Variations in Moisture Content Affect the Shrinkage of *Gigantochloa scortechinii* and *Bambusa vulgaris* at Different Heights of the Bamboo Culm

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Malaysia has more than 50 species of bamboo, but few that are utilized commercially. In this study, the physical properties of two of the most popular bamboo species in Malaysia, *Gigantochloa scortechinii* and *Bambusa vulgaris*, were evaluated. Moisture content (MC) and shrinkage variation at different height sections at both nodal and internodal categories of the bamboo culm were investigated. A comparison between the height sections and between the nodal and internodal categories, as well as between the species, was carried out. Results indicated a trend of decreasing MC along the culm from base to top, though the difference was not statistically significant. It was also observed that radial shrinkage was slightly greater than tangential shrinkage and was much greater than shrinkage in the longitudinal direction. Nodes appeared to have lower MC and a higher percentage of shrinkage compared to internodes. The shrinkage pattern of the two species of bamboo showed a small radial-to-tangential ratio of 1.15:1, which may have contributed to the dimensional stability of bamboo.

Keywords: Bamboo; Node; Internode; Moisture content; Shrinkage

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INTRODUCTION

Bamboo has been identified as one of the most important non-timber forest products and is considered to be an appropriate alternative to timber in this era of fast reduction of wood supply from the forest. Bamboo has a very fast growth rate and can replenish itself after harvesting (Anwar *et al.* 2009, 2011; Lima *et al.* 2012; Hernandez-Mena *et al.* 2014). Compared with wood, bamboo has a higher strength to weight ratio, which facilitates the harvesting, transporting, and manufacturing of products.

In the Malaysia peninsula, bamboo represents about 50 species in 11 genera, but only 13 species are currently utilized (Hamdan *et al.* 2009). Research has been carried out to improve the quality of utilization and the use of value-added products that can be competitively manufactured from bamboo. Restrictions in processing and utilization are often related to unsuitable properties. Therefore, a thorough understanding of the relationships between structures, properties, and behavior in processing and qualities is necessary for promoting the utilization of bamboo.

The high potential of bamboo and its versatile characteristics have opened a wide area of study (Gonzalez *et al.* 2002). The special natural characteristics of bamboo have attracted attention for the utilization of bamboo as a raw material in wood-based industries. There are many factors influencing the quality and possibility of bamboo to be utilized widely and commercially as an alternative material to wood. These factors include the physical and mechanical properties. There are only a few species of local bamboo that have been used commercially in the industry because there is limited basic information on the properties of different bamboo species.

Currently, bamboo is considered to be a very versatile material by the industry. It has been utilized commercially to make high-value added products such as panels, parquets, furniture, and construction materials with extremely high viability and an internal rate of return (IRR) varying from 27 to 30% (depending on the scale of manufacturing and cost of raw materials) (Pande and Pandey 2008). As a result of its excellent tensile strength (Nordahlia *et al*. 2011), bamboo can be used in manufacturing value-added products such as laminated bamboo, ply bamboo, and cross-laminated bamboo. In Asian countries, laminated bamboo is used in low-rise buildings, short-span footbridges, and construction platforms (Chung and Yu 2002). Bamboo has been chosen to be used as raw material in construction because it is readily available and environmentally friendly (Yu *et al*. 2011)

It is expected that nodes have negative effects on the strength, shrinkage, processing, and appearance of bamboo materials. However, there is little or very limited information about the variation of properties between the node and internode. In this study, we evaluate the variations in MC and shrinkage between the nodes and internodes along the culm of *Gigantochloa scortechinii* and *Bambusa vulgaris*. The interaction between MC and shrinkage of the two species was also evaluated. These properties are very important, as they affect the dimensional stability and the strength of the material. The results obtained in this work will help to increase the utilization of these two bamboo species as ready raw materials that can substitute for solid wood in the wood-based industry and provide a sustainable supply of raw materials in the future.

MATERIALS AND METHODS

Preparation of Materials

In this study, culm sections of five 4-year-old samples of *G. scortechinii* and *B. vulgaris* were extracted randomly from selected clumps around the Universiti Putra Malaysia campus at Serdang, Malaysia. The mature culms were selected based on the characteristics specified by Abd Razak *et al*. (2012). The culms were cut 30 cm above the ground level and 9 m of length were taken, while the remaining upper portion was discarded due to its small diameter and thin wall. Each sample was subsequently subdivided into three equal portions, labelled bottom, middle, and top. Each portion was immediately separated into nodes and internodes for the various tests.

