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Evaluation of Fibre Quality of *Bambusa vulgaris* (Bamboo) as a Raw Material for Pulp and Paper Production

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Abstract

This study was carried out to determine the variation in the fiber properties of Bamboo (Bambusa vulgaris), it also assessed the suitability of bamboo obtained from three locations in Nasarawa state, Nigeria for pulp and paper manufacturing. The study was laid out in a 3 x 4 x 10 factorial experiment in a completely randomized design (CRD). The treatment was analyzed with respect to 3 locations, 10 stem samples and 4 disc levels while the variable measured were:- fibre length, fibre diameter, lumen width, cell wall thickness, Runkel ratio, flexibility ratio and felting coefficient. Disc samples collected at individual axial axis were assessed after harvesting. Stock collected from Keffi had the highest mean fibre length of 3.14±0.71mm at 25% and 75% disk level followed by 2.85±0.76mm from Garaku. The physical properties of the disc samples collected at four axial levels (5%, 25%, 50% and 75%) along the individual axial axis. Stock collected from Keffi had the highest mean fibre length of 3.14±0.71mm at 25% and 75% disk level followed by 2.85±0.76mm from Garaku and least fibre length of 2.64±0.79mm from Lafia. Keffi had highest mean lumen width of 9.80±2.86µm, followed by Garaku with 9.56±3.19µm while the samples from Lafia had the least lumen width of 8.66±3.32µm. The runkel ratio (0.61±0.12) was highest in samples from Lafia, followed by 0.54±0.05 in Keffi and 0.51±0.00 in Garaku. The analysis of variance showed that there was a significant difference observed in the fibre length, lumen width, fibre diameter and cell wall thickness both within and between sample stems, while the effects of location and disc levels were not significant on the observed fibre characteristics at $p<0.05$. Bamboo (Bambusa vulgaris) fibre characteristics as reported in this study, showed that, they are well suited for tissue, corrugating medium, newsprint, and writing paper. However, detailed analysis should be conducted on Bamboo, this will enhance its suitability as a potential source of short fibre non wood pulp. Pulp and Paper industries should harness the potential in Bamboo (Bambusa vulgaris) as it can be used to revive the Nigerian pulp and paper industry.

***Keywords**: Fibre length, wall thickness, Runkel Ratio, flexibility ratio, felting coefficient*

Introduction

In the world, which is becoming increasingly concerned with depletion of its natural resources, the pulp and paper making industries stand out with agricultural activities as a prime example of man's utilization of nature in a manner, which does not reduce the total resources of materials available for further generation (Chihongo, *et al*, 2000). The growing demand for pulp and paper products in Nigeria has resulted to the development of multiple ranges of dependent industries ranging from pulp and paper mills, paper/paperboard conversion mill to newsprint, books and stationery industries (Oluwadare and Egbewole, 2008). Pulp and paper products are important requirements to the economic development of any nation. In the past few decades, there has been drastic increase in the consumption of pulp and paper products in Nigeria. For instance, Nigeria has imported ₦11 million and ₦150million worth of pulp and paper products between 1970 and 1988 respectively. Nigerian pulp and paper manufacturing sub-sector of the economy, especially in the last three decades, has not been at its best. The failure of this sector, which was caused in part by a number of factors, has inflicted colossal losses on the economy in Nigeria (RMRDC, 2003).

Long fibre raw materials for pulp and paper industries have been a major setback to paper Industry in Nigeria. Therefore an alternative raw material for pulp and paper production becomes a major concern to researchers. Hence to overcome this shortage and the increasing demand of paper product, the non-woody plants were attracted by researcher to use them as a source of paper production due to their several advantages such as short growth cycles, moderate irrigation and fertilization requirements and low lignin content which reduces the energy and chemicals used in pulping process (Hurter and Riccio, 1998).

Bamboo as alternative fibre source

Bamboo is a giant woody grass that grows in tropical and subtropical regions of the world. Bamboo has a fast growth rate of four to six years of planting. It can grow up to four feet in a day. Bamboo stalk can be cut leaving the roots intact to grow. Each plant can stay up to 75 years and bamboo reaches harvesting maturity in three to six years (Okwori and Chad, 2013). Apart from Raphia palms proposed by (Odeyemi, 1995), there exist potential to produce long fiber pulp (even at small scale basis) from some non-woods, woody grass and agricultural products, unlike woods, these plants are easily delignified and can be produced annually. Besides, they offer wide variety of physical and chemical properties that can be utilized to produce virtually different grades of paper. It has therefore become necessaries to characterize their pulps and ascertain their suitability or otherwise for paper making. In this way, there would be substantial savings in foreign exchange arising from reduced importation of long fiber pulp.

