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Anatomical, physical and strength properties of *Shizostachyum brachycladum* (Buluh lemang)

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Abstract: Anatomical, physical and strength properties of 4-year-old *Schizostachyum brachycladum* (Buluh lemang) with nodes and internodes, and the trends in these properties along the bamboo culm height were evaluated. The results showed that the fiber morphology, vascular bundle size, moisture content, radial, longitudinal and tangential shrinkage from green to oven-dry decreased from the basal portions towards the top of the bamboo culm, both in the nodes and internodes. On the other hand, the opposite trend was observed in density, modulus of rupture (MOR), modulus of elasticity (MOE), and the percentage of the vascular bundle. Higher mean value of density; and vascular bundle size, and percentage was found at the node, rather than at the internode, portions. While, internodal fiber morphology, moisture content, radial, longitudinal and tangential shrinkage, MOR, and MOE exhibited higher mean values than the nodal parts. These findings lead to the conclusion that presence of nodes in *S.brachycladum* resulted to low strength and affects the end product.

Keywords: Anatomical properties, physical properties, strength properties, density, vascular bundle

INTRODUCTION

Nowadays, bamboo has become the most popular non-wood material in the wood-based industry due to the shortage of wood raw material supplies. Besides, bamboo is a highly renewable and biodegradable material that constitutes a substantial carbon reserve (Isagi *et al*., 1997). It demonstrates excellent mechanical properties that can reduce the need for steel in the construction industry. Other than that, bamboo is a cylindrical, usually hollow, light in weight, and functionally-graded material that demonstrates optimal characteristics for the truss elements, which are frequently used in civil construction (Krause and Ghavami, 2009). Tan *et al*. (2011) highlighted that bamboo has also been used as an eco-friendly material in a wide range of applications in engineering and in civil construction which include application as scaffolding, fiber-reinforced composites and bridges. Bamboo has been used intensively in Malaysia in traditional and structural applications. Its use is no longer limited to round forms

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but has been extended to splits and strips (Hamdan *et al*., 2009). Numerous studies have investigated utilisation of bamboo culms, with particular emphasis on *Bambusa vulgaris* and *Gigantochloa scortechinii*. These two species of bamboo were reported to be suitable for manufacturing particleboards (Jamaluddin *et al*., 1999), cement-bonded particleboards (Chew *et al*., 1992), laminated bamboo boards (Razak *et al*., 1997) and plybamboo (Zaidon *et al*., 2004). These products, however, were not commercialised because of inconsistent supplies of bamboos, competition in land acquisition, and limited supplies of quality bamboo stocks for planting (Azmy and Abd Razak, 1991).

With the developing interest in the use of bamboo in various products, the basic properties of bamboo, including the anatomical, physical, and strength properties, need to be studied to assess its suitability for the intended purposes. Examination of the anatomical properties of bamboo, such as fibre morphology, has been studied due to the intrinsic relationships of these properties with strength, preservative absorption and end products, especially pulp and paper (Razak *et al*., 2002; Razak *et al*., 2005). The moisture content, density, and shrinkage are considered to be important factors in determining the suitability of bamboo for various applications and its amenability to chemical treatments (Razak *et al*., 2010). Determination of the strength properties of bamboo, MOR and MOE is very important since these properties are closely related to its industrial uses and structural applications (Bodig and Jayne, 1982; Shahril and Mansur, 2009). Extensive research has been carried out on the anatomical, physical, chemical and strength properties of bamboo. However, these studies mainly focused on the internode, rather than on the node portion of the bamboo culm (Shao *et al*., 2010).

