

Morphological Characteristics of *Bambusa vulgaris* and the Distribution and Shape of Vascular Bundles therein¹

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ABSTRACT

Bamboo culm comprises internodes and nodes and is tapered from the bottom to the top. Anatomically, bamboo culm comprises vascular bundles and parenchymal base tissue. The gross anatomical structure of a transverse section of any culm internode is determined by the shape, size, arrangement, and number of vascular bundles. The purpose of this research was to examine the morphology of culm and the distribution and shape of vascular bundles in Ampel bamboo (*Bambusa vulgaris*). Bamboo culms were harvested from the base. Test samples were obtained from a central 2-cm long segment of each internode across the entire length of the culm. Results showed an uneven spread of vascular bundles in the internode cross-section. Transitioning from the outer to the inner layer of the internode, the number of vascular bundles per unit area decreased and their shape was variable. The size of vascular bundles in the middle layer of the internode was greater than that of those in the outer and inner layers. The shape of vascular bundles was circular in the outer layer, which gradually transformed into vertical oval toward the middle layer and horizontal oval toward the inner layer. Vascular bundles were of type III and IV in the bottom of the culm and type III in the middle to the top of the culm.

Keywords: *Bambusa vulgaris*, internode length, morphology of culm, distribution and shape of vascular bundles

1. INTRODUCTION

Bamboo grows naturally in tropical and subtropical regions (Gratani *et al.*, 2008). It is a very fast growing plant (Liu *et al.*, 2012), with a uniform culm growth of 60 mm per day (Bui *et al.*, 2017). Bamboo plants reach maturity and are ready for use within 3-5 years (Troya and Xu, 2014). In Indonesia, bamboo is mostly cultivated in Java, Bali, and Sulawesi (Widjaja, 2001). It is consumed as a medicine (Kim *et al.*, 2014) as

well as food and is also used as a raw material for making furniture, buildings (Kaminski *et al.*, 2016), household equipment, handicrafts (Maulana *et al.*, 2017), and musical instruments (Kang *et al.*, 2017). Additionally, bamboo is one of the most promising alternative raw materials for manufacturing composite panels (Roh *et al.*, 2004). It is more commonly used as a building material in the rural society. Because bamboo is easily available, it is relatively cheap. Bamboo is not only a versatile resource for the livelihoods of

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people but also reduces the impact of and adaptation to climate change (Wu *et al.*, 2015).

A total of 143 bamboo species have been reported to grow in Indonesia (Widjaya, 2001). Bamboo plants native to Southeast Asia exhibit a pachymorph rhizome system wherein each rhizome has short internodes and an apex that continues to grow into a culm (Dransfield and Widjaya, 1995). Bamboo culms are usually arranged close together, forming a densely tufted (sympodial) clump. The bamboo clump expands centrifugally, with young culms on the outside surrounding the older culms (Banik, 2015).

Ampel bamboo (*Bambusa vulgaris*) is a type of bamboo that is easy to find and grows well in Indonesia, particularly in Java. *B. vulgaris* grows in extreme dry and moist areas and has been reported to grow in waterlogged areas for 2-3 months. This bamboo culm can grow as high as 20 m (Widjaya, 2001). *B. vulgaris* grows in clumps and comprises several culms, gradually growing from shoots to mature culms. This bamboo culm is hollow, hard-walled, and conical at the end, indicating a different inner and outer diameter (cavities) and thick walls. The diameter and slat thickness of bamboo culms are determined when considering its use.

Anatomically, bamboo culm comprises vascular bundles and parenchymal base tissue. Vascular bundles comprise fiber caps or sheaths surrounding the conducting elements, including vessels, sieve tubes, and companion cells (Liu *et al.*, 2012), all of which affect bamboo characteristics (Liese, 1998). Reportedly, vascular bundles spread unevenly from the outer to the inner layer of the culm (Li, 2004). Moreover, the shape and size of vascular bundles in the culm are variable.

In the present study, we investigated the morphological characteristics of *B. vulgaris* culm and the distribution and shape of vascular bundles from the bottom to the top of the culm. The results of this study are invaluable for understanding the anatomical features of *B. vulgaris* and for preparing basic databases for different types of bamboo.