Comparatively, little use is at present being made of bamboo that can be grown as a biannual crop. Before pulpwood was used, agricultural materials and residues played an important role in the paper industry and often yielded high-quality products. Such resources today are almost always utilized exclusively in small-scale operations (Phillips, 1983). Consequently, there is need to investigate the fibre characteristics of lesser-used fibrous materials like *Bambusa vulgaris*, for its pulping potential. This research work assessed the characteristics of bamboo fibres with regards to different points within and between stands and within its stems. There is now considerable evidence to show that resources whose potentials had previously been disregarded, particularly a fast grown plants like bamboo have a bright future Ajuziogu, *et al* (2010).

It is on this background that this study on fibre characteristics of bamboo (*Bambusa vulgaris)* was carried out.

Materials and Methods

Raw Materials

Samples of *Bambusa vulgaris* were collected from Tilla village Keffi, second samples from Kumdami village Garaku and the third samples from Kurikio village Lafia all in Nasarawa State, Nigeria (Table 1). In each sites, ten (10) stands were randomly selected from each location and harvested. Samples were cut into 10cm discs collected at 5%, 25%, 50% and 75% of the total height of the bamboo stems (Plate 1, 2, 3 & 4).

Plate 1: Bamboo plantation,

Plate2: Tagged samples of harvested bamboo

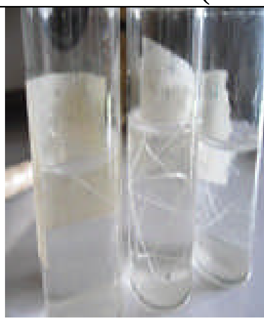

Plate3: Slivers in test tube before maceration

Plate 4:After maceration

Table 1: The coordinate of locations where *Bambusa vulgaris* (bamboo) samples were collected

		Co-ordinate		
S/n	Location	Longitude (θ)	Latitude (θ)	Elevation (m)
1	Garaku	8º 49´	8º70´	139
2	Keffi	8.725	7.830	273
3	Lafia	8.597	8.593	160

Jayeoba, (2013)

Sample Preparation

Bambusa vulgaris (Bamboo) were collected from different locations and cut into 10cm discs collected at 5%, 25%, 50% and 75% of the total height of the bamboo stems, 4 discs were cut from each bamboo stem, 10 randomly selected stem samples from each of the 3 location, a total of 120 sample discs were obtained. Each disc of 10cm long was oven-dried to reduce the moisture content. Five slivers were obtained randomly from each of the sampled disk, totaling 600 fibres used for this study. Bamboo slivers obtained were put into test tubes and macerated with an equal volume (1:1) of 10%

glacial acetic acid and 30% Hydrogen Peroxide (H_2O_2) at 100±2˚c and boiled until soft and bleached white as adopted by Franklin, 1945. The slivers were then washed, placed in 30ml-test tubes with 20ml-distiled water and shaken vigorously to separate the fibre bundles into individual fibre. The macerated fibre suspension was carefully aligned on a slide using white tread. The resulting image on Rheichert visopan microscope screen was measured for fibre length, diameter, lumen width and cell wall thickness. From these, the derived values for 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 were calculated.

Derived morphological fibre characteristics:

i. Runkel Ratio/ Rigidity Coefficient $= \frac{\text{2 x Cellwall Thickness}}{\text{Lumen width}}$

ii. Felting Coefficient/ slenderness ratio $= \frac{\text{Fibre Length}}{\text{Fibre Diameter}}$

iii. Flexibility Ratio/ Elasticity Coefficient $= \frac{\text{Lumen width x 100\%}}{\text{Fibre Diameter}}$

Source: (Saika, *et al*., 1997; Ogbonnaya, *et al*., 1997; Egbewole, *et al*., 2015).

Data analysis

The data collected were analyzed using 3 x 4 x 10 factorial experiments in a Completely Randomized Design (CRD) replicated 5 times. The model for this type of experimental arrangement is given as

Yijk = u + Ai +Bj + Ci + ABij + ACji + ABCijl + ∑kijl……………………….. (j).

