

Original Research Article

AXIAL AND RADIAL VARIATION OF FIBRE CHARACTERISTICS OF *Bambusa vulgaris*

ABSTRACT

This study was carried out to investigate the axial and radial variation of fibre characteristics of *Bambusa vulgaris*. There were eighteen treatments for both axial and radial variation. The treatments were replicated three (3) times, in Complete Randomized Design (CRD). This Study was carried out at the Wood Anatomy Section of the Department of Forest Product Development and Utilization, Forestry Research Institute of Nigeria, Ibadan between July and August, 2018. Three (3) stands of *B. vulgaris* stands were randomly selected. Samples were cut into 10cm discs collected at 25%, 50% and 75% of the total height (Axial positioning) of the bamboo stems. 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 (H₂O₂) 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 3.25mm, followed by 3.06mm of bamboo stand three (3) while the least 2.28mm was recorded in stands two (2) of 75% axial positioning and at peripheral layer. The lumen width ranged between 3.52 × 10⁻³µm to 4.46 × 10⁻³µm 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 × 10⁻³µm to 4.46 × 10⁻³µm across the three (3) bamboo stands, sampling height and radial direction sampling respectively.

Comment [AB1]: VARIATIONS

Comment [AB2]: variations

Comment [AB3]: Schrad

Comment [AB4]: applied

Comment [AB5]: Methodology

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Comment [AB8]: vulgaris

Comment [AB9]: axial

Comment [AB10]: that

Comment [AB11]: 2 °C

Comment [AB12]: 3.25 mm

Comment [AB13]: 3.06 mm

Comment [AB14]: 2.28 mm

Comment [AB15]: 10⁻³ µm

Comment [AB16]: 10⁻³ µm

Comment [AB17]: fiber

Comment [AB18]: 10⁻³ µm

Comment [AB19]: 10⁻³ µm

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

Comment [AB21]: the

28 **KEYWORDS:** *Bambusa vulgaris*, Fibre length, Fibre diameter and Lumen width.

29

30 INTRODUCTION

31 Fibre characteristics are related to many structural, physical and chemical properties of wood. The fibre
32 characteristics includes fibre diameter, fibre length and lumen width. It affects many woody-product
33 manufacturing, like pulping process, behavior in the drying process and resistance to cutting and
34 machining, variations in fibre dimensions/characteristics are also present in the tree's radial, longitudinal
35 direction and within the annual rings (Zobel and Van Buijtenen, 1989). The variation may be due to
36 genetic, physiological or silvicultural treatment

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37 In general, fibers can be classified into three categories: wood, non-wood, and non-plant. The term "non-
38 wood" was coined to distinguish plant fibers from the two main sources of wood fibers; Hardwoods and
39 softwoods. Non-wood or agro-based fibers are derived from selected tissues of various mono or
40 dicotyledonous plants and are categorized botanically as grass, bast, leaf, or fruit fibers. Some non-wood
41 fibers are classified by means of production; fibers such as sugar cane bagasse, wheat straw and corn
42 stalks are byproducts. Other non wood fibers are grouped as "fiber plants," plants with high cellulose
43 content that are cultivated primarily for the sake of their fibers such as jute, kenaf, flax, cotton, and ramie.
44 Non-wood fibers can be used to make paper, although the quality varies a great deal depending on the
45 source of the fibers.

Comment [AB26]: hardwoods

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46 *Bambusa vulgaris* (bamboo) has been one of the fastest growing plants in the world. Bamboo has social,
47 economic and cultural significance and is used extensively for building materials along with thousands of
48 uses. It is highly versatile raw material for different works. The bamboo is light weight, flexible, tough, high
49 tensile, cheap material than the other building materials like steel. Bamboo can be used in various
50 building works. Bamboo structures are reported to be to be flexible, earthquake resistant, light weight and
51 cheap. Bamboo can be used as reinforcement in various structural members. Bamboo is a green material
52 for sustainable development and has various advantages. Use of bamboo may be promoted for green
53 buildings and sustainable development (Dinesh *et al.*, 2014). In fact, bamboo culture has been described
54 as an essential part of human history and civilization, especially in Asia (Lobovikov *et al.*, 2007).