Nodes of bamboo appear at intervals of about 10 cm along the stem or even longer in some species. The node of bamboo culm consists of a sheath scar, nodal ridge, diaphragm, and intranode between the nodal ridge and sheath scar (Liese, 1998). The study on bamboo with its node present is very important to determine the influence of this portion on the properties of the bamboo (Sekhar and Bhartari, 1960). Janssen (1981) found that the effect of nodes in round bamboo culm is not significant on the mechanical properties although anatomically the fibers were truncated at the nodes. Kappel *et al*. (2004) illustrated that the presence of node diaphragm in round bamboo seems to prevent failure due to its role in cross-sectional flattening. Similarly, Shao *et al*. (2010), who studied the mechanical properties of Moso bamboo, indicated that the nodes did not impart any negative effects on the tensile, bending or compressive strength but that the nodes enhanced maximum bending, shear strength, and compressive load. However, Hamdan *et al*. (2009) in his study of *G. scortechinii* stated that the presence of a node reduces the uniformity, elasticity, and strength of the bamboo.

Malaysia is endowed with more than 50 species of bamboo of which only 14 species are known to be commercially utilised (Wong, 1989). *Schizostachyum brachycladum*, locally known as buluh lemang, is indigenous to Malaysia and is one of the most popular tropical bamboo species for plantation. Its culms are commonly used for cooking glutinous rice called 'lemang' and are also used for crafting baskets and mats (Wong, 1995; Abd. Razak and Abd Latif, 1995). However, utilisation of this bamboo has progressed from traditional to advanced end products such as laminated bamboo and plybamboo (Azmy *et al*., 2011). The objective of the present study was to determine the anatomical, physical, and strength properties of 4-year old *S.brachycladum* in the presence of node and internode of the bamboo split. The trend differences in the properties along the bamboo culm height were also examined.

MATERIALS AND METHODS

Field sampling

Three culms of 4-year old *S. brachycladum* from the same clumps, which were obtained from the Forest Research Institute of Malaysia (FRIM), were used in this study. The 4-year old *S.brachycladum* was chosen for this study due to the maturity of the culm. Abd Latif *et al*. (1990), Sattar *et al*. (1992) illustrated that the bamboo culms start maturing at the age of three years. The culm age was determined by tagging it four years earlier at an experimental area during the shoot's sprouting stage. The bamboo culms were cut at a height of about 20 cm above the ground level. Each culm was cut to a length of 12 m and was later subdivided into three equal lengths corresponding to the basal, middle and top portions. For the assessment of the physical properties, MOR and MOE were evaluated using samples in the form of splits and were tested at 12% moisture content. A split refers to a bamboo sample with intact periphery and inner skin.

Determination of the anatomical properties of bamboo

The anatomical studies of the distribution, vascular bundle size (width and length) were carried out according to the methods outlined by Abd Latif and Mohd Tamizi (1992), and Mohd Tamizi (2009). Bamboo sample blocks were cut into sections of 10 mm x 10 mm x culm wall thickness and boiled with distilled water until the bamboo samples had softened. Then, 25-µm thick sections were cut in a sledge microtome. Each section was stained with aqueous safranin-O. These sections were washed with 50% ethanol and dehydrated using a series of alcohol solutions having the concentrations 70, 80, 90, and 95% followed by three rinses using absolute ethanol. The sections were then cleared in xylene and mounted in Canada Balsam on a clear glass slide. The slides were dried in an oven at 60º C for few hours.

The maceration technique was used to determine the fibre morphology. Bamboo splits of 20 mm x 10 mm x culm wall thickness were chipped into match stick size slivers.

The slivers were macerated using a mixture of 30% hydrogen peroxide and glacial acetic acid (1:1 ratio) at 45º C (Abasolo *et al*., 2005) for 2 to 3 h until all the lignin dissolved and the cellulose fibres appear whitish (Catling and Grayson, 1982). The macerating solution was then carefully washed in distilled water until all traces of the acid disappeared. The vials were then gently agitated to ensure sufficient separation of cellulose fibres. (Dinwoodie, 1974). The vials were then half-filled with distilled water and capped securely. The macerated fibres were spread out on a glass slide and drops of safranin-O were added and a cover slip was applied.

Quantitative measurement of fibre length, diameter, thickness, lumen diameter and vascular bundle size (length and width) were made from the slides using an optical microscope (Olympus). The distributions of vascular bundles were determined by counting the number of vascular bundles on a cross-section per mm^2. The fibre wall thickness was obtained as below:

Fibre wall thickness = (Double wall thickness-lumen width)/2
A total of 60 unbroken fibres were measured and averaged for analysis.

