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Axial and Radial Variation of Fibre Characteristics of *Bambusa vulgaris*

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Authors' contributions

This work was carried out in collaboration between both authors. Author AFA wrote the protocol and the first draft of the manuscript. Author EAA designed the study, performed the statistical analysis and managed the analyses of the study. Authors AFA and EAA both managed the literature searches and proof read the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

This study was carried out to investigate the axial and radial variations of fibre characteristics of *Bambusa vulgaris*. There were eighteen treatments for both axial and radial variations. The treatments were replicated three (3) times, in Complete Randomized Design (CRD). The experiment was carried out at the Wood Anatomy Laboratory of the Department of Forest Product Development and Utilization, Forestry Research Institute of Nigeria, Ibadan. Three samples (3) stands of *B. vulgari*s were randomly selected. Samples collected were cut into 10cm discs at 25%, 50% and 75% of the total height (axial positioning). The samples discs were partitioned into two zones which are core and peripheral (bark) layers. From each of the disc, 3 slivers were obtained both from radial and axial positions. Slivers obtained were macerated with an equal volume (1:1) of 10% glacial Acetic acid and 30% Hydrogen Peroxide (H_2O_2) at 100 ±2°C. The resulting image on light microscope screen was measured for fibre length, fibre diameter and lumen width.
At 50% sampling height and at outer layer, the highest fibre length of 3.25 mm, followed by 3.06 mm of bamboo sample stand 3 while the least 2.28 mm was recorded in sample stands 2 of 75%

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axial positioning and at peripheral layer. The lumen width ranged between 3.52 × 10^{-3} µm to 4.46 × 10^{-3} µm in the radial direction from the core to the peripheral (bark) of the bamboo. The result obtained for mean values of fiber diameter along the bamboo height ranged from 3.53 × 10^{-3} µm to 4.46 × 10^{-3} µm across the three (3) bamboo stands, sampling height and radial direction sampling respectively.

Among the fibre positioning, the fibre collected from 50% of the sampling height have higher fibre diameter, lumen width and fibre diameter at the peripheral region compare to the others.

Keywords: Bambusa vulgaris; fibre length; fibre diameter and lumen width.

1. INTRODUCTION

Fibre characteristics are related to many structural, physical and chemical properties of wood. The fibre characteristics includes fibre diameter, fibre length and lumen width. It affects many woody-products manufacturing, like pulping process, behavior in the drying process and behavior to cutting and machining, variations in fibre dimensions/characteristics are also present in the tree's radial, longitudinal direction and within the annual rings [1]. The variations may be due to genetic, physiological or silvicultural treatment.

In general, fibres can be classified into three categories: Wood, non-wood, and non-plant. The term "non-wood" was developed to distinguish plant fibres from the two main sources of wood fibres; hardwoods and softwoods. Non-wood or agro-based fibres are derived from selected tissues of various mono or dicotyledonous plants and are categorized botanically as grass, blast, leaf, or fruit fibres. Some non-wood fibres are classified by means of type of production; fibres such as sugar cane bagasse, wheat straw and corn stalks are byproducts. Other non wood fibres are grouped as "fibre plants," plants with high cellulose content that are cultivated primarily for the sake of their fibres such as jute, kenaf, flax, cotton, and ramie. Non-wood fibres can be used to make paper, although the quality depends on the source of the fibers.

B. vulgaris (A bamboo species) has been considered as one of the fastest growing plants in the world. Bamboo has social, economic and cultural significance and is used extensively for building materials along with thousands of uses. It is highly versatile raw material for different works. The bamboo is lightweight, flexible, tough, high tensile, cheap material than the other building materials like steel. Bamboo can be used in various building works. Bamboo structures are reported to be flexible, earthquake resistant, lightweight and cheap. Bamboo can be used as reinforcement in various structural members. Bamboo is a green material for sustainable development and has various advantages. The use of bamboo may be promoted for green buildings and sustainable development [2]. In fact, bamboo culture has been described as an essential part of human history and civilization, especially in Asia [3]

In addition, bamboo is used for scaffolding in construction projects often to great heights. While bamboo continues to be used in these traditional ways, it has also become an important raw material for production of modern building products [4].