2. MATERIALS and METHODS

2.1. Plant material

Three-year-old *B. vulgaris* var. *vulgaris* samples with green culms were collected from the village of Sayang, District Jatinangor, Sumedang Regency, West Java

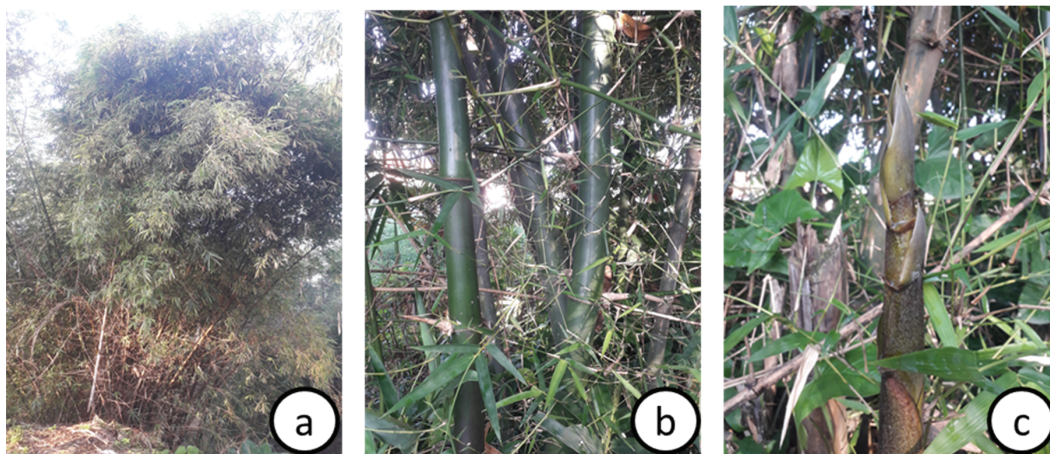


Fig. 1. Images of *B. vulgaris* var. *vulgaris* growing in West Java Province, Indonesia. These images show (a) clumps, (b) culms, and (c) shoots of bamboo.

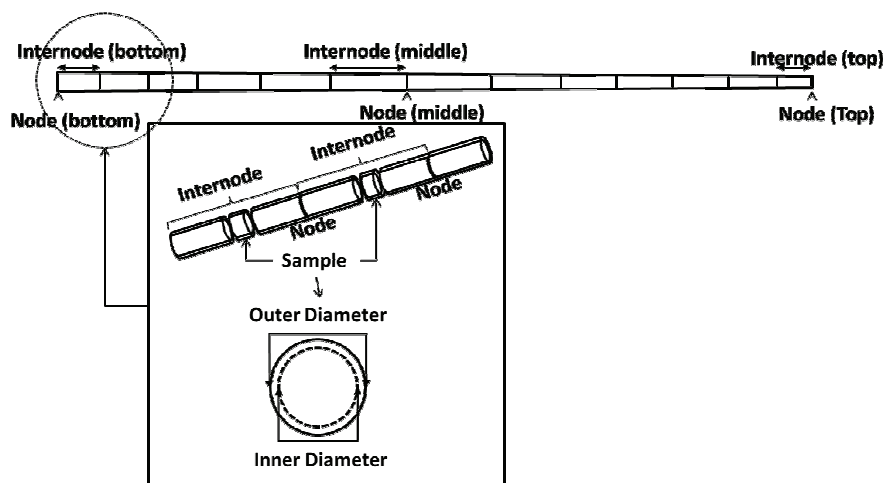


Fig. 2. Schematic representation of morphological culm measurements of *b. vulgaris* var. *vulgaris*.

Province, Indonesia (Fig. 1). Bamboo culms were harvested just above the roots, and branches on the culm were subsequently removed to obtain branchless culms.

2.2. Morphological characterization of bamboo culms

The length of each bamboo internode was measured from the base to the tip. The outer and inner diameters of each internode were measured from a central 2-cm long column-shaped area. The thickness of bamboo culm wall of each internode was calculated from the difference between the two diameters (Fig. 2).