Comment [AB30]: A bamboo specie

Comment [AB31]: considered as one

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55 In addition, bamboo is used for scaffolding in construction projects often to great heights. While bamboo
56 continues to be used in these traditional ways, it has also become an important raw material for
57 production of modern building products (Bowyer *et al.*, 2014)
58 Fibres have been regarded as one of the main components that determine the mechanical properties of
59 any woody materials including bamboo owing to their unidirectional arrangement in the tissue as well as
60 their unique cell wall structure (Gritsch *et al.*, 2004). Many study have been done regarding bamboo;
61 Fibre wall anatomy (Parameswaran and Liese), and in particular cell wall thickening (Gritsch *et al.*, 2004;
62 Murphy and Alvin, 1997) lignification (Itoh, 1990; Lybeer and Koch, 2005) and cell wall nano-structural
63 changes (Suzuki and Itoh, 2001) during development of bamboo culms, mechanical properties of fibres or
64 fibre caps (Zou, *et al.*, 2009 and Yu, *et al.*, 2011), and the underlying structure–property relationships of
65 bamboo fibres that establish the gradients across the fibre caps have been intensively studied, but there
66 has been little information on fibre characteristics variation along axial (top, middle and base) and radial
67 (back and core) dimension in relations to its pulping potentials. Therefore, this study sought to provide
68 input in this regards so as to provide information on variations across (radial) and along (axial) axis of *B.*
69 *vulgaris*.

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Comment [AB36]: Subdivide the paragraph

Comment [AB37]: studies

Comment [AB38]: , 1976

Comment [AB39]: Murphy and Alvin, 1997; Gritsch *et al.*, 2004

Comment [AB40]: Absent in the References

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71 MATERIALS AND METHODS

72 Materials

73 The materials used for determining the variation in the fibre characteristics of *B. vulgaris* from the same
74 location are; *Bamboosa vulgaris* samples, test tubes, tube rack, acetic acid (CH₃COOH), Hydrogen
75 peroxide (H₂O₂), Spatula, Beaker, Distilled water, Light microscope, saw, sharp knife, nose cover and
76 hand glove.

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77 Sample Area

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

Comment [AB46]: 07°22' N

Comment [AB47]: 03°58' E

Comment [AB48]: 1500 mm

Comment [AB49]: 26.46 °C

Comment [AB50]: Reference?

83 **Experimental Site**

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

Comment [AB51]:

86 **Sampling Technique**

87 For this study, three (3) stands of *Bambusa vulgaris* stands were randomly selected from the bamboo
88 plantation, behind horticultural nursery, Forestry Research Institute of Nigeria, Ibadan (FRIN) and
89 harvested. Samples were cut into 10cm discs collected at 25%, 50% and 75% of the total height (Axial
90 positioning) of the bamboo stems. The samples discs were later partitioned into two zones (radial
91 positioning) which are core and peripheral (bark) layers.

Comment [AB52]: The culm's age play a crucial influence on the fiber properties!

Comment [AB53]: *B. vulgaris*

Comment [AB54]: 10 cm height

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93 **Sample Preparation**

94 *B. vulgaris* (bamboo) collected were cut into 10cm discs collected at 25%, 50% and 75% (which represent
95 base, middle and top of each stands respectively) of the total height (axial positioning) of the bamboo
96 stems, from each of the disc, 3 slivers were obtained both from radial positioning (Core and peripheral
97 layers) from each bamboo stem replicated three (3) times totaling 54 fibres used for this study. Bamboo
98 slivers obtained were put into test tubes and macerated with an equal volume (1:1) of 10% glacial acetic
99 acid and 30% Hydrogen Peroxide (H2O2) at 100±2°C and boiled until soft and bleached white as adopted
100 by Franklin, 1945. The slivers were then washed, placed in 30ml-test tubes with 20ml-distilled water and
101 shaken vigorously to separate the fibre bundles into individual fibre. The macerated fibre suspension was
102 carefully aligned on a slide using white tread. The resulting image on light microscope screen was
103 measured for fibre length, fibre diameter and lumen width.

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Comment [AB58]: three

Comment [AB59]: Acetic

Comment [AB60]: 100±2 °C

Comment [AB61]: Absent in the References

Comment [AB62]: Franklin (1945).

Comment [AB63]: 30 mL-test tubes with 20 mL

Comment [AB64]: fibres

Comment [AB65]: fibres

104 **Microscopy**

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

Comment [AB66]: what kind? Model?

109 **Parameters Determined**

110 The parameters determined using the microscope is stated below.

Comment [AB67]: The follow parameters were determined:

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

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116 Experimental Design

117 The experiment was laid out in a Completely Randomized Design (CRD). There were 18 treatments
118 randomly allocated with each treatment replicated 3 times making 54 observation.

