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Variation in specific gravity and selected anatomical properties of naturally grown *Bambusa vulgaris* (Schrad) in Abeokuta, Ogun State, Nigeria

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ABSTRACT

The study investigated the pulping potentials of naturally grown *Bambusa vulgaris* at Federal University of Agriculture, Abeokuta, Ogun State, Nigeria with a view to determining its pulping potential. Specific gravity and fibre characteristics of the samples were evaluated at three stages of maturity (over-grown stage, mature stage and growing stage) and three sampling heights (bottom, middle and top). The derived values were also determined. A completely randomized block design (CRBD) was adopted. The mean specific gravity of the three different stages of maturity ranged from 0.32-0.73. The overgrown stage had the highest specific gravity which is almost twice that of the growing stage. Age significantly ($p< 0.05$) influenced specific gravity. The average mean fibre length, fibre diameter, lumen width and cell wall thickness at the three stages of maturity ranged from 2040.6-2610.8µm, 15.0-17.3µm, 8.10-9.54µm and 3.46-3.87µm respectively. The effect of sampling height was significant ($p< 0.05$) on fibre length. Mean value of Coefficient of flexibility, Felting rate and Runkel ratio ranged from 52.63-56.35, 138.8-170.6, and 0.90-0.97 respectively. Results of derived values of *Bambusa vulgaris* compare favourably with that of other species used in pulping and therefore, the species is good for paper production**.**

Keywords: *Bambusa vulgaris*, fibre characteristics, specific gravity, pulping potentials, derived values.

INTRODUCTION

Bamboo is a giant woody grass that grows in tropical and subtropical regions of the world. It is one of the fastest growing plants and needs only between 3 and 6 years to mature before they are ready for harvesting and utilization (Okwori and Chad, 2013). This makes bamboo the best possible alternative to replace timber in the future as an alternative to wood in meeting the ever increasing demand for pulp. There are several differences between bamboo and wood. There are no rays or knots in bamboo which makes bamboo more useful as its stresses are distributed evenly throughout its length (Jassen, 1995).

There is an increasing demand for pulp and paper arising from increasing population and development with its attendant pressure on the forest estate. 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/paper board conversion-mill to newsprint, books and stationery industries (Oluwadare and Egbewole, 2008). Since bamboo has an advantage of fast growth and is abundant, it has therefore become imperative to determine its fibre morphology for suitability

in paper production.

The physical and anatomical properties of bamboo culms have been known to have significant effects on their durability and strength (Abdul-Latif, 1992; Abdul-Latif and MohdTamizi, 1992; Liese, 1985). Among the various wood quality parameters, specific gravity remains the most widely studied. This easily assessable wood property is of key importance in forest product manufacture because it has a major effect on both yield and quality of fibrous and solid wood products (Davis, 1961; Barefoot *et al*., 1970; Lewark, 1979) and because it can be changed by silvicultural treatments (Williams and Hamilton, 1961) and genetic manipulations (Zobel, 1961; VanBuijtenen, 1962).

Bambusa vulgaris is a perennial, giant, woody grass belonging to the group angiosperms and the order monocotyledom. They are in the sub-family of bambusoideae and one of the most popular tropical bamboo species. This bamboo is easily cultivated and has low mortality rate. It is particularly adapted to the rain forest belt of Nigeria where it is found in abundance along riverbanks and other relatively marshy areas (RMRDC, 1996).

This study was aimed at determining the specific gravity and anatomical properties of *Bambusa vulgaris* growing naturally at Federal University of Agriculture Abeokuta with a view to determining pulp quality of its fibre.

MATERIALS AND METHODS

Study Area

The bamboo samples were collected from a growing bamboo plantation within Federal University of Agriculture Abeokuta located at Alabata road in the North-Eastern part of Abeokuta in Odeda Local Government, Ogun State, Nigeria. It is located at latitude 3° to 20°E to 37°W. The region enjoys an average temperature of 31.8°C. It has annual rainfall of about 1300mm with peaks in June and dry season of two to three months.

METHODOLOGY

The bamboo was sampled at three different stages of maturity, namely; the over-grown stage, the mature stage and the growing stage. Nine culms were randomly harvested from clumps; this means three samples for each of over-grown stage, mature stage and for the growing stage. The culms were cut at 30cm above the ground level as cutting below that level will affect other culms in the clump, each culm were cut at 12m leaving out the top parts with branches. The culms were sub-divided into three equal lengths of bottom, middle and top portions of 4m each. Samples were collected from each of the portions of the culms for determination of specific gravity and fibre characteristics.