Fibres have been regarded as one of the main components that determine the mechanical properties of any woody materials including bamboo, owing to their unidirectional arrangement in the tissue as well as their unique cell wall structure [5].

Many studies have been done regarding bamboo; Fibre wall anatomy [6], and in particular cell wall thickening [7,5] lignification [8,9] and cell wall nano-structural changes [10] during development of bamboo culms, mechanical properties of fibres or fibre caps [11] and [12], and the underlying structure–property relationships of bamboo fibres that establish the gradients across the fibre caps have been intensively studied, but there has been little information on fibre characteristics variations along axial (top, middle and bottom and radial (bark and core) dimension in relations to its pulping potentials. Therefore, this study sought to provide information in this regards on variations across (radial) and along (axial) axis of *B. vulgaris*.

2. MATERIALS AND METHODS

2.1 Materials

The materials used for determining the variation in the fibre characteristics of *B. vulgaris* from the same location are; test tubes, tube rack, acetic acid (CH_3COOH), Hydrogen peroxide (H_2O_2), Spatula, Beaker, Distilled water, Light microscope, saw, sharp knife, nose cover and hand glove.

2.2 Sample Area

The *B. vulgaris* sample stands used for the experiments were collected from Forestry Research Institute of Nigeria (FRIN), Ibadan, Oyo State. The Institute lies between Latitude 07°22' N and Longitude 03°58' E (Map of the World, 2017) of the Greenwich meridian. It is characterized by mean annual rainfall of 1400-1500 mm, while the mean annual temperature is 26.46°C. The relative humidity ranges between 80-85% (FRIN, 2017).

2.3 Experimental Site

The experiment was carried out at Wood Anatomy laboratory, Department of Forest Products Development and Utilization (FPD&U), Forestry Research Institute of Nigeria (FRIN), Ibadan.

2.4 Sampling Technique

For this experiment, 3 sample stands of *B. vulgaris* were randomly selected from the bamboo plantation, behind horticultural nursery, Forestry Research Institute of Nigeria (FRIN), Ibadan and harvested. Samples collected were cut into 10 cm height at 25%, 50% and 75% of the total height (axial positions) of the bamboo stems. The sample discs were later partitioned into two zones (radial positioning) which are core and peripheral (bark) layers.

2.5 Sample Preparation

B. vulgaris discs of size 10 cm were collected at 25%, 50% and 75% (which represent bottom, middle and top of the three (3) stands respectively). 3 slivers each were also obtained from radial positioning (Core and peripheral layers) from each bamboo stem. 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. The slivers were then washed, placed in 30 ml-test tubes with 20 ml distilled water and shaken vigorously to separate the fibre bundles into individual fibres. The macerated fibres suspensions were carefully aligned on a slide using white tread. The resulting image on light microscope screen was measured for fibre length, fibre diameter and lumen width.

2.6 Microscopy

The separated fibres per samples in each test tube were mounted on microscope slide and examined under a Riechert microscope with a tracer reflector. The magnified and transparent fibres were projected by the tracer reflector on which the fibres were viewed and traced under magnification ×10. Few fibres were measured with calibration on the eye piece.

2.7 Parameters Determined

The following parameters were determined:

- **Fibre length of the sample:** It was measured using the microscope by aligning fibre length of the chip sideway to the graduated ruler in the microscope;
- **Fibre diameter of the sample:** This was measured by placing the graduated ruler in the microscope in horizontal direction at the middle of the fibre.
- **Lumen width of the sample**: This is the width of the inner space.

