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Influence of fiber characteristics of Nigerian grown *Bambusa vulgaris* Schrad on its relative density and burst strength

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Abstract: Strength properties of *Bambusa vulgaris* with increasing culm height was studied considering its fiber characteristics with particular reference to the presence or absence of nodes. At the internode, an increase in fiber length with increasing culm height (2.78 mm-3.73 mm from base to top) was observed, while fiber diameter behaved conversely, showing a reduction from base to top (0.033 mm-0.013 mm). Relative density and burst strength had a similar trend as they both showed reduction in values from base to top (0.62-0.51 and 8.2KN/mm^2 – 5.3KN/mm^2 respectively). At the node, reduction in fiber length from base to top (1.79 mm-1.39 mm) was observed, while fiber diameter increased from base to top (0.023 mm-0.031mm). Relative density showed a reduction from base to top (0.64-0.52), while burst strength had a similar trend having a range of above 11KN/mm^2-5.4KN/mm^2 from base to top. Statistical analysis of the data from the node revealed a strong direct correlation between fiber length and relative density, while fiber diameter showed a weak and inverse relationship. Burst strength showed a direct but weak relationship with fiber length, while it had an inverse and weak correlation with fiber diameter. At the internode, a weak and inverse relationship was revealed between density and fiber length, while fiber diameter showed a direct but weak relationship. Burst strength and fiber length showed a strong but inverse correlation, while fiber diameter and burst strength revealed a direct and significant correlation.

Key words: *Bambusa vulgaris*, fiber length, fiber diameter, relative density, burst strength.

INTRODUCTION

Bamboo belongs to a unique group of gigantic grasses of the family Poaceae. Bamboo is a versatile fast growing species which has been described as segmented and complex subterranean system (Janssen, 2000). It attains its full length in 2 to 3 months and its maturity in 2 to 3 years (Gnanaharan *et al.*, 1994). Bamboos can grow at sea level to as high as 3000 m a.s.l. and they are well adapted to growing in plains, hilly and high altitude mountain regions and in most soil types except desert, marsh and alkaline soils.

Even though, bamboo grows in different parts of the world, it is found in abundance in most Asian countries and as a result of its ready availability, easy usability coupled with

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high strength to weight ratio, it plays a vital role in the rural economy of many countries.

Having been recognized as a fast growing natural resource with better qualities in physical and mechanical properties compared to most wood species. they are said to be good substitutes for wood (Li, 2004). Bamboo species available in Nigeria are *Bambusa vulgaris* Schrad, *Oxytenanthera abyssinica* Munro, *Guadella macrostachys* Pilger, *G. densiflora* Clayton and *G. humilis* Pilger, of which *B. vulgaris* is predominant (Oyebode and Ogedengbe, 2001).

The reason behind bamboos' strength is that each strand of the grain (fiber) is perfectly straight (Hunter, 2005). Bamboo fibers contribute about 60 - 70 per cent by weight of total culm tissue (Liese, 1992) and their length shows considerable differences between species as well as within one culm (Armstrong, 2006). The percentage of fibers is higher in the outer third of the wall than in the inner as well as in the upper part of the culm, compared to the base (Liese, 1992). The properties of bamboo also depend on its microstructure (Ahmad, 2000). Liese (1998) noted that the physical and mechanical properties of a bamboo culm is directly linked with its anatomical structure reporting that specific gravity which varies between 0.5 to 0.9 depends mainly on the fiber content, fiber diameter and cell wall thickness. As the culm matures, it increases due to the thickening of fiber walls and it varies within culm and between species.

Kabir *et al.* (1996) evaluated some physical properties of *Dendrocalamus hamiltonii*, a bamboo species found in Bangladesh and found that moisture content, specific gravity and volumetric shrinkage, vary significantly with height, presence of node and branch. The node of the culm was found to have higher specific gravity but lower moisture content and volumetric shrinkage, while the specific gravity of the culm was found to be higher than that of the branch. Ahmad (2000) worked on the physical and mechanical properties of *D. strictus*. Results from his research showed that average relative density of *D. strictus* is 0.643. This is higher than that of some timber species used for composites production, *e.g.*, Yellow poplar and Douglas fir with relative densities 0.42 and 0.48, respectively. Sattar (1995) attributed the density of bamboo (which is said to vary from 500 to 800 kg/m^3) to anatomical structure of the culm which for example is the distribution and quantity of fibers around the vascular bundles. Furthermore, he stated that density decreases from the outer part to the inner portion, while maximum density is obtained in about 3 years.