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119 Data analysis

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

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124 RESULTS AND DISCUSSION

125 Fibre Length of *Bambusa vulgaris*

Comment [AB72]: *B. vulgaris*

126 The mean fibre length was presented in Table 1. The longest fibre length of $3.25 \pm 0.15 \text{ mm}$ was observed
127 axially at 50%, followed by $3.23 \pm 0.11 \text{ mm}$ at 75% and the least fibre length of $2.28 \pm 0.25 \text{ mm}$ was observed
128 at 75% disc level. Samples collected from bamboo stands three (3) had the highest fibre length of
129 $3.25 \pm 0.15 \text{ mm}$, followed by $3.06 \pm 0.07 \text{ mm}$ of bamboo stand three (3) while the least $2.28 \pm 0.25 \text{ mm}$ was
130 recorded in *Bambusa vulgaris* stands two (Table 1). It was observed that there was an increase in the
131 fibre length in the radial position from the core section to the peripheral section.

Comment [AB73]: $3.25 \pm 0.15 \text{ mm}$

Comment [AB74]: height

Comment [AB75]: $3.23 \pm 0.11 \text{ mm}$

Comment [AB76]: $2.28 \pm 0.25 \text{ mm}$

Comment [AB77]: *B.*

Comment [AB78]: $3.25 \pm 0.15 \text{ mm}$

Comment [AB79]: $1.63 \pm 0.50 \text{ mm}$

Comment [AB80]: Egbewole *et al.* (2015)

Comment [AB81]: 2.7 mm

Comment [AB82]: Absent in the References

Comment [AB83]: by Atchison (1987)

Comment [AB84]: 0.7 mm -1.6 mm

Comment [AB85]: 1.7 mm

Comment [AB86]: Absent in the References

132 The mean fibre length of $3.25 \pm 0.15 \text{ mm}$ observed in this study was higher than $1.63 \pm 0.50 \text{ mm}$
133 reported by Egbewole, *et al.*, 2015 for *Saccharum officinarum* and above 2.7mm reported by (Atchison,
134 1987) on fibre lengths of selected softwoods. It is also higher to the minimum 0.7mm -1.6mm value for
135 hardwood fibre sources and to 1.7mm values reported by Noah (2009) for bagasse fibres. Fibre length
136 has been considered as a critical factor to be considered in selecting any species for the production of

137 high quality pulp for paper making (Dinwoodie, 1965). The long fibre length of bamboo is characterized by
 138 high degree of opacity; stiffness and smoothness which are very suitable for making bank notes which
 139 can withstand rough handling (Noah, 2009).
 140 The result of the analysis of variance shows that the fibre length in radial (core and peripheral) position
 141 differ significantly ($p < 0.05$) but that of axial position (75%, 50% and 25%) does not have significant effects
 142 on the fibre length of the fibre examined (Table 2). However, there is significant difference in the
 143 interaction between the two position (axial and radial position), axial positioning and bamboo stands, the
 144 three way interactions (radial position* bamboo stands*axial position), whereas, the interaction between
 145 radial position and bamboo stands does not have significant difference on the fibre length of bamboo
 146 examined. This thus indicates that the effects of radial position of the fiber length are independent of the
 147 radial position between the fibres of the bamboo stands.

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Comment [AB90]: positions (axial and radial)

Comment [AB91]: Thus, this

Comment [AB92]: fibers radial position

Comment [AB93]: Average of B, vulgaris fiber length

148 **Table 1: Mean value for Fibre length of *Bambusa vulgaris* in relation to sampling height**
 149 **and radial position**

	Sampling height (%)	Radial Positioning	Bamboo Stand	Mean
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	

Comment [AB94]: Average (mm)

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151 **Table 2: Analysis of Variance (ANOVA) on Fibre length of *B. vulgaris***

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		

Comment [AB95]: *B. vulgaris* fiber length

152 *=Significant at 5% probability level ($P \leq 0.05$); ns= not Significant ($P \geq 0.05$)

Comment [AB96]: ? RP? AP? BS?

153

154 **Lumen Width of *Bambusa vulgaris***

Comment [AB97]: B.

155 The mean fibre length was presented in Table 3 below. The results revealed that the mean lumen width

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156 ranged between $3.52 \times 10^{-3} \mu\text{m}$ to $4.46 \times 10^{-3} \mu\text{m}$ in the radial direction from the core to the peripheral

Comment [AB99]: $3.52 \times 10^{-3} \mu\text{m}$ to $4.46 \times 10^{-3} \mu\text{m}$

157 (bark) of the bamboo. The values increase along the axial direction from top (75%) to the base of the

Comment [AB100]: bottom

158 bamboo stands (25%) and from the core to the peripheral (radial position). The pattern of variation

159 observed from the results also shows some form of inconsistency as the value decrease from the core to

160 the peripheral and along the sampling height. This finding is in accordance with Monteoliva, (2005). The

Comment [AB101]: However, this

161 mean value observed was lower than the values observed on *Sterculia setigera* by Oluwadare and

Comment [AB102]: Monteoliva (2005). Absent in the References

162 Egbewole (2008).

Comment [AB103]: average

163 The result of analysis of variance (ANOVA) on the lumen width is presented in table 4. The result shows

Comment [AB104]: those

164 that there is significant difference among the bamboo stands, lumen width of the fibre in the radial

Comment [AB105]: Table

165 position, axial position (sampling height), whereas, there is no significance difference in the two way

166 interaction (BS*AP and BS*RP) and the three way interactions (BS * AP * RP) respectively.