Moisture Content Determination

As many as 20 replicates for each condition (2 species, 3 portions, and 2 categories) were cut from the four culms for MC determination with the samples sized 20 mm x 20 mm x culm wall thickness (mm). The samples' initial weight (W_i) was taken. The samples were then oven-dried at a temperature of 103 ±2 ºC until reaching constant weight (W_o). The MC was calculated using Eq. 1,

$$MC\ (\%) = 100\% \times [W_i - W_o] / W_o \qquad (1)$$

where W_i is the initial weight before drying (g) and W_o is the oven-dried weight (g).

Preparation of Shrinkage Samples

Shrinkage for each condition (2 species, 3 portions, 2 categories) was tested on round and strip samples. Tangential and longitudinal shrinkages were measured from the round-shaped node and internode of 20 mm and 50 mm long, respectively. Tangential, radial, and longitudinal shrinkages on an internode strip of 20 mm x 20 mm x culm wall thickness (mm) were tested for comparison. As many as 20 replicates were prepared for each type of sample.

Shrinkage Determination

The round node and internode samples were dried in an oven at 103 ±2 ºC until reaching a constant weight. The final dimensions were then recorded to determine the percentage shrinkage of the culm longitudinally and tangentially (circumference) on the outer periphery using Eq. 2,

$$\text{Shrinkage (\%)} = 100\% \times [D_i - D_f] / D_i \quad (2)$$

where D_i is the initial dimension before oven drying (mm) and D_f is the final dimension after oven drying (mm).

Another set of strip samples was dried in an oven until reaching a constant weight, after which the final dimensions were recorded in the tangential, radial, and longitudinal directions. The percentage of shrinkage for each dimension was then calculated using Eq. 2.

Statistical Analysis

The data were analyzed statistically to assess significant differences within the section (basal, middle, and top) and category (internodes, node) of the culm in terms of MC and shrinkage using SPSS statistical tool. Regression analysis was performed to determine the relationship between MC and the position along the culm height of the two bamboo species. The MC and shrinkage were analyzed using analysis of variance (ANOVA).

RESULTS AND DISCUSSION

The MC and shrinkage of the bamboo among the three sections and the two categories for the two bamboo species are presented in Table 1. Tables 2 through 4 show statistical analysis of MC and shrinkage for the two species.

Green Moisture Content

The MC results for *G. scortechinii* and *B. vulgaris* for internodes and nodes of the culm (Table 1) showed the same trend, a decrease from the basal section to the top, although the ANOVA showed no significant differences (Table 2). Hamdan *et al.* (2009) found similar trend to elaborate the initial work of Hamdan (2004).

Table 1. Mean Moisture Content and Shrinkage of Nodes and Internodes for *G. scortechinii* and *B. vulgaris*

Species	Section	MC (%)		Shrinkage (%)						
				Round culm				Strip		
				Longitudinal (L)		Circumference (C)				
		Node	Internode	Node	Internode	Node	Internode	Tangential (T)	Radial (R)	Longitudinal (L)
G. schortechinii	Basal	90.71	95.66	1.98	0.24	4.34	6.47	7.13	8.1	0.11
		(14.33)	(36.80)	(1.03)	(0.04)	(0.59)	(0.67)	(2.47)	(3.04)	(0.12)
	Middle	82.7	87.25	2.66	0.27	4.47	6.37	11.33	7.75	0.13
		(13.52)	(23.53)	(3.39)	(0.26)	(0.72)	(0.70)	(3.79)	(1.85)	(0.04)
	Top	76.25	84.37	2.88	0.30	5.29	7.72	11.47	5.82	0.19
		(12.34)	(14.19)	(3.71)	(0.12)	(1.47)	(3.53)	(1.21)	(3.48)	(0.15)
	Mean	**83.22**	**89.09**	**2.5**	**0.27**	**4.7**	**6.85**	**9.98**	**7.22**	**0.14**
B. vulgaris	Basal	95.80	99.99	1.07	0.56	10.58	12.32	7.46	6.26	0.19
		(23.17)	(33.38)	(0.66)	(0.12)	(3.01)	(4.19)	(2.35)	(6.26)	(0.11)
	Middle	94.10	95.05	1.54	0.72	10.50	13.63	10.29	11.29	0.23
		(29.47)	(27.50)	(1.42)	(0.45)	(3.11)	(3.59)	(2.34)	(2.2)	(0.19)
	Top	85.02	92.81	0.52	0.49	10.95	12.11	12.38	11.9	0.2
		(19.40)	(37.28)	(0.30)	(0.27)	(2.92)	(2.08)	(6.25)	(5)	(0.11)
	Mean	**91.64**	**95.95**	**1.34**	**0.59**	**10.68**	**12.69**	**10.04**	**11.57**	**0.21**