The samples collected were subjected to a gravimetric procedure developed by Smith (1954) in which specimen were completely saturated with water by boiling. Each sample was removed from water, to remove excess water, weighed and oven dried to a constant weight at 103^0C and the Specific gravity was determined using this formula:

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

SG = specific gravity
Ws = saturated weight
Wo = Oven dry weight
1.53 = Average specific gravity

The anatomical studies of fibres were carried out according to methods outlined by Abd. Latif (1992), Abd.Latif and MohdTamizi (1992). Specimens of bamboo splits of 2cm length were prepared from three portions (bottom, middle and top), the fibre dimensions were determined by reducing some of the representative sample into splint and then placed inside a test tube containing acetic acid (CH_3COOH) and Hydrogen peroxide (H_2O_2) of equal volume ratio for maceration and later placed inside an oven for 3 hours at 80^oC. The macerated fibres were washed with distilled water several times before the fibres were mounted on slide for measurement. The fiber dimensions were determined using a calibrated microscope at reasonable magnifications of 10X and for this 10 fibers were measured. After the three hours, the samples were observed to have been bleached and softened with the help of Acetic acid and hydrogen peroxide respectively.

Determination of the Fibre Dimension
The following fibre dimensions were determined:

Fibre diameter
The fibre diameter of the specimen was measured in calibrated plane in the Electron microscope. It was measured at the middle of each fibre.

Fibre length
These were measured using the microscope by aligning the fibres along the graduated mark in the microscope.

Fibre lumen width
The diameter of the inner cavity was measured by aligning the graduated mark on the microscope to the width of the lumen.

Fibre wall thickness
This is the average difference between fibre diameter and the lumen divided by 2. Mathematically expressed as $\frac{FD - LU}{2}$
Where FD is the fibre diameter and the LU is the fibre lumen width.

Derived Values:
Three derived values were calculated for assessing the fiber quality for paper production using the fiber dimensions (Saikia *et al.,* 1997; Ogbonnaya *et al.,* 1997).
A) Slenderness Ratio or Felting coefficient = Fiber length/ Fiber diameter
B) Runkel Ratio or Rigidity coefficient = 2 x Cell wall thickness/Lumen diameter
C) Flexibility Ratio or Elasticity coefficient = Fiber lumen diameter/ Fiber diameter x 100.

The values were then compared with those of soft and hardwoods to assess the species suitability as reasonable alternative raw material for paper production.

STATISTICAL ANALYSIS
Analysis of variance (ANOVA) was used to determine whether or not the differences in means were significant.

RESULTS

Specific gravity

The mean specific gravity of the three stages of maturity ranged from 0.3 - 0.7 (Table 2). The specific gravity value reduced steadily from the over-grown stage drastically down to the growing stage. Specific gravity value of the over-grown stage is more than twice that of the growing stage. Age significantly ($P<0.05$) influenced specific gravity.

Fibre Dimensions

The result of fibre dimensions is presented in Table 1. Variation existed in the fibre dimensions of bamboo at different stages of maturity. The mean fibre length varies from 2040.6µm-2610µm. An inconsistent pattern of variation was recorded. The average mean value of the fibre length increased drastically from overgrown to mature and later slightly decreased at the growing stage. The sampling position significantly ($p<0.05$) influenced the fibre length of bamboo as fibre length decreased consistently from base to top.

The mean value of fibre diameter ranged from 15.0 to 17.3 µm. An irregular pattern of variation was recorded. The highest mean was obtained at the mature stage. At the over-grown stage fibre diameter decreased from base to top while at the mature stage fibre diameter decreased from base to middle and slightly increased at the top portion. At the growing stage, fibre diameter increased at the middle and later decreased at the top. The effects of age and sampling position did not significantly ($p<0.05$) affect the fibre diameter.

The mean value of lumen width ranged from 8.09 to 9.54 µm. The pattern of variation observed shows that lumen width in the over-grown decreased from base to top following a consistent pattern of variation while in the mature stage, it decreased from base to middle and later increased. Both age and sampling position did not influence the lumen width significantly

The mean cell wall thickness recorded ranged from 3.46 - 3.87 µm. The pattern of variation in the cell wall was generally inconsistent. Effects of age and sampling position were not significant ($p<0.05$). The highest value recorded was 4.35µm while the least was 3.16µm.