Where,

Yijlk = individual observation

Ai =effect of factor A (geographical locations) (3 levels)

Bj =effect of factor B (5%, 25%, 50% and 75%, position along the bole) (4 levels)

Ck = effect of factor C (Individual stem of bamboo) (10 levels)

ABij = effect of interaction between factor A and B

ACik = effect of interaction between factor A and C

BCjk = effect of interaction between factor B and C

ABCijk = effect of interaction between factor A, B and C

∑kijl = experimental error

i = level of factor A = 3 locations (Keffi, Garaku and Lafia)

j =level of factor B = 4 levels (5%, 25%, 50% and 75%)

J = level of factor C = 5 bamboo stock per locations (Keffi, Garaku and Lafia)

k = number of observation per cell (5)

Results and Discussion

(a) Results of physical characteristics of *Bambusa vulgaris*

The results of physical properties of *Bambusa vulgaris* showed mean wet weight of 158.32±62.32g, mean dry weight of 2.81±0.58g, mean density of 1.23±0.60g/cm^3, hole diameter of 4.76±0.28cm, total diameter of 10.98±1.36cm, thickness of 3.22±0.67cm, mean grain orientation of 9.99±0.36^0, disc length of 11.82±5.07cm, volume of 1.38±0.31cm^3, while the mean percentage moisture content was 67.30± 2.86%. The result revealed that the *Bambusa vulgaris* collected from Lafia had the highest mean density of 1.10±0.55g/cm^3, this was followed by 1.08±0.50g/cm^3 in Keffi while the least mean density of 0.86±0.27g/cm^3 was recorded in *Bambusa vulgaris* collected from Garaku. The result further revealed that the *Bambusa vulgaris* collected from Lafia had the highest mean grain orientation of 10.00±0.14^0, followed by 9.99±0.78^0 in Keffi while the least mean of grain orientation of 9.98±0.14^0 was recorded in *Bambusa vulgaris* collected from Garaku (Table 2).

(b) Result of fibre characteristics of *Bambusa vulgaris*

The results of the fibre characteristics of *Bambusa vulgaris* showed that the mean fibre length was 2.88±0.78mm, mean lumen width of 9.55±3.46µm, fibre diameter of 14.80 ±4.88µm and mean cell wall thickness of 2.55±0.88µm (Table 3).

(i) Results of fibre length of *Bambusa vulgaris*

The mean fiber length was 2.88±0.78mm. The longest fibre length of 2.88±0.78mm was observed axially at 75% and 25% disc level, followed by 2.89±0.79mm at 50% and the least fibre length of 2.85±0.79mm was observed at 25% disc level. Samples collected from Keffi had the highest fibre length of 3.14±0.71mm, followed by 2.86±0.76mm at Garaku while the least 2.65±0.79mm was recorded in *Bambusa vulgaris* collected Lafia. (Table 3).However the analysis of variance showed that there was a significant difference observed in the fibre length, lumen width, fibre diameter and cell wall thickness both within and between sample stems, while the effects of location and disc levels were not significant on the observed fibre length, lumen width, fibre diameter and cell wall thickness of *Bambusa vulgaris* at $p<0.05$ (Table 3).

The mean fibre length of 2.88±0.78mm observed in *Bambusa vulgaris* was higher than 1.63±0.50mm reported by Egbewole, *et al.,* 2015 for *Saccharum officinarum* and not too far from 2.7-4.6mm reported by (Atchison, 1987) on fibre lengths of selected softwoods.it is also higher to the minimum 0.7mm -1.6mm value for hardwood fibre sources and to 1.7mm values reported by Noah (2009) for bagasse fibres. Ogunwusi (1997) reported a close fibre length value of 2.41mm for naturally grown *Steculia setigera* while 2.64mm was reported by Oluwadare and Egbewole (2008) for grown *Steculia setigera.* Fibre length is a critical factor to consider in selecting any species for the production of high quality pulp for paper making (Dinwoodie, 1965). The long fibre length of bamboo is characterized by high degree of opacity; stiffness and smoothness which are very suitable for making bank notes which can withstand rough handling (Noah, 2009).

(ii) Results of fibre diameter of *Bambusa vulgaris*

The results revealed that the mean fibre diameter was 14.80±4.88µm ranging between 14.34±5.26µm and 14.96±4.44µm. The fibre diameter of the bamboo samples collected at different locations showed an increase of fibre diameter of 14.98±4.37µm from Keffi, 14.44±4.91µm at Garaku while the least fibre diameter of 13.89±4.73µm was recorded in samples from Lafia. Axial decrease was observed in fibre diameter with 13.96±0.44µm at 5%, 14.34±5.26µm at 25% 14.52±4.88µm, 14.34±5.26µm at 50% and 14.74±4.88µm was observed in fibre diameter at 75% disc level.