Note: Values in parenthees are standard deviation

Table 2. ANOVA of Moisture Contents of *G. scortechinii* and *B. vulgaris*

Species	Variable	F value	P value
G. scortechinii	Section	0.493^{ns}	0.618
	Category	2.374^{ns}	0.139
B. vulgaris	Section	0.131^{ns}	0.878
	Category	0.146^{ns}	0.707

Note: ^{ns} indicates no significant different at $p > 0.05$, * indicates significance different at $p < 0.05$, ** indicates significance different at $p < 0.005$, and *** indicates significance different at $p < 0.0001$.

Table 3. ANOVA of Culm Shrinkage among the Section of Sample for Different Species, Categories, and Directions

Species	Category	Direction	F value	P value
G. scortechinii	Nodes	L	4.409*	0.044
		C (T)	1.051ns	0.389
	Internodes	L	172.525***	0.0001
		C (T)	0.508ns	0.618
B. vulgaris	Nodes	L	1.229ns	0.337
		C (T)	0.025ns	0.975
	Internodes	L	0.699ns	0.522
		C (T)	0.233ns	0.797

Note: ns not significant, $p > 0.05$, * significant up to 95%, $p < 0.05$, ** significant up to 99.5%, $p < 0.005$, *** significant up to 99.99%, $p < 0.0001$, L: longitudinal, C: circumference, T: tangential

Table 4. ANOVA of Strip Shrinkage among the Section of Sample for Different Species and Directions

Species	Direction	F value	P value
G. scortechinii	L	172.525***	0.0001
	T	3.733ns	0.066
	R	1.046ns	0.390
B. vulgaris	L	0.243ns	0.789
	T	0.102ns	0.904
	R	0.507ns	0.618

Note: ns not significant, $p > 0.05$, * significant up to 95%, $p < 0.05$, ** significant up to 99.5%, $p < 0.005$, *** significant up to 99.99%, $p < 0.0001$, L: longitudinal, T: tangential, R: radial

Generally, internodes presented slightly higher MC than the nodes for both species. The MC decreased along the culm from basal sections to the top sections, with *B. vulgaris* internodes recording the highest (99.99%) and *G. scortechinii* the lowest (76.25%). Khabir *et al.* (1995) reported a similar trend in other species of bamboo (*Dendrocalamus hamiltoni),* while Bakar *et al.* (2008, 2013) and Dungani (2013) observed a similar trend for oil palm trunk (OPT) and attributed it to the increasing vascular bundle proportion and decreasing parenchyma tissue proportion from the base to the top. Bamboo has a similar anatomical structure with a higher presence of vascular bundles than parenchyma cells that serve as a site for water storage (Nahar and Hassan 2013) in the internodes than nodes, which may contribute to the higher MC in the internodes. The decreasing trend from the base to the top might be due to the smaller proportion of vascular bundles at the basal section compared to the top section. Lo *et al.* (2004) reported that the highest mean concentration of vascular bundles was observed at the top location, regardless of the age of culm. The higher density of vascular bundles at the top portion of bamboo has also been explained by Grosser and Liese (1971) as a result of the decrease in culm thickness. Nevertheless, the MC variation along the culm was not significantly different among the basal, middle, and top sections.

Compared to the work of Hamdan (2009), the MC results recorded were slightly lower. However, Anwar *et al.* (2005) also had similar results, which were lower than those obtained by Hamdan *et al.*, even though the samples came from the same location. Liese (1985) reported that a difference in MC might occur with season.

Regression analysis (Fig. 1) showed a strong linear relationship between MC and the section (Hamdan *et al*. 2009) of the two bamboo species. The coefficients of determination for both node and internode of the two species were found to be between 0.865 and 0.996. The negative relationship indicated a decrease in MC with culm height, which occurred in the node and internodes of both species. The higher MC present in the internode than in the node may have been due to the higher percentage of conducting tissues occurring in the internode than the node (Florian *et al.* 1991). This feature would greatly affect the seasoning and penetration of preservatives in the node.

