

## Characterization of the Properties of Buluh Madu (*Gigantochloa albociliata*)

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Thirteen bamboo species are reported to be in commercial use in Malaysia. However, Buluh madu (*Gigantochloa albociliata*) did not make to the list. As a species, *G. albociliata* is cultivated for its delicious bamboo shoot and is demonstrated to possess great potential to produce commercialised products such as laminated bamboo panel. Unlike common bamboo, which has hollow cylindrical culms, *G. albociliata* has thick culms at the base, with smaller hollow cavities at the top portion. Therefore, it can be easily converted into high-thickness strips, thus improving the processing efficiency of laminated bamboo. To validate this theory, the anatomical, chemical, physical, and mechanical properties of *G. albociliata* were evaluated. The round bamboo and strips from the top and bottom sections of the bamboo stem were tested. It was found that *G. albociliata* has a vascular bundle type similar to that of the *Gigantochloa* genus bamboo. The fibre in *G. albociliata* is long and strong. The top section of bamboo has longer fibres, a higher density, and a higher specific gravity than the bottom section. As a result, bamboo from the top section has greater bending strength than bamboo from the bottom section. The *G. albociliata* species was discovered to have high mechanical strength, dimensional stability, and good wettability, making it an ideal material for laminated products.

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### INTRODUCTION

The bamboo area in Peninsular Malaysia is estimated to be 421,722 ha, or about 7% of the forest land. According to reports, only 13 bamboo species out of 59 found in Peninsular Malaysia, primarily from the *Bambusa*, *Gigantochloa*, and *Dendrocalamus* genus, are commercially used (Siam *et al.* 2019). Among these, only two species, which

are *G. scortechinii* and *G. levis*, have been widely reported to be suitable for the production of various panel products (Hanim *et al.* 2013). This is because the natural hollow cylindrical shape and thin wall of bamboo have prevented it to be used effectively, as converting the bamboo strip into an engineered bamboo panel would be time-consuming.

Buluh madu (*G. albociliata*) is a type of bamboo known for its delicious bamboo shoots. It is a native species to Thailand and Burma, where it is well known as “Phai rai” in Thailand and “Wa-hpyu-ka-le” in Burma (Duriyaprapan and Jansen 1995). It has been introduced to India and Indochina for agricultural and construction purposes. In Malaysia, *G. albociliata* was introduced and cultivated to fulfil the demand for honey bamboo shoots, as it is a favourite food of many, particularly in traditional Malay cuisine. This bamboo is utilized because harvesting requires only a short maturation period of about 8 months for the shoots and 3 to 4 years for the stems. The *G. albociliata* has advantageous characteristics for use as a construction material, with a height of 6 to 10 m, a long internode of 15 to 40 cm, and a thick culm of 1.5 to 3 cm (Johar Mohamed 2012). One of the most intriguing characteristics of *G. albociliata* is its thick culm wall when compared to other bamboo species. Thus, *G. albociliata* has advantages over other bamboo species as it can produce thick strips of > 20 mm. Theoretically, lamination efficiency improves, and less glue lines are required to achieve a specific thickness of the laminated panels.

Despite the potential shown by *G. albociliata*, a comprehensive study on the anatomical structure, fibre morphology, chemical structure, and physical and mechanical properties of the bamboo should be conducted. Understanding these characteristics is helpful in identifying appropriate processing techniques such as drying, preservation, and treatment procedures. The investigation into the chemical, physical, and mechanical properties of the bamboo species will provide information on the workability and glue spreading ability of the bamboo species were it to be used in the production of laminated panels. Thus far, no article reporting on the basic characteristics of *G. albociliata* has been published, to the best of the authors’ knowledge. Therefore, this study aimed to investigate the basic characteristics of *G. albociliata* and its potential in laminated panels production.

## EXPERIMENTAL

### Materials

Four-year-old *G. albociliata* was harvested from a plantation in Sik, Kedah. The harvested bamboo culm was divided into two parts: top and bottom. The bamboo’s bottom part begins one metre above the ground and extends to the first hollow internode. Meanwhile, the bamboo’s top is measured from the first hollow internode to the first branch of the stem. Most bottom parts of bamboo do not have a hollow round cavity (it is solid), and almost all top parts of bamboo have a hollow round cavity, with only a few having a cavity on one end and tapering to the other (no hole). The bamboo culm was used in its natural state and was designated as round bamboo. Meanwhile, the bamboo culm was run through a four-sided planer to obtain a 20 mm × 20 mm square strip. The properties of both round bamboo and strips were evaluated.

### Methods

#### *Determination of anatomical structure and fibre morphology*

The method outlined by Latif Mohmod and Tamizi Mustafa (1992) were adopted to determine the anatomical studies on the types of vascular bundles and their distributions.