The mean 14.80±4.88µm fibre diameter for *Bambusa vulgaris* falls below the range of 20- 40µm fibre diameter for hardwood fibres as reported by (Usta and Eroghe, 1987), it is also at a distance range to the 20.0µm fibre diameter in baggase as reported by Noah (2009) and 20.78±0.34µm by Egbewole, *et al.,* 2015 for *Saccharum officinarum*. This is lower than the observed trend reported by Ogunsanwo and Onilude (2000) on *Triplochiton scleroxylon.*

However, The observed trend is lower compared to some non-wood materials for paper making reported by Ogbonnaya, *et al.* (1992) and Pahkala (2001) (Table 6) which showed the comparism of the *Bambusa vulgaris* with other non-wood fibre sources that revealed that the fibre diameter gotten was to the observed 15.45µm in *Thaumatococcus danielli* (Sotande, 2000), Bamboo (15.0µm) by Pande (1998), same with *Hibiscus cannabinus* by Pande (1998) but lower than 34.87µm fibre diameter observed by Osadare and Udohitinah (1993) on *Abelmoschus esculentus*, 28.16µm in *Hibiscus cannabinus*, *Bombax buonopozense* 29.85µm, *Musa sapentium* 30.16µm and 28.53µm in *Sterculiar oblonga*.

(iii)Results of lumen width of *Bambusa vulgaris*

The results revealed that the mean lumen width was 9.55±3.46µm ranging between 8.80±3.10µm and 9.34±3.26µm. The lumen width of the bamboo samples collected at different locations showed an increase of lumen width of 8.66±3.32µm from Lafia, 9.56±3.19µm at Garaku while the highest lumen width 9.80±2.86µm was recorded in samples from Keffi. Axial decrease was observed in lumen width with 13.30±0.22µm observed at 25%, 13.23±0.21µm at 50% disc level while 13.22±0.45µm was observed in lumen width at 75% disc level. The mean value observed was 13.26µm±0.34 which is lower than the values observed on *Steculia setigera* by Oluwadare and Egbewole (2008) and higher than those reported for similar non wood fibres (Table 5).

(iv) Results of cell wall thickness of *Bambusa vulgaris*

The results revealed that the mean cell wall thickness was 2.52±0.88µm, it ranged between 2.53±0.88µm and 2.65±0.85µm. The cell wall thickness of the bamboo samples collected at different locations showed that cell wall thickness of 2.44±0.82µm from Garaku, 2.59±0.73µm at Keffi while the highest cell wall thickness of 2.60±1.09µm was recorded in samples from Lafia. Axial increase was observed in cell wall thickness with 2.43±0.81µm observed at 5%, 2.51±0.88µm at 25% disc level while 2.64±0.89µm was observed in cell wall thickness at 50% disc level (Table5). However the analysis of variance showed that there was a significant difference in the cell wall thickness observed within and between sample stems, while the effects of location and disc levels were not significant on the cell wall thickness of *Bambusa vulgaris* at $p<0.05$ (Table 3).

The mean value for cell wall thickness was 2.52±0.88µm which is lower than 8.56µm reported by Sotannde (2000) on *Thaumatococcus danielli* and 2.94µm observed in *Steculia setigera* as reported by Oluwadare and Egbewole (2008). It is however considered that the fibre is fairly thin compared to Eucalyptus and Pine species (Hicks and Clark, 2001; Osadare, 2001) and as reported in (Table 5) for other non-wood fibre sources. Colley (1973) reported that cell wall thickness affects specific gravity of fibrous raw materials which in turn has a marked effect on the pulp sheet properties.