Determination of the physical properties, MOR and MOE

Physical properties were tested using the Indian Standards (Anonymous, 1976). Samples of size 20 mm x 20 mm x culm wall thickness were obtained from the basal portion (locations 2 and 3), middle portion (locations 10 and 11) and top portion (locations 18 and 19), comprising both nodes and internodes for analyses of moisture content, density and shrinkage from green to oven-dry. A total of 90 specimens were used in the study.

The moisture content was determined by green to oven-dry weight method using the equation :

$$MC(\%) = \left(\frac{W_i - W_o}{W_o} \right) \times 100 \qquad \text{[Equation 1]}$$

Where W_i = initial weight of sample, g W_o = oven-dry weight of sample, g

Density was determined on the basis of the oven-dry weight to green volume basis. The green volume of each block was obtained using the water displacement method. The sample blocks were oven dried for 48 hours at 103±2° C until constant weights were attained. The samples were cooled in a desiccator and oven-dry weight obtained. The basic density was calculated using the following equation:

$$\text{Density } (kg/m^3) = \frac{W_o}{V_g} \qquad \text{[Equation 2]}$$

Where W_o = oven-dry weight (kg) V_g = green volume, (m^3)

The radial, longitudinal, tangential sections of each sample were marked and measured using a digital vernier calipers to the nearest 0.01 mm. All samples were placed in an oven maintained at 103 ± 2º C for 48 h and the shrinkage test was conducted during progress from the green to the oven-dry conditions and then shrinkage was calculated using the equation:

$$S_o(\%) = \left(\frac{D_i - D_o}{D_i} \right) x100 \qquad \text{[Equation 3]}$$

Where S_o = shrinkage from green to oven-dry conditions, D_i = initial dimension (mm) and D_o = oven-dry dimension (mm).

For MOR and MOE the split samples were air-dried in the shade for about a month and then conditioned for two weeks in a conditioning room at 65% relative humidity and 20º C. Then, samples of 300 mm by 20 mm size were prepared. This material was obtained from the basal, middle, and top portions of the bamboo culm from locations 4 to 8, 12 to 17 and 20 to 25 and comprised both nodes and internodes. A total of 60 specimens were used in this study. A 100 KN Shimadzu testing machine was used and testing was performed with central loading and a cross-head speed of 0.65 mm/ sec. with two supports over a span of 140 mm. The samples were tested in accordance with the procedure described by Gnanaharan *et al*. (1994) as per Indian Standard Methods of Test for Split Bamboos (IS 8242:76, Anonymous, 1976).

Statistical Analysis

One-way analysis of variance (ANOVA) was conducted to determine whether or not the differences in means were significant. If the differences were significant, the least significant difference (LSD) test was used to determine which of the means were significantly different from one another.

RESULTS AND DISCUSSION

Anatomical properties

Table 1 presents the anatomical properties of the bamboo which include the fibre morphology, vascular bundle size and percentage along the culm height and also the mean value of these properties between the internode and nodal portions. The fibre length, width, thickness, and lumen diameter for both the nodes and internodes of *S.brachycladum* decreased significantly at ($p \leq 0.05$) from the basal to the top of the culm. Similar findings were reported by Razak *et al*. (2010) and Wang *et al*. (2010) in

Table 1. Anatomical properties of *Schizostachyum brachycladum* (Buluh lemang) nodes and internodes at three height levels