Bamboo sample blocks of size (10 mm × 10 mm × culm wall thickness) were observed using a wireless digital microscope (Koolertron Wireless WiFi Digital USB Microscope (1000x magnification); Koolertron, Shenzhen, China). Bamboo strips from lower and upper sections were chipped into a matchstick size and macerated using a mixture of 30% hydrogen peroxide: glacial acetic acid (1:1 ratio) and placed in a water bath at 70 °C for 3 to 4 h. A higher temperature and longer time were needed to ensure that all the lignin had dissolved and the cellulose fibres appeared whitish. The maceration solution was then washed in distilled water until all traces of the acid disappeared. The cellulose fibres were then placed in the vials and gently agitated to give sufficient separation. The vials were then half-filled with distilled water and secured with a cap. The macerated fibres were then spread on the glass slide before drops of safranin-O was added. A cover slip was applied on the slide. The quantitative measurements of the fibre length, fibre width, fibre lumen diameter, and fibre cell wall thickness from each top and bottom sections of *G. albociliata* were conducted. The quantitative measurement was made using an optical microscope, and at least 50 fibres were measured. From the fibre measurement, the Runkle ratio, coefficient of suppleness, and Felting Power or *L/D* factor were calculated using the formulas below:

$$\text{Runkel ratio} = 2w/l \quad (1)$$

$$\text{Coefficient of suppleness} = (l \times 100) / D \quad (2)$$

$$\text{Felting Power or } L/D \text{ ratio} = L / D \quad (3)$$

where *w* is fibre wall thickness (µm), *l* is lumen diameter (µm), *D* is fibre width (µm), and *L* is fibre length (mm).

#### *Determination of chemical composition*

Fresh felled bamboo was divided into top and bottom sections and chipped before drying in an oven at 60 °C for three days. The sample was then powdered using a Fritsch pulverisette with a sieved size of 0.25 mm. TAPPI test method T257 (1993) was used to determine the chemical composition of *G. albociliata*.

#### *Determination of moisture content and specific gravity*

*Gigantochloa albociliata*'s moisture content and specific gravity were determined using ISO 22157 (2019). A small section measuring approximately 30 mm (round sample) and 60 mm (strip sample) in length was cut. The section was cut at the internode to remove any defects or failures (away from the node). The sections were then dried in an oven at 103 ± 2 °C for more than 24 h, or until the weight was constant. The moisture content of the bamboo was then calculated based on the difference of its initial weight and oven-dried weight while the specific gravity was calculated by dividing the density of bamboo with the density of water.

#### *Determination of dimensional stability*

*Gigantochloa albociliata*'s dimensional stability was tested in accordance with Indian Standard (IS) 6874 (2008). Each sample's radial, longitudinal, and tangential sections were marked and measured with digital Vernier calipers. All samples were dried in an oven and kept at 103 ± 2 °C for 48 h. The shrinkage test was performed under conditions that progressed from green to oven dry. The difference in initial and final dimensions on the radial, longitudinal, and tangential planes was used to calculate the

bamboo shrinkage percentages. The samples were placed in a water saturated environment until a constant weight was reached, at which point the swelling percentage was calculated.

#### *Determination of mechanical properties*

Static bending of the round bamboo and strip was conducted according to an in-house testing method by Forest Research Institute Malaysia (FRIM). The bamboo measured approximately 1000 mm in length. The test employed a three-point loading method with an 800-mm span. Throughout the test, a constant loading speed of 6.6 mm/min was used. The Shimadzu Universal Testing Machine (AG-1/100KN AG-IS; Shimadzu Corporation, Kyoto, Japan) and the Shimadzu software TrapeziumX were used. The Trapezium software calculated the modulus of elasticity (MOE) and modulus of rupture (MOR) using basic engineering principles.

#### *Determination of wettability*

Prior to testing, bamboo strips (20 mm × 20 mm × 4 mm) were conditioned at 20 ± 2 °C for a week. A total of 0.02 mg distilled water was dropped onto the outermost layer of the bamboo strips using the sessile drop technique. The bamboo green has already been removed by four-sided planer. Using dpiMAX software (DataPhysics Instruments, version 1, Filderstadt, Germany), the angle formed between the droplet and the bamboo surface was measured at 0 s, 2 s, 30 s, 60 s, 90 s, and 120 s.

#### *Data analysis*

All data were analysed using one-way analysis of variance (ANOVA), and Duncan's multiple range test (DMRT) was used to determine the significant difference between variables.