(c) Results of Derived fibre Morphological Indices

(i) **Result of Flexibility Ratio (FR)**

The mean flexibility ratio was 64.62±3.34 ranging between 65.90±3.77 and 64.93±4. The flexibility ratio of the samples collected at different locations showed an increase of flexibility ratio of 62.46±4.70 from Lafia, 65.19±2.11 at Keffi while the highest flexibility ratio 66.20±0.00 was recorded in samples from Garaku. The mean flexibility ratio of 64.62±3.34% observed in *Bambusa vulgaris* was higher compared to other non woody fibre sources as reported in (Table 6). Sotannde, (2000) reported 22% flexibility ratio on *Thaumatococcus danielli* (Sweet Prayers Plant), Osadare and Udohitinah, (1993) reported 22% flexibility ratio on *Abelmoschus esculentus* (okra bark), 21% on *Hibiscus cannabinus* (Kenaf), 20% on *Bombax buonopozense (*Gold coast bombax), Egbewole, *et al.,* 2015 reported 63.81% on *Saccharum officinarum* (sugarcane bagasse) and 15% on *Musa sapentium* (bark). However, it is lower compared to 78% reported by Oluwadare and Egbewole (2008) on *Steculia setigera*. Flexibility ratio is another important criterion for evaluating fibre quality. This value falls under the second category of Osadare (1988) classifications. This implies that the fibre will collapse partially and give an elliptical cross sectional form, good surface contact and fibre to fibre bonding. However, this high flexibility shows that the pulp of bamboo may be suitable to produce paper with greater burst and tensile which require high flexibility. Bamboo fibers for its high fibre characteristics are well suited for tissue, corrugating medium, newsprint, and writing paper as stated by Kellomäki (1998), Covey, *et al*. (2006).

(ii) Slenderness ratio/ Felting coefficient

The average Felting coefficient of *Bambusa vulgaris* was 112.55±46.29. It ranged between 108.89±79.10 and 79.23±2.90116.98±32.25[a]. The Felting coefficient of the samples collected at different locations showed an increase of Felting coefficient of 108.42±37.92. From Lafia, 110.99±37.10 at Garaku while the highest Felting coefficient 118.22±60.04 was recorded in samples from Keffi. Felting coefficient of 117.03±32.72 was observed at 5%, 118.26±68.4925% disc level and 108.70±36.33[a] at 50% level while 106.19±38.31was observed at 75% disc level. The mean value for the felting coefficient of bamboo was 112.55±46.29. This is high compared to other non woody fibre sources as reported in (Table 5). Egbewole, *et al.*, 2015 reported 76.73 on *Saccharum officinarum,* Oluwadare and Egbewole (2008) reported 101.50 felting coefficient on *Steculia setigera*. According to Young (1998) and Bektas, *et al*. (1999), if the slenderness ratio is lower than 70, it is invaluable for pulp and paper production. The slenderness ratio was found to be 112.55, it is greater than ≥70 and so can be utilized by the pulp and paper industry.

(iii) Runkel Ratio

The average Runkel Ratio of *Bambusa vulgaris* was 0.55±0.87. It ranged between 0.53±0.05 and 0.57±0.01. The Runkel Ratio of the samples collected at different locations showed Runkel Ratio of 0.51±0.00 from Lafia, 0.54±0.05 from Keffi, while the least Runkel Ratio 0.51±0.00 was recorded in samples from Garaku. Axial increase was observed in Runkel Ratio with 0.55±0.10 observed at 5%, disc level and 25%, 0.57±0.04 was observed at 50% level while 0.57±0.04 again was observed in Runkel Ratio at 75% disc level. However the analysis of variance showed that there was no significant difference in the Runkel Ratio, slenderness ratio and flexibility ratio observed within and between sample stems and at various disk levels, also, there was significant difference in the Runkel Ratio observed within and between sample stems and at various locations at $p<0.05$ (Table 4).

However, the average of 0.55 runkel ratio observed in *Bambusa vulgaris* was lower compared with the observation made by Oluwadare (1998) on non-wood species like 0.78 in *Musa texilis,* 0.95 in the bast of *Adansonia digitata* and 0.76 in *Hibiscus cannabinus.* The runkel ratio of the bamboo samples is also lower than 0.79 for tropical Pine species (Ajala, 1997), 0.99 reported for both *Anthonatha macrophylia* and *Dalium guinensis* hardwood species in Nigerian Rainforest Ecosystem (Ezeibekwe, *et al*., 2009), 0.75 was reported by Awuku (1994) for some tropical hardwood species but the value was higher than the 0.25 and the range (0.28 and 0.68) reported for *Gmelina arborea* and some *Ficus spp* respectively (Ogunkunle, 2010) and in a close range with 0.57 reported by Egbewole, *et al.*, 2015 on *Saccharum officinarum*. The value is lower than 0.59 as reported for *Leucaena leucocephala* (Oluwadare & Sotannde, 2007), and the 0.70 for *Dacryodes edulis* (Ajuziogu *et al*., 2010).

Dinwoodie, 1965 stated that, the basis for establishing the suitability of raw material for pulp and paper making is that the Runkel ratio must be less than one . Volkomer, 1969 in agreement stated that, if the Runkel ratio is less than one, such fibre source is suitable for paper production. In the same vain, Bektas, *et al*., 1999 stated that higher Runkel ratio gives lower paper strength properties especially lower burst, tear and tensile indexes, this was corroborated by Oluwadare and Egbewole, 2008 who stated that Runkel ratio is closely associated with cell wall thickness and it influences paper strength properties, this was corroborated by. Therefore, the average of 0.55 Runkel ratio observed in bamboo established its suitability as a raw material for pulp and paper making.