Positions	Fibre morphology								Vascular bundle					
	Fibre length (μm)		Fibre diameter (μm)		Lumen diameter (μm)		Cell wall thickness (μm)		No/mm^{2}		Width (μm)		Length (μm)	
	I	N	I	N	I	N	I	N	I	N	I	N	I	N
Base	3195^{a}	2124^{a}	25.60^{a}	25.90^{a}	6.40^{a}	8.93^{a}	10.10^{a}	9.02^{a}	14^{a}	22^{a}	718^{a}	968^{a}	620^{a}	716^{a}
	(556.9)	(354.6)	(3.67)	(4.38)	(4.53)	(6.13)	(2.65)	(2.23)	(6)	(8)	(104)	(118)	(123)	(112)
Middle	2758^{b}	1962^{b}	22.93^{b}	22.20^{b}	6.93^{a}	5.03^{b}	9.00^{b}	8.38^{b}	14^{a}	24^{a}	699^{a}	833^{b}	633^{a}	700^{a}
	(467.9)	(454.3)	(2.68)	(3.13)	(4.53)	(1.92)	(2.36)	(2.86)	(6)	(8)	(93.5)	(96.0)	(121)	(95.7)
Top	2566^{c}	1907^{b}	22.67^{b}	21.77^{b}	5.97^{a}	4.50^{b}	8.43^{b}	8.07^{b}	16^{a}	30^{b}	629^{b}	716^{b}	586^{b}	567^{b}
	(493.6)	(276.1)	(4.05)	(3.57)	(4.23)	(1.59)	(2.13)	(2.56)	(8)	(6)	(55.1)	(85.0)	(86.7)	(54.5)
Mean	2840	1998	23.73	23.29	6.43	6.15	9.18	8.49	15	25	682	839	613	661

Values in parentheses are standard deviations. Cell values differing by a letter in the superscript in each column are significantly different at the 0.05 probability level. I = Internode, N = Node.

Bambusa vulgaris and *Phyllostachys pubescens***.** The finding that the highest fiber length values were found in the basal and middle of the bamboo culm might be due to the long internodes in this portion. As shown in Table 2, the highest internode length value was found in the basal and middle portion while the shortest internode was found at the top of the culm. This is supported by the finding of Weicheng *et al.* (2010) that the mean value of fibre length of an internode was correlated with the internode length in *Oxytenanthera braunii*. On the other hand, the fibre diameter, thickness, and lumen width tend to decrease towards the top of the culm. According to Liese (1998), the fibres are generally thicker in the basal portion than in the middle and top portion of the bamboo culm. The mean values of fiber length, thickness, and lumen diameter were higher at the internode than at the node portion (Table 1). Similar results were reported by Liese (1987) and Weicheng *et al.* (2010) in *Phyllostachys edulis* and *Oxytenanthera braunii*. However, the results show that the fiber diameters were not significantly different (P=0.05) between the internode and node portion of the bamboo culm. The short fibers at the nodes may be related to fiber forking and also the distortion of the vascular bundles.

The highest mean percentage of vascular bundles was observed at the top portion of bamboo culm followed by the middle portion while the lowest percentage of vascular bundles were found at the basal portions, both in the nodes and internodes (Table 1). This finding is probably related to the decrease in culm wall thickness from the basal to the top of the bamboo culm as shown in Table 2. Similar results were obtained by Grosser and Liese (1971) and Abd Latif *et al*. (1992) who mentioned that the vascular bundles percentage was higher at the top portion are mainly due to tapering of the bamboo culm towards the top portions. The vascular bundle size decreased significantly towards the top in the nodes and internodes (Table 1), which can also be related to the gradual reduction in the culm wall thickness (Liese, 1998). However, according to Abd Latif and Mohd Tamizi (1992) the reason for high vascular bundle sizes near the

Table 2. Internode length and culm wall thickness in the three height levels

Positions	Internode length	Culm wall thickness
Base	57.70[a]	7.48[a]
	(3.13)	(1.44)
Middle	56.50[a]	5.56[b]
	(4.88)	(1.09)
Top	43.12[b]	4.19[c]
	(12.49)	(0.91)
Average	52.44	5.74

Values in parentheses are standard deviations. Cell values differing by a letter in the superscript in each column are significantly different at the 0.05 probability level.

basal region is the abundance of matured tissues there. The size and percent values of vascular bundles were found higher at the nodes than at the internodes as shown in Table 1. According to Hamdan (2004), this result can be explained by the thicker culm walls of the nodes than of the internodes. Besides that, the higher mean values of vascular bundle size at the nodes may be described to distortion of the vascular bundles at this portion.