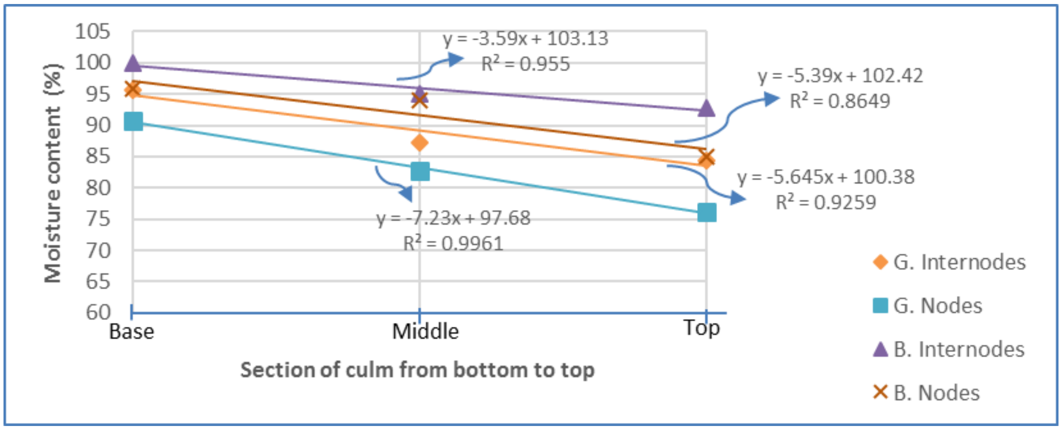

Fig. 1. Moisture content of green *G. scortechinii* and *B. vulgaris* at node and internode along the culm height

Shrinkage

Figure 2 shows the mean shrinkage of nodes and internodes for *G. scortechinii* and *B. vulgaris* along the culm height. The longitudinal shrinkage increased from basal to the top for both species and on both node and internode, except the *B. vulgaris* top, which dropped by a slight margin in both node and internode. The longitudinal shrinkage had mean values of 2.5% and 0.27% at the node and 1.34% and 0.59% at the internode for *G. scortechinii* and *B. vulgaris*, respectively. The percentage of shrinkage of the node was observed to be four times that of the internode. This may be due to a higher presence of reinforced fibers, which are common in the internodes but run almost randomly in the nodes (Amada and Untao 2001). Nordahlia *et al.* (2011) found similar results for *Shizostachyum brachycladum*, which they attributed to the short fibers and high lignin content in the nodal region.

Circumferential shrinkage, which we measured as the tangential shrinkage, showed a trend similar to that of the longitudinal shrinkage for the three sections, as the basal section recorded the lowest shrinkage compared to the middle and top sections (Fig 2) in both node and internode. It is possible that the shrinkage differences are related to differences in density in the three sections. Pliura *et al.* (2005) found a negative correlation between wood density and longitudinal shrinkage and positive correlations between density and both radial and tangential shrinkages, suggesting that selection for high wood density may lead to increased transverse wood shrinkage but decreased longitudinal shrinkage (Abd. Latif *et al.* 1993; Yu *et al.* 2008; Erakhrumen and Ogunsanwo 2009).

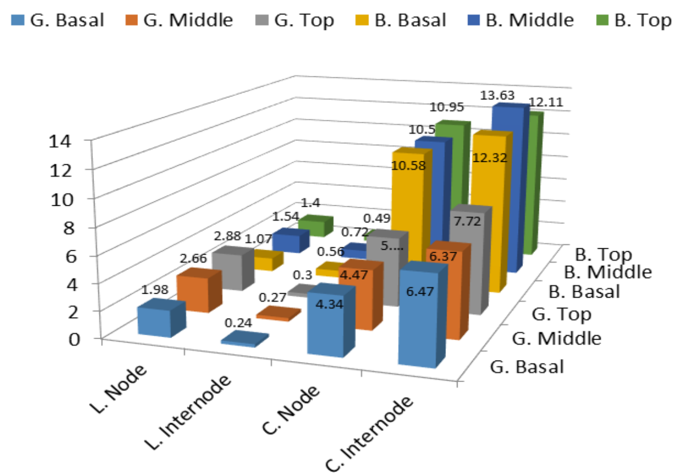

Fig. 2. Comparison of shrinkage (longitudinal (L) and circumference (C)) between *G. scortechinii* and *B. vulgaris* along the culm height

Across the culm wall, the fiber length often increases from the periphery toward the middle and decreases toward the inner part. More parenchyma but fewer fibers and conducting cells were found in the inner part of the culm wall than in the periphery (Razak *et al*. 2010). This structure causes the culm to have higher stress at the inner region, which causes the outer part of the culm to shrink toward the inside, resulting in some of the bamboo culm splitting during the drying process.