2.8 Data Analysis

The data collected were analyzed using 3 × 3 × 2 factorial experiments in a Completely Randomized Design (CRD). Each treatment was replicated 3 times making 54 observations. The data gotten from the experiment was subjected to Analysis of Variance (ANOVA). The follow up test was conducted to obtain the difference between the means using the Duncan Multiple Range Test (DMRT) at 5% probability levels.

3. RESULTS AND DICUSSION

3.1 Fibre Length of *B. vulgaris*

The average fibre length is presented in Table 1. The longest fibre length of 3.25±0.15 mm was observed axially at 50% height, followed by 3.23±0.11 mm at 75% height and the least fibre length of 2.28±0.25 mm was observed at 75% height disc level. Samples collected from bamboo sample stands 3 had the highest fibre length of 3.25±0.15 mm, followed by 3.06±0.07 mm of bamboo stand 3 while the least 2.28±0.25 mm was recorded in *B.vulgaris* stands 2 (Table 1). It was observed that there was an increase in the fibre length in the radial position from the core section to the peripheral section (bark).

The average fibre length (FL) of 3.25±0.15 mm observed in this study *is* lower compared to the work of [13] who reported 3.65 mm for *Bambusa bambus* (5.62 mm) from middle to top sampling, whereas, the results (fibre length) corroborate the work of [14] who reported fibre length 2.8 mm to 3.7 mm from base to the top in Nigeria *B. vulgaris.* The FL values examined in this study is higher than 1.63±0.50 mm reported by [15] on non-wood fibre of *Saccharum officinarum* and above 2.7 mm reported by [16] on fibre lengths of selected softwoods. It is also higher to the minimum 0.7 mm -1.6 mm value for hardwood fibre sources and to 1.7 mm values reported by [17] for bagasse fibres. An increasing trend of fibre length was evidenced across the width of the culms examined.

The result of the analysis of variance shows that the fibre length in radial position (core and peripheral) differ significantly ($p<0.05$) but that of axial position (75%, 50% and 25%) does not have significant effects on the fibre length of the fibre examined (Table 2).

However, there is significant difference in the interaction between the two position (axial and radial), axial positioning and bamboo stands, the three way interactions (radial position* bamboo stands*axial position), whereas, the interaction between radial position and bamboo stands does not have significant difference on the fibre length of bamboo examined. Thus, this indicates that the effects of radial position of the fiber length are independent of the fibers radial position between the fibres of the bamboo stands.

3.2 Fibre Lumen Width of *B. vulgaris*

The average fibre lumen width is presented in Table 3. The results revealed that the average lumen width ranged between 3.52×10^{-3} µm to 4.46×10^{-3} µm in the radial direction from the core to the peripheral (bark) of the bamboo. The values increase along the axial direction from top (75%) to the bottom of the bamboo stands (25%) and from the core to the peripheral (radial position). The pattern of variations observed from the results also shows some form of inconsistency as the value decrease from the core to the peripheral and along the sampling height. However, this finding is in accordance with [18].

The average value observed in this study (4.46 µm) was higher that the *B.vulgaris* fiber lumen diameter (2.3 µm -2.6 µm) reported by [19]. However, the values is lower to findings of [13] on *B. bamboos* (24.96 µm) and 23 µm - 37 µm reported by [20] on *B. bluemeana*.

Table 1. Average value of *B. vulgaris* fibre length in relation to sampling height and radial position

	Sampling height (%)	Radial positioning	Bamboo stand	Average (mm)
Fibre length	75	Core	B_1	2.66 ± 0.10
			B_2	2.34 ± 0.10
			B_3	2.94 ± 0.28
		Peripheral	B_1	2.97 ± 0.16
			B_2	2.28 ± 0.25
			B_3	2.73 ± 0.11
	50	Core	B_1	2.45 ± 0.09
			B_2	2.51 ± 0.14
			B_3	3.06 ± 0.07
		Peripheral	B_1	2.87 ± 0.12
			B_2	2.72 ± 0.24
			B_3	3.25 ± 0.15
	25	Core	B_1	2.65 ± 0.22
			B_2	2.36 ± 0.31
			B_3	2.95 ± 0.04
		Peripheral	B_1	2.67 ± 0.09
			B_2	2.80 ± 0.08
			B_3	3.23 ± 0.11