Furthermore, Liese (1992) reported that the fiber length of different species shows significant differences as well as the fiber diameter. Some bamboo species are known to have shorter fibers: *Phyllostachys edulis* (1.5 mm), *P. pubescens* (1.3 mm), while longer ones include *D. giganteus* (3.2 mm), *Oxytenanthera nigrocilliata* (3.6 mm), and *D. membranaceus* (4.3 mm). He also stated that fiber length influences density and strength properties, *e.g.*, elastic bending stress, while the number of vascular bundles per mm^2 is closely related to elastic modulus. Moreover, he noted that the shorter fibers are always seen near the nodes.

Owing to its pipelike nature and considering the possibility of using bamboo in small-scale irrigation and drainage applications, there is need to investigate these trends and the extent to which the fibers of *B. vulgaris* affect these properties (burst strength and relative density).

MATERIALS AND METHODS

After examining the physical conditions of potential culms, experimental samples were derived from mature and healthy ones felled at the Olodo Forest in Egbeda Local Government area of Ibadan, Nigeria. The culms were measured and then divided into three equal parts in line with the recommendations of International Standards Organization (2000). They were labeled "base", "middle" and "top". Samples were collected from these with some containing nodes at mid-span within the test region, while others were taken from the internodes only. The experiments were done in two stages, the first being investigations on the fiber characteristics of the culms, while the second involved the determination of relative density and burst strength, considering the presence or absence of nodes.

Fiber characteristics

The bamboo specimens were cut into pieces of 2 x 1 cm dimensions and boiled in water for 24 h to soften it, after which they were sliced into small pieces and macerated using Schluz's fluid (a mixture of equal volumes of 10 per cent chromic acid and 10 per cent nitric acid) for two days. The macerates were preserved in 50 per cent ethanol after they had been washed in five changes of water. From these, fiber length (FL) and fiber diameter (FD) were determined using the ocular/stage micrometer.

Relative density

This was determined in accordance with the recommendations of ISO (2000). The criteria used were: Ovendry mass/Green volume. The volume was determined by water displacement method. The sampling intensity was 12 samples a piece and the mean was used to represent the relative density of the portion from which the samples were taken from. The test was carried out at the Agricultural and Environmental Engineering Laboratory, University of Ibadan.

Burst strength

This was performed to determine the maximum pressure in KN/mm^2 at which a bamboo section of 300 mm length would burst taking note of its thickness and moisture content. The samples were taken from the top, middle and base portions of the culm to see the differences in their burst strength with particular reference to the nodes and internodes. The testing criterion was based on the principle of equipment used in testing burst strength of very large diameter steel pipes in some factories. The jig fabricated for the test incorporated an external water pump to serve the purpose of introducing water into the bamboo pipe which has been held tightly by the jig to prevent water leakage. Burst pressure was read directly from the pressure gauge in the jig.

Statistical analysis

The Pearson's Product Moment Correlation Coefficient was used to analyze the correlation between the fiber characteristics (*i.e.* fiber length and diameter), density and burst strength of different portions of the culm as well as to establish the strength of these relationships.

RESULTS AND DISCUSSION

The average values obtained for fiber characteristics and strength properties of *B. vulgaris* are given in Tables 1 and 2. Figures 1-4 represent the varying trends in fiber length (FL), fiber diameter (FD), relative density (RD) and burst strength (BS) of *B. vulgaris* respectively. Observations revealed that FD, RD and BS at the nodes reduced with increasing culm height, being highest at the base and lowest at the top, while FL behaved conversely, increasing with increasing culm height. However, the internodes, FL, RD and BS reduced with increasing culm height, being highest at the base and lowest at the top, while FD behaved conversely, increasing with increasing culm height.

In comparison with the values obtained from samples taken from the node, RD and BS from the internode had the same trend, while FL and FD behaved conversely, FD

Table 1. Fiber characteristics and strength properties of specimens from the internode (mean values)

	FL (mm)	FD (mm)	Relative density	Burst strength (KN/mm^2)
Base	2.78	0.033	0.62	8.2
Middle	3.41	0.018	0.59	6.9
Top	3.73	0.013	0.51	5.3

Table 2. Fiber characteristics and strength properties of specimens from the node (mean values)

	FL (mm)	FD (mm)	Relative density	Burst strength (KN/mm^2)
Base	1.79	0.023	0.64	11
Middle	1.74	0.028	0.6	8
Top	1.39	0.031	0.52	5.4