Another possible reason for the shrinkage difference in the circumference and the longitudinal directions is the difference in concentration of nanograins, found to be closely packed longitudinally in the cell wall, which is longitudinally reinforced strongly at the internode and randomly at the node (Amada *et al*. 2001). This fiber irregularity in the node section is also expected to adversely affect the strength and machinability of the section.

Table 1 shows the mean shrinkage (L, R, and T) of strip samples between the three sections, two categories, and two species. The shrinkage increased from the base to the top in all three axis directions, except for the tangential direction of the *G. scortechinii*, which showed an opposing trend. The radial shrinkage was higher than the tangential, although the difference was not significant. The shrinkage trend was inversely proportional to the MC trend along the culm height. This indicates that the MC has a close correlation to the shrinkage of bamboo.

The results also show that the internode strips tended to shrink slightly more in the radial direction compared to the tangential and longitudinal directions. This is similar to the trend discovered by Liese (1985) with *Phyllostachys pubescens.* The percentage of shrinkage in the radial direction (Fig. 3) was slightly higher than the percentage of shrinkage in the tangential direction. The top section still had the highest percentage of shrinkage in the radial direction. The same pattern was exhibited in both species.

The shrinkage properties of bamboo are also influenced by the anatomical structure of the bamboo. The dimensional changes shown by bamboo occur in timber as well. This behaviour occurs in timber because most of the microfibrils (S2 layer) are

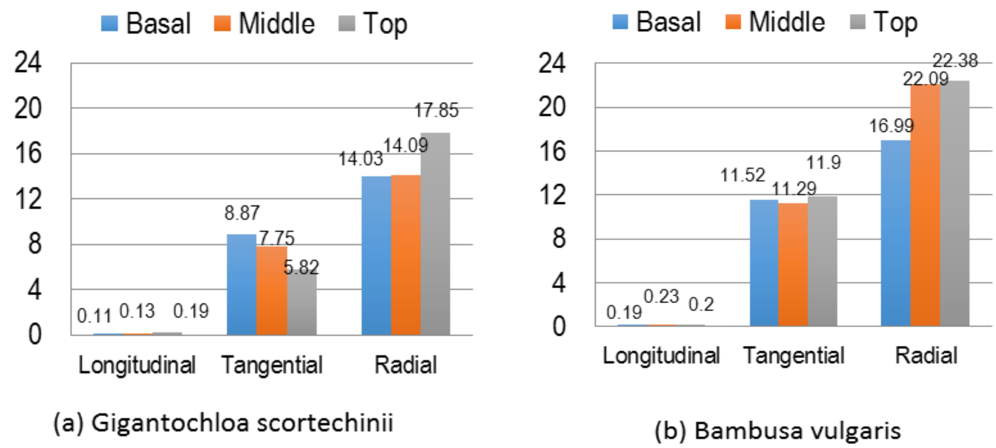

Fig. 3. Mean shrinkage of strips for *G. scortechinii* and *B. vulgaris*

aligned parallel to the longitudinal axis. The explanation for this behavior also applies to bamboo. According to Liu *et al.* (2012), there are two types of microfibril orientations in bamboo; narrow lamellae show a large microfibril angle of 85 to 90º with respect to the axis, and broader ones have angles almost parallel to the axis. Although the fibers in bamboo demonstrate a polylamellate nature (8 lamellae compare to 3 lamellae in wood (S1, S2, and S3), the broad fibril layer parallel to the axis is greater when compared to the narrow lamellae.

CONCLUSIONS

1. The MC for both nodes and internodes for the two bamboo species decreased along the culm from the base to the top section.
2. Nodes present along the culm generally had lower MC compared to internodes.
3. From the dimensional changes or shrinkage of the strips tested, it is clear that the MC and the anatomical characteristics of bamboo influenced the shrinkage behavior of bamboo.
4. The shrinkage pattern of the two species of bamboo studied also revealed that the radial directions tending to shrink slightly more compared to the tangential directions, with a ratio of 1.15: 1. This minimal differential radial and tangential shrinkage contributes to the dimensional stability of bamboo.

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