Table 2. Analysis of variance (ANOVA) of *B. vulgaris* fibre length

SV	SS	DF	MS	F
RP	0.37	1	0.37	16.82*
AP	0.26	2	0.13	5.81^{ns}
BS	1.72	2	0.86	37.74*
RP * AP	0.16	2	0.08	$3. 46^{ns}$
RP * BS	0.57	2	0.03	1.25^{ns}
AP * BS	0.56	4	0.14	6.11*
RP * AP * BS	0.28	4	0.07	3.04*
Error	0.82	36	0.03	
Total	4.21	53		

**=Significant at 5% probability level (P≤ 0.05); ns= not Significant (P≥ 0.05)*
BS=Bamboo stands; AP=Axial Positions; and RP=Radial Positions

The result of analysis of variance (ANOVA) on the lumen width is presented in Table 4. The result shows that there is significant difference among the bamboo stands, lumen width of the fibre in the radial position and axial position (sampling height), whereas, there is no significance difference in the two way interaction (BS*AP and BS*RP) and the three way interactions (BS * AP * RP), respectively.

3.3 Fibre Diameter of *B. vulgaris*

The result obtained for average values of fiber diameter along the bamboo height (along stem) i.e. from top to bottom for the three sample stands of bamboo is presented in Table 5. The average values ranged from 3.52 µm to 7.02 µm, 3.58 to 4.41 µm and 3.44 µm to 4.36 µm across the 3 bamboo stands, sampling height and radial direction specimens respectively. Among the sampling height, the specimens collected from the middle that represent the 50% of the sampling height have higher fibre diameter at the peripheral region compare to others. Whereas, the least fibre diameter (3.44 µm) was recorded at the bottom (representing the 25% of the total height) and this was obtained from the core region of the sample.

The result shows that the fibre lumen diameter are smaller and lower for region of base to top compare to result obtained on *Dindrocalamus strictus (13.37* µm) [13]. It is also at a distance range to the 20.0 µm fibre diameter in *Saccharum officinarum* as reported by [17] and lower than the observed trend reported by [21] on *Triplochiton scleroxylon.*

Table 3. Average value for lumen width of *B. vulgaris* in relation to sampling height and radial position

	Sampling height (%)	Radial positioning	Bamboo stands	Mean (µm)
Lumen width	75	Core	B_1	4.01 ± 0.34
			B_2	3.77 ± 2.39
			B_3	6.48 ± 0.12
		Peripheral	B_1	6.83 ± 1.17
			B_2	6.37 ± 0.29
			B_3	6.53 ± 0.34
	50	Core	B_1	5.97 ± 0.49
			B_2	6.43 ± 0.77
			B_3	7.31 ± 1.22
		Peripheral	B_1	6.83 ± 0.40
			B_2	6.89 ± 0.26
			B_3	7.34 ± 0.52
	25	Core	B_1	6.67 ± 1.91
			B_2	6.69 ± 0.45
			B_3	7.05 ± 0.41
		Peripheral	B_1	6.35 ± 0.54
			B_2	6.94 ± 0.42
			B_3	6.75 ± 0.31

Table 4. Analysis of variance (ANOVA) on lumen width of *B. vulgaris*

SV	SS	DF	MS	F
BS	7.04	2	3.52	6.42*
AP	14.63	2	7.32	13.35*
RP	6.92	1	6.92	12.62*
BS * AP	2.9	4	0.72	1.32^{ns}
BS * RP	4.22	2	2.11	3.85^{ns}
AP * RP	9.06	2	4.53	8.26*
BS * AP * RP	3.74	4	0.94	1.71^{ns}
Error	19.74	36	0.55	
Corrected Total	68.24	53		

