***

| Source of Variance | Degree of Freedom | Fibre Length | Fibre Diameter | Lumen Width | Fibre Thickness |
|---|---|---|---|---|---|
| Tree Number | 1 | 5.88* | $0.007^{ns}$ | $0.000055^{ns}$ | $1.68^{ns}$ |
| Sampling Height (SH) | 2 | 147.06* | 116.23* | $3.64^{ns}$ | $3.80^{ns}$ |
| Major plot error | 2 | $2.94^{ns}$ | $1.20^{ns}$ | $1.00^{ns}$ | $0.18^{ns}$ |
| Radial Position (RP) | 2 | 11.76* | $2.44^{ns}$ | $0.67^{ns}$ | $4.00^{ns}$ |
| SH * RP | 4 | 29.41* | $2.90^{ns}$ | $2.17^{ns}$ | $3.40^{ns}$ |

| | |
|---|---|
| Sub plot error | 6 |
| Total | 17 |

*Significant @ 5% probability level ns Not Significant

**Table 3: Follow-Up Test on Fibre Dimension of *Senna siamea***

| Parameter | Top | Middle | Base | Corewood | Middlewood | Outerwood |
|---|---|---|---|---|---|---|
| Fibre Length | 1.20a | 1.25b | 1.33c | 1.26ab | 1.28a | 1.25b |
| Fibre Diameter | 18.58a | 199.08a | 20.67b | | | |

Means with the same alphabet are not significantly different

From table 4, FD has highly positive correlation (r =0.78) with LW, meaning that the species has good paper web conformity, hence, higher tendency for good strength properties.

FT has positive but relatively low correlation (r =0.45) with LW, this implies that the species has good pulpability for paper making.

FL has highly positive correlation (r =0.70) with FD. This is a very good indication that *S. siamea* fibre collapsibility is very good, hence, interfibre bonding is highly enhanced thereby resulting in higher strength properties especially, tensile and bursting values.

FL has relatively high positive correlation (=0.51) with FT, meaning that the species has good paper web comformity, hence, higher tendency for good strength properties (Table 4).

FL has high positive correlation (r =0.67) with FW. This means the larger the space the greater the bonding, hence, increase in contact area for bonding and this will enhance strength properties of paper from such fibres.

FD has high positive correlation (r =0.59) with FT. This implies fibre flexibility is increasing and this will result in good web formation and enhanced interfibre bonding, thereby leading to increase in strength properties.

A wood species with a high runkel ratio will possess a stiff fibre with less flexibility and poor bonding ability (Ohshima *et al.*, 2005), thus producing bulkier paper than fibre with low runkel ratio. For a good paper formation and high pulp yield Ohshima *et al.* (2005) stated that the runkel ratio should be less than 1 (<1). The runkel ratio for *Senna siamea* is 0.70, which is less than 1. This is a good fibre morphological index, indicating that *S. siamea* is pulpable and very suitable for paper making (Ajala and Onilude, 2007, Oluwadare and Sotonnde, 2007, Adejoba and Onilude 2012, Noah *et al.*, 2015 and Ajala and Noah 2019). The values obtained in this study compare favourably well with *Pinus caribaea*, *Gmelina arborea* and other lesser-known tropical species that have been studied (Table 5).

Oluwadare and Sotonnde, (2007) opined that the thinner the cell wall, the more flexible and collapsible the fibres are during web conformability. This is indicated in the coefficient of suppleness (62.24) and felting power (65.82) recorded for *S. siamea.* Ogbonnaya *et al.* (1992) disclosed that coefficient of suppleness of =50 are necessary for paper making because paper strength tends to improve with increasing coefficient of suppleness. Therefore, with coefficient of suppleness of 62.24 recorded for *S. siamea*, its fibres are flexible and will produce good surface contact for increased fibre-to-fibre bonding. Thus the wood of *S. siamea* is suitable for paper making.

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**Table 4: Correlation Matrix of Fibre Characteristics of *Senna siamea***

| | FL | FD | LW | FT |
|---|---|---|---|---|
| FL | - | | | |
| FD | 0.70 | - | | |
| LW | 0.67 | 0.78 | - | |
| FT | 0.51 | 0.59 | 0.45 | - |

FL= Fibre length, FD= Fibre diameter, LW= Lumen width, FT= Fibre cell wall thickness

**Table 5: Mean Fibre Dimension of *Senna siamea* in Comparison with values for other Lesser-Known Tropical Species and Popular Paper Species**

| Fibre Characteristics | *Senna siamea** | *Aningeria robusta*[1] | *Ficus mucoso*[2] | *Gerdenia ternifolia*[3] | *Gmelina arborea*[4] | *Pinus caribaea*[5] |
|---|---|---|---|---|---|---|
| Fibre Length (mm) | 1.29 | 1.76 | 1.60 | 1.38 | 1.24-1.38 | NA |
| Fibre Diameter (µm) | 19.6 | 29.47 | 28.6 | 27.79 | 21.47-22.76 | 0.06 |
| Lumen Width (µm) | 12.2 | 16.18 | 23.8 | 14.80 | 25.66-26.19 | 0.046-0.047 |
| Fibre Thickness (µm) | 4.3 | 6.61 | 3.9 | 6.48 | 2.43-2.91 | 0.06-0.08 |
| Runkel Ratio | 0.70 | 0.82 | 0.46 | 0.88 | 0.80-1.03 | 0.74-0.88 |
| Coefficient of Suppleness (Flexibility) | 62.24 | 54.90 | 83.22 | 53.70 | NA | 0.74-0.77 |
| Felting Power (Slenderness) | 65.82 | 58.48 | 55.17 | 49.66 | 57.75- 60.63 | 40-59 |

*Current study; [1]Ajala and Noah (2019); [2]Adejoba and Onilude (2012); [3]Noah *et al.* (2015); [4]Palmer *et al.* (1984); [5]FAO (1975)

## Conclusion and Recommendation

The study has revealed that *Senna siamea* compares favourably well with *Pinus caribaea* and *Gmelina arborea* which are popular timber species for pulp and paper making though, an inconsistent variation was noticed across the radial plane of the species studied. All sources of variation in the fibre length were significant at 5% probability level. Judging from its runkel ratio (0.70) that conforms to the less than 1 standard for paper making and its coefficient of suppleness that is greater than 50, *Senna siamea* is satisfactorily pulpable and can therefore be used in pulp and paper making. Despite this, conventional chemical pulping of the wood should be carried out to confirm its pulpability. Moreover, plantation establishment of *Senna siamea* should be encouraged to boost the utilisation potential of *Senna siamea*. Blending its pulp with fibrous stock from other wood species like pines is also recommended in a bid to enhancing the desired finished paper properties.

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