Conclusion and Recommendation

Conclusion

From the results of the study on the Fibre characteristics of *Bambusa vulgaris (*Bamboo) as a material for pulp and paper production, the following conclusions were reached:

1. The fibre length of *Bambusa vulgaris* fall within short fibre, non-wood cellulosic materials
2. Axial sampling of *Bambusa vulgaris* showed no significant differences in the fibre qualities at any height of the bomboo stem with the exception Runkel ratio and flexibility ratio. This is indicating that bamboo possesses good pulping qualities suitable for pulp and paper production.
3. *Bambusa vulgaris* fibre characteristics as reported in this study, showed that, they are well suited for tissue, corrugating medium, newsprint, and writing paper.

Recommendations

The following recommendations should be considered:

1. Samples from different ecological zones should be looked into in order to assess the variations in the properties of the species from various regions
2. Detailed analysis should be conducted on bamboo which should include its nodes. This will enhance its suitability as a potential source of short fibre non wood pulp.
3. Pulp and Paper industries should harness the potential in *Bambusa vulgaris* as it can be used to revive the Nigerian pulp and paper industry.

Table 2: Mean Values of physical characteristics of *Bambusa vulgaris*

s/n	Source of variation	Wet weight (g)	Dry weight(g)	Density (g/cm^3)	Hole Diameter (cm)	Total Diameter (cm)	Thickness (cm)	grain orientation (0^0)	Disc length (cm)	Volume (cm^3)	% m.c (%)
Location											
1	**Keffi**	147.14±61.43^{a}	2.67±0.53^{a}	1.08±0.50^{a}	4.62±0.76^{a}	10.67±1.34^{a}	3.05±0.60^{a}	9.99±0.78^{a}	113.60±51.11^{a}	1.33±0.31 ^{a}	77.76±21.05^{ab}
2.	**Garaku**	177.81±61.42^{b}	3.27±0.45^{b}	0.86±0.27^{a}	5.13±0.75^{b}	10.92±`1.33^{a}	3.25±0.60^{b}	9.98±0.60^{a}	123.48±52.67^{a}	1.47±0.29 ^{a}	91.78±45.67^{b}
3.	**Lafia**	158.32±62.32^{a}	2.48±0.43^{a}	1.10±0.55^{a}	4.53±0.72^{a}	10.05±1.38^{b}	3.05±0.68^{a}	10.01±0.14^{a}	115.46±50.05^{a}	1.33±0.30 ^{a}	69.18±13.51 ^{a}
Disc level											
1	**75%**	81.00±19.63^{d}	2.75±0.6^{a}	1.16±0.60^{c}	3.96±0.49^{a}	10.61±1.19^{a}	3.60±0.51^{b}	10.03±0.16^{b}	63.02±19.17 ^{a}	1.32±0.22 ^{a}	86.42±30.87 ^{a}
2	**50%**	141.41±35.42^{c}	3.03±0.65^{a}	1.38±0.70^{b}	4.73±0.65^{b}	10.79±1.15^{b}	0.79±0.14^{b}	9.99±0.80a^{b}	103.57±28.51^{b}	1.42±0.38 ^{a}	79.08±17.81 ^{a}
3	**25%**	185.57±27.31^{b}	2.80±0.55^{a}	1.38±0.70^{b}	4.95±0.59^{b}	10.09±1.96^{c}	1.09±0.96^{a}	9.95±0.09a^{b}	130.61±29.47^{c}	1.48±0.35 ^{a}	79.60±25.35 ^{a}
4	5%	225.30±40.85^{a}	2.65±0.46^{a}	1.68±0.78^{a}	5.40±0.63^{c}	10.42±1.25^{d}	1.42±0.25^{a}	10.00±1.00^{a}	175.53±40.00^{d}	1.32±0.27 ^{a}	73.20±45.00 ^{a}
Grand mean		**158.32±62.32**	**2.81±0.58**	**1.23±0.60**	**4.76±0.28**	**10.98±1.36**	**3.22±0.67**	**9.99±0.36**	**118.18±50.69**	**1.38±0.31**	**67.30±2.86**

Note: Mean with the same alphabet on the same column are not significantly different