Physical properties, MOR and MOE

The trend along the culm height and the mean value between the node and internode for physical properties, MOR and MOE of *S. brachycladum* are shown in Table 3. The results reveal that the differences in moisture content (MC) between the three studied heights are the same in the nodes and internodes where the MC decreases from the basal of the bamboo culm to its top. Anwar *et al*. (2005) and Kamruzzaman *et al*. (2008) reported similar findings for the MC in *G. scortechnii* and *Bambusa balcooa*. According to Abd. Latif and Mohd Zin (1992), the reason behind this phenomenon is related to the decrease in culm wall thickness from the basal to the top of the bamboo culm. The high culm wall thickness at the basal position corresponds to a high percentage of parenchyma tissues that contribute to water storage, ultimately leading to high MC at the basal portion of the culm. The fact that the lowest value of MC was observed at the top portion is explained by the low amount of parenchyma tissues at the top portion of the bamboo culm. The highest MC value was observed in the internode (93.07%) whereas, the MC of the node was only 69.9%. This finding also can be associated with the higher percentage of parenchyma tissues at the nodal area than at the internode portion (Liese, 1998).

The density of *S. brachycladum* is inversely related to MC, the density increased towards the top of bamboo culm in both the nodes and internodes. Increases in the density values from basal to top were also observed in *Phyllostachys pubescens* (Wang *et al.,* 2010) and *Guadua angustifolia* (Correal *et al*., 2010). This result may be associated with the higher value of vascular bundles, coupled with the increases in the silica content, in the same direction (Liese, 1987; Abd Latif and Mohd Tamizi,

Table 3. Physical and strength properties of *Schizostachyum brachycladum* (Buluh lemang) nodes and internodes at three height levels

Positions	Density (kg/m^3)		Moisture content (%)		Shrinkage from green to oven dry (%)						Modulus of rupture (N/mm^2)		Modulus of elasticity (N/mm^2)	
					Radial		Longitudinal		Tangential					
	I	N	I	N	I	N	I	N	I	N	I	N	I	N
Basal	550.03^{b}	555.71^{b}	106.29^{a}	90.62^{a}	10.76^{a}	8.90^{a}	0.90^{a}	0.57^{a}	8.13^{a}	6.05^{a}	208.37^{b}	140.30^{a}	15817^{a}	12119^{a}
	(82.69)	(72.56)	(18.37)	(12.67)	(0.84)	(2.91)	(0.35)	(0.09)	(0.84)	(1.12)	(20.40)	(21.59)	(2387)	(3139)
Middle	596.53^{a}	701.22^{a}	88.76^{b}	64.19^{b}	7.43^{b}	6.74^{b}	0.35^{b}	0.38^{b}	5.49^{b}	4.44^{b}	217.43^{b}	151.34^{a}	21540^{b}	17717^{b}
	(39.81)	(85.07)	(15.59)	(14.80)	(1.43)	(2.42)	(0.24)	(0.09)	(1.43)	(1.23)	(26.80)	(24.73)	(1415)	(1789)
Top	619.47^{a}	764.02^{a}	84.16^{b}	54.88^{b}	6.31^{c}	5.95^{b}	0.30^{b}	0.31^{b}	3.73^{c}	2.81^{c}	361.59^{a}	155.53^{a}	26051^{c}	22918^{c}
	(34.09)	(105.07)	(10.54)	(15.5)	(1.62)	(1.34)	(0.19)	(0.20)	(1.62)	(0.62)	(33.78)	(76.27)	(4291)	(2573)
Mean	588.68	673.65	93.07	69.90	8.17	7.20	0.52	0.42	5.78	4.43	262.46	149.06	20890	17368

Values in parentheses are standard deviations. Cell values differing by a letter in the superscript in each column are significantly different at the 0.05 probability level. I = Internode. N = Node.