Table 1: Fibre characteristics of *Bambusa vulgaris at* the three different stages of maturity

Bamboo stage	sampled parts	Fibre length (µm)	Fibre diameter (µm)	Lumen width (µm)	Cell wall thickness (µm)
over-grown	Base	2649.8±641.0	17.8±4.09	9.84±2.22	3.96±1.07
	Middle	2042.2±582.5	14.0±1.19	7.46±0.84	3.28±0.18
	Top	1456.7±231.2	13.3±2.33	7.00±1.08	3.16±0.64
	Mean	2040.6±684.0	15.0±3.19	8.10±1.86	3.47±0.73
Mature	Base	2827.1±495.9	17.1±3.51	9.79±0.50	3.68±1.75
	Middle	2608.4±259.6	15.9±4.05	8.69±1.53	3.59±1.26
	Top	2396.9±476.9	18.8±3.35	10.13±1.33	4.35±1.01
	Mean	2610.8±412.2	17.3±3.41	9.54±1.23	3.87±1.24
Growing	Base	2609.7±258.4	15.3±0.55	8.20±0.36	3.57±0.16
	Middle	2353.2±205.7	16.2±1.05	8.97±0.76	3.59±0.15
	Top	2284.7±652.6	14.4±1.17	7.94±1.52	3.22±0.30
	Mean	2415.8±394.7	15.3±1.13	8.37±0.98	3.46±0.26

Mean values with standard deviation

Derived Values

The Flexibility ratio of the fiber ranged from 52.63 to 54.71 with the growing stage having the highest mean value of 54.71. Effects of both age and sampling position were not significant ($p<0.05$).

Felting rate of the fibre of bamboo ranged from 138.8 to 170.6. An irregular pattern of variation was recorded both at sampling position and maturity stage. Both sampling position and age significantly ($p<0.05$) influenced the felting rate of bamboo.

The mean Runkel ratio ranged from 0.904 to 0.974 (Table 2). The overgrown had the highest while the mature had the least. Both age and sampling positions did not significantly ($p<0.05$) affect the Runkel.

Table 2: Fibre derived values and specific gravity of *Bambusa vulgaris at* the three different stages of maturity

Bamboo stage	Sampled parts	Runkel ratio	Coefficient of flexibility	Felting rate	Specific gravity
Over-grown	Base	0.91±0.1	54.9±3.7	157.9±11.3	0.73±0.1
	Middle	0.92±0.1	51.12±4.2	144.8±38.7	0.74±0.1
	Top	1.10±0.2	51.85±2.3	113.7±22.2	0.71±0.1
	Mean	0.97±0.1	52.63±3.5	138.8±30.3	0.73±0.1
Matured	Base	0.91±0.4	59.16±9.3	173.8±6.6	0.65±0.0
	Middle	0.94±0.1	54.87±3.6	173.7±14.6	0.63±0.1
	Top	0.87±0.0	55.03±2.2	134.3±5.8	0.66±0.1
	Mean	0.90±0.2	56.35±5.5	160.6±21.5	0.65±0.1
Growing	Base	0.99±0.1	54.58±4.4	191.0±45.6	0.38±0.0
	Middle	0.89±0.1	55.22±1.9	158.0±13.2	0.29±0.0
	Top	0.98±0.2	54.33±6.7	162.9±35.0	0.29±0.1
	Mean	0.95±0.1	54.71±4.1	170.6±33.3	0.32±0.1
Almond tree*		2	32.8	58.7	
Softwoods*		0.35	75	95-120	
Hardwoods*		0.4-0.7	55-70	55-75	

*** Vervesis *et al.* (2003)**

Table 3: Fibre dimensions, Derived values and the Specific gravity of *Bambusa vulgaris*

	Fibre length	Fibre diameter	Lumen width	Cell wall thickness	Runkel ratio	Coefficient of flexibility	Felting rate	Specific gravity
Over-grown	2049.59[a]	15.03[a]	8.10[a]	3.47[a]	0.97[a]	52.63[a]	138.80[a]	0.73[c]
Mature	2610.78[a]	17.28[a]	9.54[b]	3.87[a]	0.90[a]	56.35[a]	160.61[ab]	0.65[b]
Growing	2415.85[ab]	15.29[a]	8.34[ab]	3.46[a]	0.95[a]	54.71[a]	170.64[b]	0.32[a]

Mean with the same superscript in the same column are not significantly different at 5% probability.