2.3. Vascular bundle distribution in bamboo culm cross-section

To examine the distribution and shape of vascular bundles in bamboo, culm cross-sections were prepared using a sharp knife and observed under a Nikon SMZ 745T stereomicroscope, Nikon Corporation, Tokyo, Japan. Morphological data were analyzed using NIS-Elements v.4.00.00 imaging software. The number

of vascular bundles per unit area (VB/mm^2) was counted from the outer to the inner layer of the bamboo wall. The shape of vascular bundles was assessed by measuring the radial diameter (R) and tangential diameter (T) of each vascular bundle from the outer layer toward the inner layers. An R/T ratio of 1 indicated circular vascular bundles, whereas R/T ratios of <1 and >1 indicated oval lengthwise tangential and oval lengthwise radial vascular bundles, respectively. Stages of morphological observations of the culm and the distribution and shape of vascular bundles of *B. vulgaris* var. *vulgaris* are shown in Fig. 3.

3. RESULTS and DISCUSSION

3.1. Morphology of bamboo culm

Bamboo culm comprises nodes and internodes. Within a culm, the node appears as a diaphragm between the cavities. The internode, which is the region between two consecutive nodes, showed varying lengths. The mid-section of the internode was longer in size than the bottom and top sections (Fig. 4). These data are consistent with those recorded for other bamboo types

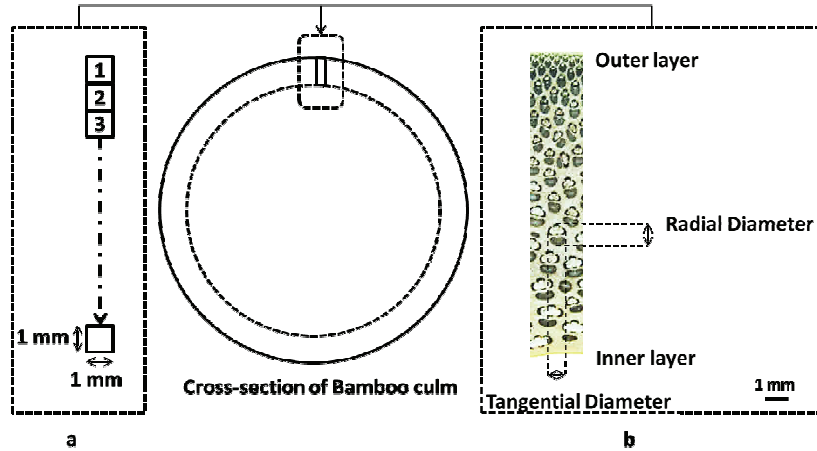


Fig. 3. Measurements of (a) the distribution and (b) shape of vascular bundles in *B. vulgaris* var. *vulgaris*.

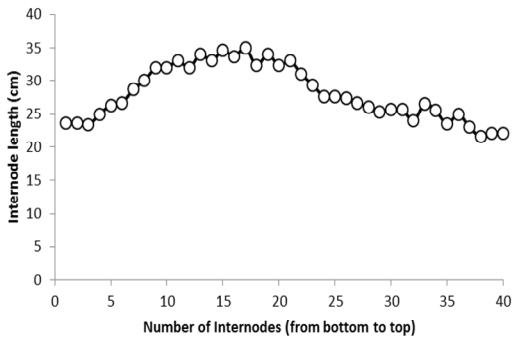


Fig. 4. Internode length of *B. vulgaris* var. *vulgaris* from the bottom to the top of the bamboo culm.

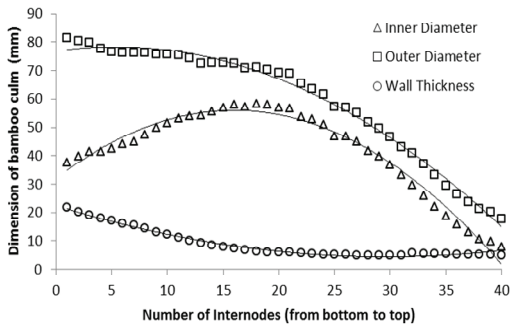


Fig. 5. Internode dimensions of *B. vulgaris* var. *vulgaris* culm from the bottom to the top.