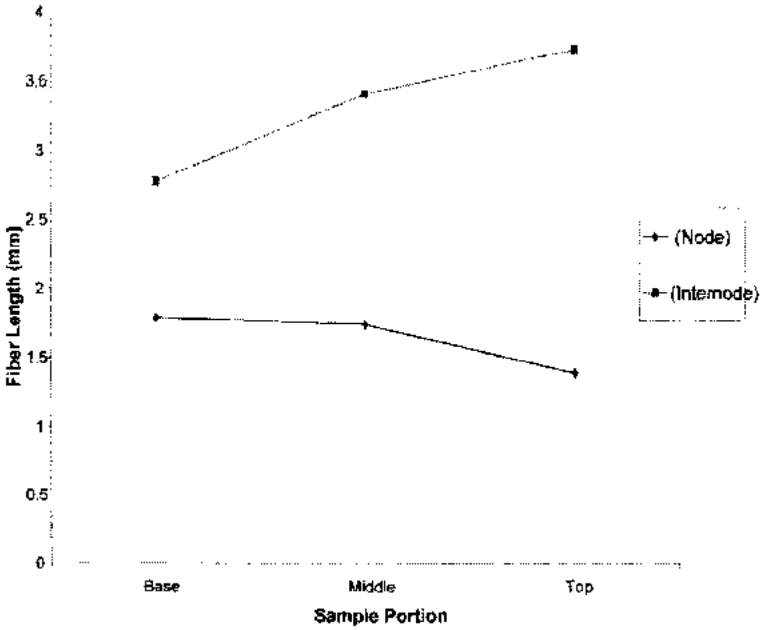

Figure 1. Variations in fiber length of *B. vulgaris* with increasing culm height

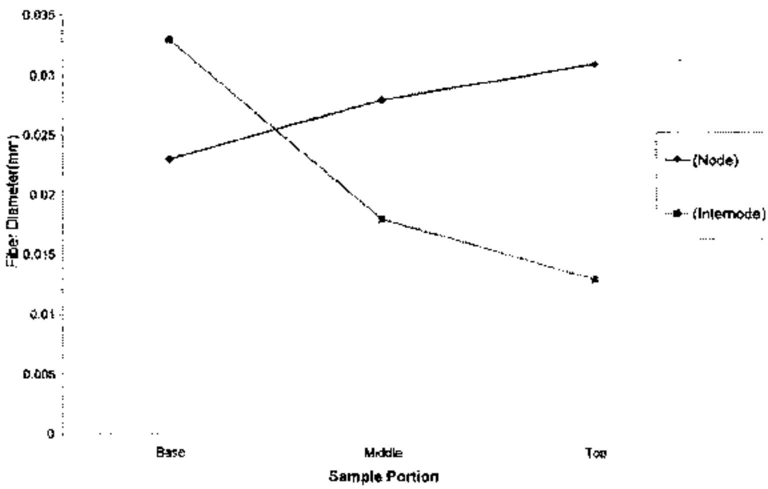

Figure 2. Varitions in fiber diameter of *B. vulgaris* with increasing culm height

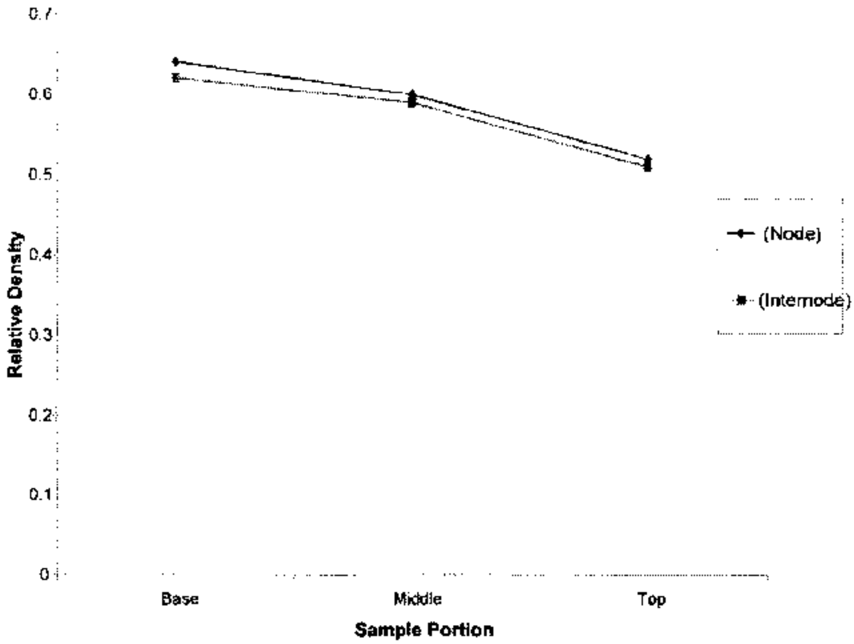

Figure 3. Variations in relative density of *B. vulgaris* with increasing culm height