DISCUSSION

The importance of specific gravity of any structural material particularly to its strength cannot be overemphasized. The mean specific gravity of the three stages of maturity which ranged from 0.3-0.7 is within the range of 0.3-0.8 reported for bamboo elsewhere (Lee *et al,* 1994). According to Kristova, 1999, the high density value is an indication of normal liquor to solid ratio, impregnation and high pulp yield by digester volume.

Variations existed in the specific gravity recorded at different stages of maturity and the observed variations could be as a result of changes in cell size and cell wall thickness that are associated with annual and periodic growth cycles and the increasing age of the cambium (Rigatto, 2004). This showed that there was a difference in the variability of the materials in terms of mass of dry woody substance per volume of the bamboo examined as they grow older. An irregular pattern of axial variation was recorded contrary to Falayi and Soyoye (2015) and Sattar *et al* (1994) reported that specific gravity was highest at the top and lowest at the base. It was only at the mature stage that specific gravity was highest at the top. The specific gravity at different heights was not statistically different as reported by Li X (2004).

Fibre length influences the physical and mechanical properties of the plant material and is often associated with its toughness, workability and durability (Parameswaran and Liese 1976; Espiloy, 1987). It is a critical factor to consider in selecting any species for the production of high quality pulp for papermaking (Dinwoodie, 1965). The average mean value of the fibre length was 2040.6 - 2610.8 µm and it increased drastically from overgrown to mature and later slightly decreased at the growing stage. This pattern of variation could be due to the correlation between fibre length and internode as longer fibres were found in the basal portion of the culm with the longest internode. This is supported by Liese (1998) who reported that the mean fibrelength of an internode was correlated with the internode length. The mean fibre length of 2040.6 - 2610.8µm was lower than 2.88±0.78mm observed in *Bambusa vulgaris* in Nassarawa State as reported by Egbewole *et al*. (2015) but higher than 1.63±0.50mm reported by Egbewole, *et al.* (2015) for *Saccharum officinarum,* 1.48mm for *Vitex doniana* (Ogunjobi *et al.*, 2013) and 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 *Steculiase tigera* while 2.64mm was reported by Oluwadare and

Egbewole (2008) for grown *Steculiase tigera.* In similar observation, Oluwadare (2007) recorded 0.65mm as fibre length of *Leucaena leucocephala.* Similar fibre length ranges of 1.50 to 2.9mm and 1.46 to 2.91mm were recorded for bamboos in Sudan and Thailand respectively (Khristova *et al.,* 2005; Nitisoravut *et al.,* 2007). According to Oluwadare (1998), these values are within acceptable range for hardwoods for paper making. 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). These indicate that strong paper with good tearing resistance could be obtained from the plant since a strong relationship exists between the strength properties of pulp and the fiber length constituting the pulp (Ververis *et al*; 2004). The decrease in the fibre length from base to top, gradual increase from over-grown stage towards the mature stage and decrease down to growing stage could be due to the correlation between fibre length and internode as longer fibres were found in the basal portion of the culm with the longest internode. This is supported by Liese (1998) who reported that the mean fibre length of an internode was correlated with the internode length. It could be concluded that based on its relatively long fibres, bamboo can produce papers of same quality as some other wood. Fibre diameter is one of the factors that determine coefficient of flexibility and felting rate. The mean fibre diameter of 15.0 - 17.3 µm was within the range reported for coniferous and commercial pulp woods (Hammett *et al,* 2001 and Ververis *et al*., 2004). It is higher than 14.80±4.88µm recorded by Egbewole *et al*. (2015) for Bamboo but falls below 20.0µm fibre diameter in baggase as reported by Noah (2009) and 20.78±0.34µm by Egbewole *et al.* (2015) for *Saccharum officinarum*. It is equally lower than the observed trend reported by Ogunsanwo and Onilude (2000) on *Triplochiton scleroxylon* and Ogunjobi *et al* (2013) on *Vitex doniana.* The observed difference in value recorded by Egbewole *et al*, 2015 could be attributed to difference in location.