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168 Table 3: Mean value for Lumen Width of *Bambusa vulgaris* in relation to sampling height
 169 and radial position

Comment [AB107]: Average

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	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	

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189 **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		

190 *=Significant at 5% probability level ($P \leq 0.05$); ns= not Significant ($P \geq 0.05$)

191

192 **Fibre Diameter of *Bambusa vulgaris***

193 The result obtained for mean values of Fiber diameter along the bamboo height (along stem) i.e. from top
 194 to base for the three stands of bamboo is presented in Table 5 below. The mean values ranged from
 195 3.52µm to 7.02µm, 3.58 to 4.41µm and 3.44µm to 4.36µm across the three (3) bamboo stands, sampling
 196 height and radial direction sampling respectively. Among the sampling height, the sampling collected from
 197 the middle which represent the 50% of the sampling height have higher fibre diameter at the peripheral
 198 region compare to others. Whereas, the least fibre diameter (3.44µm) was recorded at the base
 199 (representing the 25% of the total height) and this is from the core region of the sample.

200 The highest mean fibre diameter value gotten from the study (7.02µm) falls below the range of 20- 40µm
 201 fibre diameter for hardwood fibres as reported by Usta and Eroghe (1987), it is also at a distance range to
 202 the 20.0µm fibre diameter in baggase as reported by Noah (2009) and 20.78µm by Egbewole et al., 2015
 203 for *Saccharum officinarum*. This is lower than the observed trend reported by Ogunsanwo and Onilude
 204 (2000) on *Triplochiton scleroxylon*.

Comment [AB109]: BS? AP? RP?

Comment [AB110]: B.

Comment [AB111]: fiber

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Comment [AB114]: average

Comment [AB115]: 3.52 µm to 7.02 µm, 3.58 µm to 4.41 µm and 3.44 µm to 4.36 µm

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Comment [AB119]: 3.44 µm

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Comment [AB121]: was obtained

Comment [AB122]: 7.02 µm

Comment [AB123]: 20- 40 µm

Comment [AB124]: Absent in the References

Comment [AB125]: 20.0 µm

Comment [AB126]: bagasse

Comment [AB127]: Egbewole et al. (2015)

Comment [AB128]: Difference? Bagasse and *S officinarum*?

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

Comment [AB129]: fibre

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210 **Table 5: Mean value for Fibre Diameter of *Bambusa vulgaris* in relation to sampling**
 211 **height and radial position**

Comment [AB133]: Fibre diameter

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FIBRE DIAMETER	Sampling Height (%)	Radial Positioning	Bamboo Stands	Mean	
	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	

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222 **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		

Comment [AB136]: fibre diameter

223 *=Significant at 5% probability level ($P \leq 0.05$); ns= not Significant ($P \geq 0.05$)

Comment [AB137]: BS? AP? RP?

224

225 **CONCLUSION**

226 The axial and radial fibre characteristic of *B. vulgaris* was successfully carried out in this study. Fiber
 227 characteristics such as fibre length, fiber diameter and lumen width along the stem (sampling height) and
 228 across the stem (radial position) for the three (3) bamboo stands examined. It was observed that there
 229 was an increase in the fibre length in the radial position from the core section to the peripheral (back)
 230 section. Along the length of the fibre of the bamboo stands examined (sampling height), there was an
 231 inconsistency in the pattern of the variation of the fibre length from 75% to 25% sampling height which
 232 could be as a result of environmental factor of the growing site and age of the bamboo stands. Along the
 233 length of the fibre of the bamboo stands examined (axial position), there was an inconsistency in the
 234 pattern of the variation of the fibre length from 75% to 25% sampling height which may be as a result of
 235 environmental factor such as growing site and age of the bamboo stands.

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236 Among the sampling height, the fibre collected from the middle **which** represent the 50% of the sampling
237 height have higher fibre diameter at the peripheral region compare to others. Whereas, the least fibre
238 diameter was recorded at the **base** (representing the 25% of the total height) and this is from the core
239 region of the sample. It was also **indicted** generally that, the highest mean value of lumen width was
240 found at the middle of the bamboo stem inward. This range also indicates the inconsistency in the lumen
241 width of the fibre assessed.

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Comment [AB144]: strictus

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Comment [AB145]: Italic

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