(Dransfield and Widjaya, 1995). The shortest length has been reported for the lowest internodes of *Gigantochloa atter* (Marsoem *et al.*, 2015).

Additionally, the outer and inner diameters (cavities) of culm internodes, and consequently, the thickness of the culm wall were variable. The outer diameter of the bamboo culm decreased from the bottom to the top. The inner diameter of the mid-section of the internode was greater than those of the bottom and top sections. A reduction in the outer diameter of the culm from the bottom to the top resulted in the conical shape of the bamboo culm, causing the thickness of the culm wall to decrease from the bottom to the top (Fig. 5). Zakikhani *et al.* (2017) have reported similar results in other bamboo species.

3.2. Cross-sectional distribution, type and shape of vascular bundles in bamboo culm

Being a monocot plant, bamboo culm comprises vascular bundles and parenchymal base tissue. The culm cross-section showed an uneven distribution of vascular bundles. The density of vascular bundles is reportedly

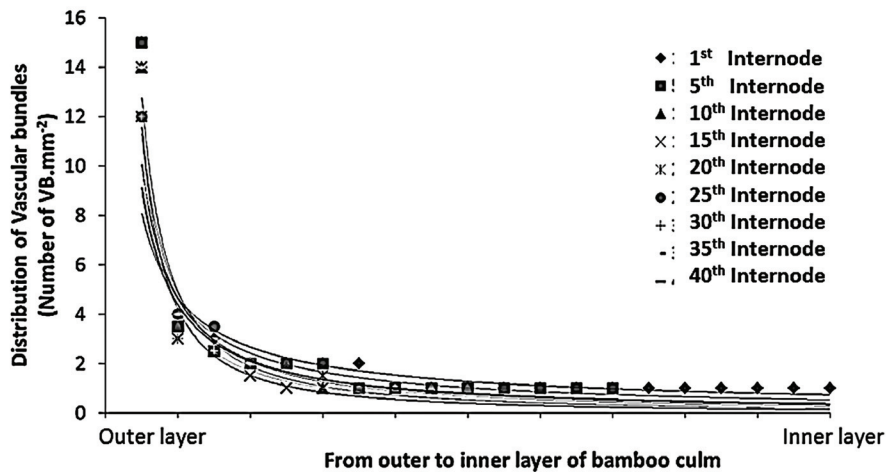


Fig. 6. Distribution pattern of vascular bundles in culm internodes of *B. vulgaris* var. *vulgaris* from the outer to the inner layer.

higher in the outer layer of the culm than in the inner layer (Jeon *et al.*, 2018). These data are consistent with the results of our study. We showed that the number of vascular bundles per unit area decreases from the outer to the inner layer (Fig. 6), and vascular bundles in the outer layer appear more dense/compact than those in the inner layer (Fig. 7). The number of vascular bundles per unit area of the internode also decreased from the bottom to the top of the culm (Fig. 6). Additionally, vascular bundles in the bottom internodes tended to be smaller in size than those in the top internodes of the bamboo culm (Fig. 7). Thus, the number of vascular bundles per unit area in the bottom internodes was greater than those in the top internodes. The distribution pattern of vascular bundles in bamboo was described as an exponential function, similar to the distribution of vascular bundles in oil palm trunk (Darwis *et al.*, 2013).

Bamboo culm cross-sections showed variability in the type of vascular bundles from the outer to the inner layer. The 1st, 5th, and 10th internodes contained two types of vascular bundles, type III and type IV, whereas the 15th-40th internodes contained only type III vascular

bundles (Fig. 7). Type III vascular bundles typically contain only one fiber sheath at the bottom of the main vascular bundle, whereas type IV vascular bundles contain two fiber sheaths, one above and the other below the main vascular bundle (Liese, 1998). The presence of different types of vascular bundles was influenced by the thickness of bamboo walls, which decreased from the bottom to the top. Varying sizes of vascular bundles in bamboo culm cross-sections have been reported previously, wherein vascular bundles in the outer layer appear smaller than those in the inner layer (Wahab *et al.*, 2009; Mustafa *et al.*, 2011).