Table 3: Analysis of Variance for Measured fibre characteristics of *Bambusa vulgaris*

Sources of		Fibre Length		Fibre Diameter		Lumen Width		Ce1llwall Thickness		Runkel Ratio		Felting Power		Flexibility Ratio	
Variation	df	f	Sig.	f	Sig.	F	Sig.	F	Sig.	f	Sig.	f	Sig.	F	Sig.
Location (L)	2	11.71	0.00**	1.52	0.22^{ns}	3.957	0.020*	1.29	0.28 ^{ns}	264.53	0.00**	1.29	0.28^{ns}	254.23	0.00**
Stem (S)	9	3.12	0.02 *	0.78	0.54^{ns}	1.01	0.403^{ns}	0.52	0.721 ^{ns}	16.97	0.00**	0.34	0.85 ^{ns}	17.91	0.00**
Disk level (D)	3	0.81	0.45^{ns}	0.47	0.71^{ns}	0.306	0.821 ^{ns}	1.05	0.373 ^{ns}	13.94	0.00**	1.34	0.26 ^{ns}	14.63	0.00**
L * S	18	1.92	0.06^{ns}	3.49	0.00**	4.46	0.000**	3.12	0.002*	77.83	0.00**	3.51	0.00**	83.69	0.00**
L* D	6	2.94	0.01*	0.38	0.89^{ns}	0.294	0.940 ^{ns}	0.64	0.699 ^{ns}	13.33	0.00**	0.69	0.65 ^{ns}	13.64	0.00**
S * D	27	1.83	0.05 *	0.91	0.54^{ns}	0.758	0.693 ^{ns}	1.59	0.096 ^{ns}	21.67	0.00**	1.16	0.31 ^{ns}	20.67	0.00**
L * S * D	54	1.19	0.24 ^{ns}	1.24	0.21ns	1.282	0.176 ^{ns}	1.45	0.086 ^{ns}	18.22	0.00**	1.03	0.41 ^{ns}	17.01	0.00**
Error	480														
Total	599														
R^2			**0.342**		**0.247**		**0.273**		**0.274**		**0.8928**		**0.243**		**0.894**

Note: ** = highly significant at 1% probability level, * = significant at $p<0.05$, ns = not significant

Table 4: Mean values of fibre characteristics of *Bambusa vulgaris*

s/n	Source of variation	Fiber Length (mm)	Fiber Diameter (µm)	Wall T hickness (µm)	Lumen Width (µm)	Runkel Ratio	Flexibility Ratio (%)	Felting Power
Location								
1	**Keffi**	3.14 ±0.71[b]	14.98±4.37[a]	2.59 ±0.73[a]	9.80± 2.86[a]	0.54±0.05[b]	65.19±2.11[a]	118.22±60.04[a]
2.	**Garaku**	2.85±0.76[a]	14.44±4.91[a]	2.44±0.82[a]	9.56±3.19[a]	0.51±0.00[a]	66.20±0.00[b]	110.99±37.10[a]
3.	**Lafia**	2.65±0.79[a]	13.89±4.73[a]	2.60±1.09[a]	8.66±3.32[a]	0.61±0.12[c]	62.46±4.70[c]	108.42±37.92[a]
Disc level								
1	**75%**	2.88±0.78[a]	14.74±4.88[a]	2.60±0.87[a]	9.54±3.16[a]	0.55±0.10[a]	64.58±3.59[b]	106.19±38.31[a]
2	**50%**	2.85±0.79[a]	14.52±4.88[a]	2.64±0.89[a]	9.41±3.16[a]	0.57±0.10[b]	63.92±3.70[b]	108.70±36.33[a]
3	**25%**	2.88±0.78[a]	14.34±5.26[a]	2.51±0.88[a]	9.32±3.46[a]	0.55±0.10[b]	64.75±2.88[a]	118.26±68.49[a]
4	**5%**	2.84±0.78[a]	13.96±4.44[a]	2.43±0.81[a]	9.10±2.84[a]	0.55±0.10[c]	64.58±3.59[c]	117.03±32.72[a]
Stem Samples								
1	**Stem 1**	2.86±0.89[a]	14.40±4.99[a]	2.53±0.88[a]	9.34±3.26[a]	0.55±0.05[a]	64.70±2.02[a]	110.39±36.77[a]
2	**Stem 2**	2.63±0.84[a]	15.06±5.79[a]	2.58±0.94[a]	9.90±3.82[a]	0.53±0.05[b]	65.52±2.03[b]	108.89±79.10[a]
3	**Stem 3**	2.88±0.79[b]	13.88±4.79[a]	2.54±0.81[a]	8.80±3.10[a]	0.56±0.08[b]	64.06±8.20[a]	116.98±32.25[a]
4	**Stem 4**	2.98±0.72[b]	14.38±4.07[a]	2.53±0.85[a]	9.32±2.62[a]	0.55±0.13[c]	64.93±4.71[b]	111.34±35.34[a]
5	**Stem 5**	3.08±0.65[b]	14.62±4.52[a]	2.65±0.85[a]	9.32±2.88[a]	0.57±0.01[c]	65.90±3.77[c]	115.13±30.27[a]
6	**Stem 6**	2.65±0.79[a]	13.89±4.73[a]	2.60±1.09[a]	8.66±3.32[a]	0.61±0.12[c]	62.46±4.70[c]	108.42±37.92[a]
7	**Stem 7**	2.63±0.84[a]	15.06±5.79[a]	2.58±0.94[a]	9.90±3.82[a]	0.53±0.05[b]	65.52±2.03[b]	108.89±79.10[a]
8	**Stem 8**	2.88±0.79[b]	13.88±4.79[a]	2.54±0.81[a]	8.80±3.10[a]	0.56±0.08[b]	64.06±8.20[a]	116.98±32.25[a]
9	**Stem 9**	2.85±0.79[a]	14.52±4.88[a]	2.65±0.89[a]	9.41±3.15[a]	0.57±0.10[b]	63.92±3.70[b]	108.70±36.33[a]
10	**Stem 10**	2.88±0.78[a]	14.34±5.26[a]	2.51±0.88[a]	9.32±3.46[a]	0.55±0.10[b]	64.75±2.88[a]	118.26±68.49[a]
Grand mean		**2.88±0.78**	**14.80±4.88**	**2.52±0.88**	**9.55±3.46**	**0.55±0.87**	**64.62±3.34**	**112.55±46.29**