1992). Besides, according to Correal *et al*. (2010) a high amount of schlerenchyma fibers at the top portion can also contribute to the high density at the top of the bamboo culm. Table 3 illustrates that the density of *S. brachycladum* is significantly higher at the node potion (673.65 kg/m^3) than at the internode portion (588.68 kg/m^3), probably due to short fibres and high lignin content at the nodal region (Liese, 1998). Furthermore, the high percentage of truncated vascular bundles at the node could have contributed to the high density of this bamboo part (Liese, 1998). Higher node than internode densities were also observed by Khabir *et al*. (1995) in *Dendrocalamus hamiltonii* and Hamdan *et al*. (2009) in *G. scortechinii*.

The result of radial, longitudinal, and tangential shrinkage from green to oven-dry condition are presented in Table 3. It can be seen (Table 3) that shrinkage value decreases from base to the top of the bamboo culm in the nodes and internodes. According to Liese (1998), the basal portion shrinks more than the other bamboo culm portions probably due to the presence of higher initial moisture content and to the lower number of vascular bundles in this portion. The radial, longitudinal, and tangential shrinkage mean values of the internodes were 8.17%, 0.52%, and 5.78%, respectively. On the other hand, the mean values of the radial, longitudinal, and tangential shrinkage in the nodes were 7.20%, 0.42%, and 4.43%, respectively. The lower shrinkage values for the nodes than for the internodes are probably due to the shorter fibers and distorted vascular bundles of the former than the latter (Khabir *et al*., 1995).

As regards to MOR and MOE, a tendency for increase in these properties was noticed along the culm height at the internode and nodal regions. This tendency is consistent with the results obtained with *Guadua bamboo* (Gnanaharan *et al*., 1994) and *Gigantochloa scortechinii* (Shahril and Mansur, 2009). On the other hand, the tendency for increases in MOR and MOE was accompanied by higher value in the amounts of vascular bundles. Besides that, the high mean density of the top portion might have influenced the increase in MOR and MOE towards the top of the bamboo culm. The values of MOR and MOE were higher at the internodes than at the nodes (Table 3). The mean values of MOR for the internodes and nodes were 262.46 N/mm^2 and 149.06 N/mm^2, respectively. On the other hand, the mean values of MOE were 20890 N/mm^2 for the internodes and 17368 N/mm^2 for the nodes. The presence of nodes decreased the MOR and MOE significantly. According to Shahril and Mansur (2009), the fiber length is a good predictor of MOR and MOE in the node location where the shortest fiber at nodes contributed to the lowest mean values of these properties. Besides that, the nodal region of bamboo culm is weak in strength due to high amount of lignin coupled with less amount of cellulose fibres. In addition to this, according to Liese (1998) the forked fibers and distorted vascular bundles that can be found mostly at the node area can be suggested as factors contributing to the reduction in the MOR and MOE values within the node area. Reduced MOR and MOE values at the node parts were also observed by Shahril and Mansur (2009) in *G. scortechnii* and by Mohd Tamizi (2009) in *G. wrayii*.

CONCLUSION

The results of the present study demonstrate that the fiber morphology; vascular bundle size; moisture content; and shrinkage from green to oven-dry decrease from basal to the top of the bamboo culm, both in the nodes and internodes. On the other hand, the opposite tendency was observed in the percentage of vascular bundles, density, MOR, and MOE. Higher mean values of density, and vascular bundle size, and percentage were observed at the nodes than the internodes while the opposite held true in the case of fiber morphology, moisture content, shrinkage, MOR, and MOE.

In conclusion, presence of nodes results in low strength and affects the end product of the bamboo. Significant differences in moisture content and density between the nodes and internodes constitute disadvantages for the use of bamboo as laminated material, as the variations result in inconsistencies within the whole composite board. In order to overcome these problems, the nodes should be removed from the bamboo for the production of particle boards and oriented strand boards (OSB). However, it would not be technically feasible or economically justifiable to remove the nodes when the material is to be used as laminated bamboo lumber or for manufacturing long, continuous composites. Therefore, other alternatives such as finger jointing techniques may be introduced to the system or the weak nodes should be arranged randomly throughout the composite system.

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