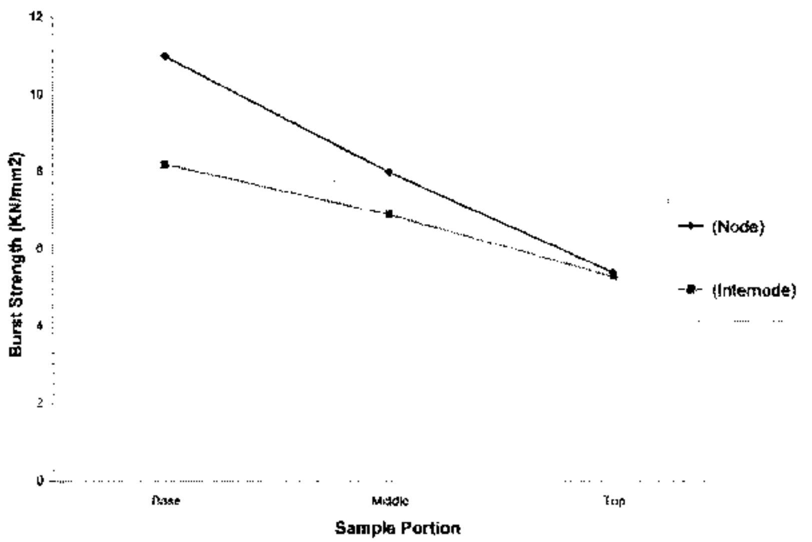

Figure 4. Variations in burst strength of *B. vulgaris* with increasing culm height

being lowest at the top, while FL was highest at the top. RD variation trend is comparable with that of most tropical wood species, but is contrary to what has been reported for some other bamboos in which RD was found to be highest at the top and lowest at the base (Abd. Latif, 1996). Also, average RD values obtained fell within the range reported by Kumar *et al.* (1994). Similarly, BS values obtained are similar to what was reported by Purwito (1995).

Correlation between fiber characteristics and strength properties

Statistical analysis was performed to know the effect of FL and FD on the RD of *B. vulgaris* and this yielded a Pearson's correlation coefficient "r^2" ($P < 0.05$) values of 0.76 and -0.397 for FL and FD respectively for the node. This implies that FL has a direct and significant relationship with nodal relative density (*i.e.* as FL increases, RD increases) and FD behaves conversely (*i.e.*, as FD increases, RD decreases), whereas, a different pattern was obtained at the internodes as "r^2" values were -0.103 and 0.470 for FL and FD respectively. This implies an insignificant and inverse relationship between FL and relative density (*i.e.*, as FL increases, RD decreases), while FD similarly has an insignificant but direct relationship with relative density at the internode (*i.e.*, as FD increases, RD increases). Similarly, statistical analysis on the effect of FL and FD on the BS of *B. vulgaris* yielded a Pearson's correlation coefficient "r^2" ($P < 0.05$) of 0.406 and -0.488 for FL and FD respectively for the node. This implies that FL has a direct but weak relationship with nodal BS (*i.e.* as FL increases, BS increases), while FD has both indirect and weak correlation with it (*i.e.*, as FD increases, BS decreases). Analysis at the internodes yielded Pearson's correlation coefficient "r^2" ($P < 0.05$) of -0.674 and 0.723 for FL and FD respectively. This implies that FL has an indirect but strong correlation with internodal BS (*i.e.* as FL increases, BS decreases), while FD has both direct and strong correlation with internodal BS (*i.e.*, as FD increases, BS increases).

Observations from this study have shown that *B. vulgaris* possess a microstructure that aids its relative density and ultimately its strength. The dense arrangement of fibers at the nodes and generally at the base including parts of the middle portions constitutes reinforcement in these areas. In general, fiber length is higher at the internode than at the node, while fiber diameter is greater at node. The high concentration and compact arrangement of fibers at the node is responsible for the higher relative density of the node. Liese (2004) noted that fiber length varies from species to species, but it usually ranges between 1.5 to 3.5 on the average confirming that content and length influence the relative density which for bamboo ranges from 0.5 to 0.9. The fiber length of *B. vulgaris* obtained from this study is relatively higher than that was reported by Ahmad (2000) who gave a range of 0.006-0.008 mm, even though, he did not specify whether it is *B. vulgaris* Schrad or *B. vulgaris* (*vitata*), otherwise known as Hawaiian gold.

Average fiber length value of 2.3 mm quoted by Li (2004) falls within the range obtained for the internode. Abd. Latif (1991), gave a range between 1.74-3.76 mm. Liese (2004) also confirmed that bamboo fibers are shorter at the nodes and they have great influence on culms' mechanical strength due to higher specific gravity. The presence of nodes is an advantage to the strength of the culm in withstanding burst pressure. Generally, the higher strength values found at the nodes can be accounted for by the increased density at the r1egion (which has been attributed to higher concentration of fibers). Observations made while converting the culms into test specimens confirmed this as there was more resistance to cutting and conversion at the nodal areas than at the internodes.

CONCLUSION

Fiber length at the nodes has positive effect on both relative density and burst strength, while fiber diameter has a negative effect on them. At the internodes however, the reverse is the case as fiber diameter has positive effect on relative density and burst strength, while fiber length has a negative effect on them. Also, relative density has positive correlation with burst strength as portions of the culm with higher density recorded higher burst strengths.

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