Note: Mean with the same alphabet on the same column are not significantly different

Table 5: Comparative assessment of Fibre Characteristics of *Bambusa vulgaris* and other fibrous materials

S/no	Non wood fibre	Fibre Length (mm)	Fibre Diameter (µm)	Lumen Width (µm)	Cellwall Thickness (µm)	Runkel Ratio 2 x CW/LW	Felting Coefficient FL/FD	Flexibility Ratio LW/FDx100 (%)
1	+ *Bambusa vulgaris* (Bamboo)	2.88	14.80	9.55	2.52	055	112.55	64.62
2	**Saccharun officinarum* (Sugarcane bagasse) **(Egbewole, *et al* 2015)**	1.62	20.78	13.26	7.52	0.57	76.73	63.81
3	***Thaumatococcus danielli* (Sweet Prayers Plant) (**Sotannde, 2000)**	2.54	15.45	3.45	8.56	0.81	165.48	22
4	**xx** - Bamboo **(Pande, 1998)**	2.7	15.0	-	-	-	180	-
5	**x** - Kenaf bast fibre(*Hibiscus cannabinus*) **(Pande, 1998)**	2.6	20.0	-	-	-	130	-
6	**zz** - Jute (*Chorchorus capsularis*) **(Pande, 1998)**	2.5	20.0	-	-	-	135	-
7	**z** *Abelmoschus esculentus* (okra) (bark) (**Osadare and Udohitinah, 1993**)	3.49	34.87	7.63	19.62	0.78	100	22
8	**kk** *Hibiscus cannabinus* (Kenaf) (**Osadare and Udohitinah, 1993**)	2.90	28.16	6.08	16.0	0.76	105.1	21
9	**Bombax buonopozense(* Gold coast Bombax)	3.83	29.85	5.80	18.25	0.68	114.1	20
10	**Musa sapentium* (bark)	4.48	30.16	4.34	21.44	0.42	149.1	15
11	**Steculiar oblonga* (yellow steculia)(bark)	3.27	28.53	8.49	11.54	1.77	115.1	30
12	*p*- Reed (*Arundo donax*) **(Pande, (1998)**	1.8	20	-	-	-	90.0	-

+ = *Current work, * = sugarcane bagasse (Egbewole et a, 2015), ** sweet prayer plant (Sotande, 2000), xx= Bamboo (Pande, 1998), x = Kenaf bast, (Pande, 1998), zz =Jute (Pande, 1998), z = okra bark (Osadare and Udohitnah 1993), kk = Hibiscus* **(***Osadare and Udohitnah 1993***),** *p = Reed (Pande)*

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