Lumen width plays a major role on the beating property of a paper. The larger the fibre lumen width the better will be the beating of pulp because of the penetration of liquids into the fibre lumen. The mean value observed was 8.09 to 9.54 µm, the highest average mean of the lumen width was obtained at mature stage having the value of (9.54 µm) and later decreased at the Growing stage with the value of (8.37 µm). The value recorded is lower than 13.26µm±0.34 observed on *Steculiase tigera* by Oluwadare and Egbewole (2008) and 12.7µm by Ogunjobi *et al.* (2013) on *Vitex doniana.*

Cell wall thickness affects specific gravity of fibrous raw materials which in turn has a marked effect on the pulp sheet properties (Colley, 1973). The average mean cell wall thickness recorded was 3.46 - 3.87 µm and it was close to 3.7µm reported for bamboo in Sudan (Khristova, 2005). It was higher than 2.52±0.88µm recorded by Egbewole *et al.* (2015) on Bamboo and 2.94µm observed in *Steculiase tigera* as reported by Oluwadare and Egbewole (2008) but lower than 4.9µm reported by Ogunjobi *et al* (2013) on *Vitex doniana*, 8.56µm reported by Sotande (2000) on *Thaumatococcus danielli*. Generally, an inconsistent pattern of variation was observed along the culm. The fibre cell wall thickness in the mature stage was slightly greater than that of the over-grown and the growing stage. Age did not significantly affect these properties.

Flexibility ratio is an important criterion for evaluating fibre quality. The Flexibility ratio of the fiber ranged from 52.63 to 54.71 with the growing stage

having the highest mean value of 54.71. It has been reported that Flexibility ratio of between 50 and 70 gives good paper with high strength properties (Istas *et al.*, 1954). The mean flexibility ratio is lower than 64.62±3.34% observed in *Bambusa vulgaris* by Egbewole *et al* 2015 but higher than 22% flexibility ratio on *Thaumatococcus danielli* (Sweet Prayers Plant) reported by Sotannde (2000). Also, Osadare and Udohitinah (1993) reported 22% flexibility ratio on *Abelmoschus esculentus* (okra bark), 21% on *Hibiscus cannabinus* (Kenaf), 20% on *Bombax buonopozense* (Goldcoast bombax), Egbewole *et al*. (2015) reported 63.81% on *Saccharum officinarum* (sugarcane bagasse) and 15% on *Musa sapentium* (bark). It is equally lower than 78% reported by Oluwadare and Egbewole (2008) on *Steculiase tigera*. The high flexibility recorded shows that the pulp of bamboo may be suitable to produce paper with greater burst and tensile which require high flexibility.

Felting rate also known as slenderness ratio is a measure of tearing property of pulp in paper making. The fibres with high slenderness ratio/felting rate are long, thin and have high tearing resistance whereas short and thick fibres have less slenderness ratio and tearing resistance. According to Young (1981) and Bektas *et al*. (1999), if the Slenderness ratio is lower than 70, it is invaluable for quality pulp and paper production. The felting rate of the bamboo fibre was found at the ranges of 138.8 to 170.6 which are higher than 112.55±46.2970 reported by Egbewole *et al.* (2015) on *Bamboo vulgaris* and 76.73 on *Saccharum officinarum.* Oluwadare and Egbewole (2008) also reported 101.50 felting coefficient on *Steculiase tigera*.

The Runkel ratios of the three selected stages of maturity of the bamboo sample are less than 1. 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. Also, Bektas, *et al*. (1999) stated that higher Runkel ratio gives lower paper strength properties especially lower burst, tear and tensile indexes and this was corroborated by Oluwadare and Egbewole (2008). According to Eroglu, (1980), when Runkel ratio or Runkel's proportion is greater than 1, it is assessed as fibre having thick wall and cellulose obtained from this type of fibres is least suitable for paper production. Therefore, fibers of all selected stage of maturity can be considered for pulp and paper making since the runkel ratio is less than 1. The average value 0.90-0.97 recorded was higher than 0.55 runkel ratio observed in *Bambusa vulgaris* by Egbewole *et al*. (2015), 0.78 by Oluwadare (1998) on non-wood species like *Musa texilis*, 0.95 in the bast of *Adansonia digitata* and 0.76 in *Hibiscus cannabinus,* 0.79 for tropical Pine species (Ajala, 1997) but lower than 0.99 reported for both *Anthonatham acrophylia* and *Dalium guinensis* hardwood species in Nigerian Rainforest Ecosystem (Ezeibekwe *et al*., 2009).

CONCLUSION

The study showed that Specific gravity was significantly affected by age while the effect of sampling height was significant on fibre length. There were variations within and between the bamboo and same species from another location. This may be as a result of environmental conditions and inherent properties. The bamboo investigated exhibited long fibre length since the mean fibre length of above 1.60mm are said to be long. The good derived values places Bambusa vulgaris at a vantage position as an alternative in pulp and paper production since a strong relationship exists between the strength properties of pulp and the fiber length constituting the pulp.

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