In the present study, we measured the shape of vascular bundles as the R/T ratio. Vascular bundles were circular in the outer layer and gradually transitioned to an oval shape in the inner layer. With an increase in the value of R, vascular bundles gradually acquired an oval-like vertical shape toward the middle layer. In contrast, an increase in the value of T induced the vascular bundles to acquire an oval-like horizontal shape toward the inner layer (Fig. 8). Based on the R/T ratio, the vascular bundles in the bottom internodes were smaller than those in the top internodes.

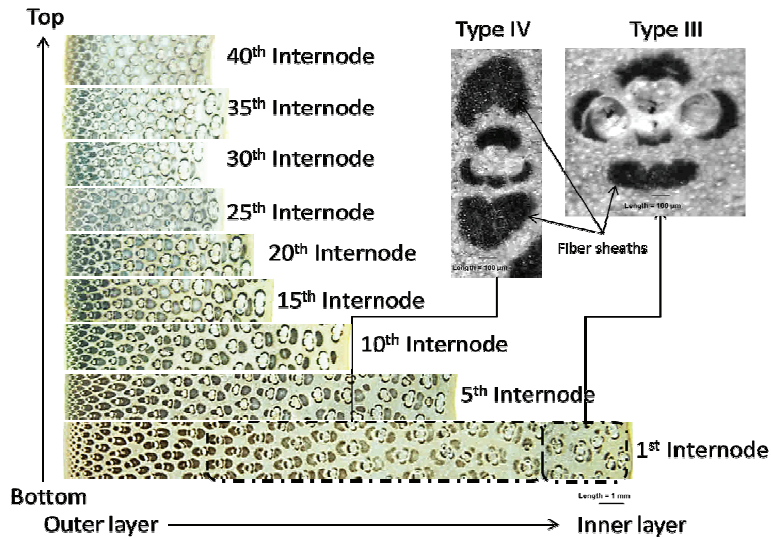


Fig. 7. Micrographs of vascular bundles in culm internodes of *B. vulgaris* var. *vulgaris* from the outer to the inner layer.

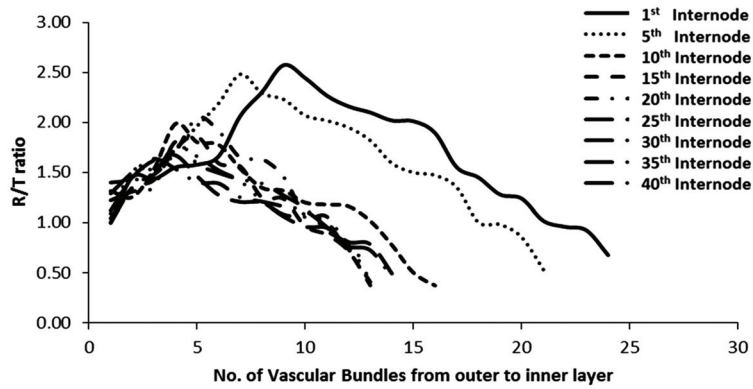


Fig. 8. Ratio of radial diameter (R) to tangential diameter (T) of vascular bundles from the outer to the inner layer of internode cross-sections of *B. vulgaris* var. *vulgaris*.

4. CONCLUSION

Bamboo culm compound internodes showed variable lengths and diameters. The length of the internode increased from the bottom to the mid-section and then

decreased toward the top. The conical shape of the culm indicated that the outer diameter decreased from the bottom of the culm to the top. The inner diameter of the mid-section of the bamboo culm decreased both toward the bottom and the top, resulting in decreased

thickness of the bamboo culm.

Vascular bundles, one of the main constituents of bamboo culm, were unevenly distributed at the cross-sections. Those in the outer layer appeared more dense/compact than those in the inner layer, and their distribution showed an exponential function graph. According to the R/T ratio, the shape of vascular bundles in culm cross-sections varied from circular to oval. Additionally, bamboo culms contained type III and IV vascular bundles at the bottom and type III vascular bundles at the middle and top.

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