**=Significant at 5% probability level (P≤ 0.05); ns= not Significant (P≥ 0.05)*
BS=Bamboo stands; AP=Axial Positions; and RP=Radial Positions

The result of analysis of variance (ANOVA) on the fibre diameter is presented in Table 6. The result shows that there is significant difference among the bamboo stands, with no significance difference in the radial position and axial position (sampling height). Whereas, there were significant differences in the two ways interactions (BS*AP and BS*RP) and the three ways interactions (BS * AP * RP), respectively, of the fibre diameter assessed.

Table 5. Mean value for fibre diameter of *B. vulgaris* in relation to sampling height and radial position

	Sampling height (%)	Radial positioning	Bamboo stands	Mean (µm)
Fibre diameter	75	Core	B1	7.02 ± 0.50
			B2	4.3 ± 0.13
			B3	3.52 ± 0.30
		Peripheral	B1	4.28 ± 0.17
			B2	4.11 ± 0.22
			B3	3.82 ± 0.44
	50	Core	B1	3.79 ± 0.21
			B2	3.58 ± 0.32
			B3	3.77 ± 0.67
		Peripheral	B1	4.3 ± 0.17
			B2	4.11 ± 0.53
			B3	4.41 ± 0.37
	25	Core	B1	3.44 ± 0.28
			B2	3.47 ± 0.08
			B3	4.11 ± 0.93
		Peripheral	B1	4.36 ± 0.25
			B2	4.19 ± 0 .37
			B3	3.74 ± 0.28

Table 6. Analysis of variance (ANOVA) on fibre diameter of *B. vulgaris*

SV	SS	DF	MS	F
BS	3.99	2	1.99	12.40*
AP	0.51	2	0.26	1.59ns
RP	0.55	1	0.55	3.45ns
BS * AP	14.33	4	3.58	22.27*
BS * RP	2.2	2	1.1	6.84*
AP * RP	4.93	2	2.47	15.33*
BS * AP * RP	5.37	4	1.34	8.35*
Error	5.79	36	0.16	
Corrected Total	37.68	53		

**=Significant at 5% probability level (P≤ 0.05); ns= not Significant (P≥ 0.05)*
BS=Bamboo stands; AP=Axial Positions; and RP=Radial Positions

4. CONCLUSION

The axial and radial fibre characteristics of *B. vulgaris* were successfully carried out in this study. Fiber characteristics such as fibre length, fiber diameter and lumen width along the stem (sampling height) and across the stem (radial position) for the 3 bamboo stands were examined. It was observed that there was an increase in the fibre length in the radial position from the core section to the peripheral (bark) section. Along the length of the fibre of the bamboo stands examined (sampling height), there was an inconsistence in the pattern of the variations of the fibre length from 75% to 25% sampling height which could be as a result of differences in the age of the bamboo stands harvested for the study and the ecological zone of extraction when compared the results to same and other species from other region. Along the length of the fibre of the bamboo stands examined (axial position), there was an inconsistence in the pattern of the variations of the fibre length from 75% to 25% sampling height which may be as a result of age of the bamboo stands.

Among the sampling height, the fibre collected from the middle that represent the 50% of the sampling height have higher fibre diameter at the peripheral region compare to others. Whereas, the least fibre diameter was recorded at the bottom (representing the 25% of the total height) and this is from the core region of the sample. It was also noted generally that, the highest mean value of lumen width was found at the middle of the bamboo stem inward.

The fibre length of *B. vulgaris* used for this study falls within short fibre cellulosic materials. The Axial sampling of *B. vulgaris* showed no significant differences in the fibre qualities examined at any height of the bamboo stems except on lumen width. This is indicating that the bamboo possesses good pulping qualities suitable for pulp and paper production at any point of fibre collection (axial and radial positions).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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