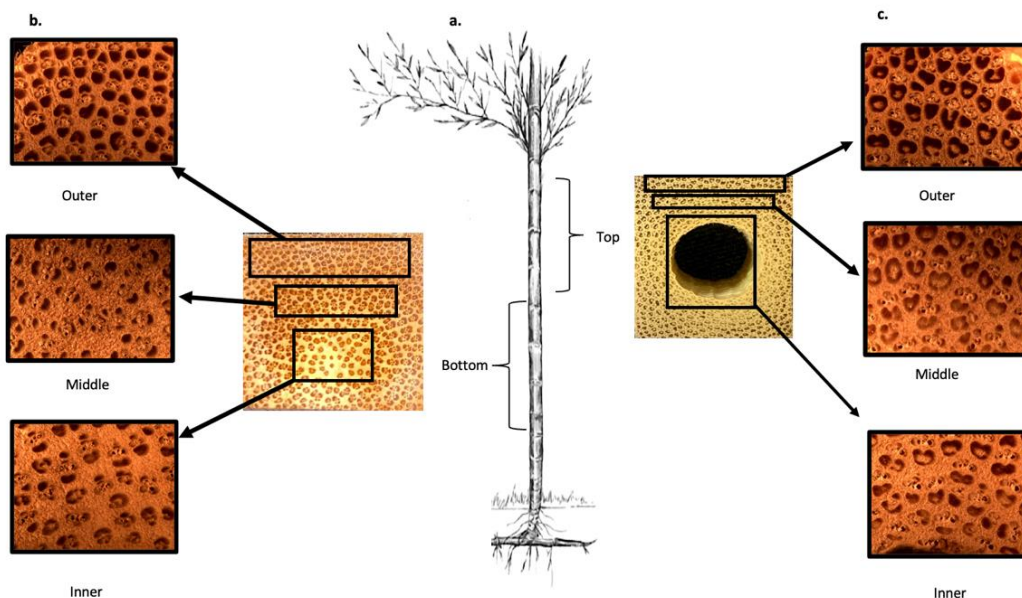
## RESULTS AND DISCUSSION

### Anatomical Structure

Figure 1 shows the anatomical structure of *G. albociliata* at different sections of the bamboo stem. Along the stem, one can see that the bottom part of the bamboo is solid, and hole is non-existent. The hole became detectable as the point of observation moved towards the top of the stem and grew larger along with the height of the bamboo. According to the study by Siam *et al.* (2019) and Liese (1985), the type of vascular bundle distribution of *G. albociliata* is a mixture of type III and type IV. The top part of *G. albociliata* was comprised of type III vascular bundle, while the bottom part was comprised of type IV vascular bundle. There was a distinction between the top and bottom sections of the bamboo, as two fibre strands were identified at the bottom and a single fibre strand at the top. Grosser and Liese (1971) discovered that the type IV vascular bundle of *Gigantochloa* was always combined with the type III vascular bundle, particularly at the base internodes.

The vascular bundle is also longer and smaller in the outer layer but shorter and larger in the inner layer, resulting in a denser vascular bundle in the outer layer than the inner layer. It can be seen that the size of vascular bundle distribution decreases from bottom to top. The shape of vascular bundle is also seen as roundish and oval at the top section compared to the bottom of the bamboo. This is because of the reducing cell wall thickness within the culm height (Grosser and Liese 1971). Aside from shrinking in shape and size within the culm height, it can also be seen that the number of vascular bundles

decreases from bottom to top but becomes tightly packed together at the top of the bamboo. As a result, higher density at the top section is expected.



**Fig. 1.** a) Morphology of *G. albociliata*; b) vascular bundle of *G. albociliata* at bottom section at 7x magnification; and c) vascular bundle of *G. albociliata* at top section at 7x magnification

### Fibre Morphology

Table 1 compares the means of fibre length, width, lumen width, cell wall thickness, Runkle ratio, coefficient of suppleness, and  $L/D$  ratio of *G. albociliata* between sections. The *G. albociliata* fibre width ranges from 26.81 to 28.79  $\mu\text{m}$ , with a higher value at the bottom. This finding is consistent with the trend of bamboo species studied by Siam *et al.* (2019), with the exception of *G. ligulata* and *B. vulgaris*, which have larger fibre width. This finding supports the findings of Liese (1998), who discovered that fibre is typically thicker at the bottom.

The fibre length of *G. albociliata* is 2.01 mm and 1.96 mm at the top and bottom sections, respectively, and it can be classified as long fibre ( $> 1.9$  mm), as reported by Kiaei *et al.* (2014). The cell wall thickness is significantly greater at the bottom (3.15  $\mu\text{m}$ ) than at the top (2.93  $\mu\text{m}$ ), as is the Runkel ratio, which is 0.66 at the bottom compared to 0.54 at the top.

Meanwhile, the top part of the bamboo has a significantly higher suppleness coefficient and  $L/D$  ratio than the bottom part. *G. albociliata*'s fibre length and lumen width are not significant between sections, and it is shorter and smaller than other bamboo species previously reported (Wahab *et al.* 2010; Siam *et al.* 2019; Khantayanuwong *et al.* 2023). According to Granholm *et al.* (2010), thick-walled fibres have a Runkel ratio greater than 1, while thin-walled fibres have a Runkel ratio less than 1. Fibres with a Runkel ratio greater than 1 are expected to have low mechanical strength. In this study, the *G. albociliata* fibres have a Runkel ratio between 0.54 and 0.66, indicating that they have good mechanical properties.

**Table 1.** Fibre Length, Fibre Width, Lumen Width, Cell Wall Thickness, Runkle Ratio, Coefficient of Suppleness, and L/D ratio of *G. albociliata* at Top and Bottom Sections

Section	Fibre Length (mm)	Fibre Width ( $\mu\text{m}$ )	Lumen Width ( $\mu\text{m}$ )	Cell Wall Thickness ( $\mu\text{m}$ )	Runkle Ratio	Coefficient of Suppleness (%)	L/D Ratio
Top	2.01 <sup>a</sup> (0.28)	26.81 <sup>a</sup> (5.07)	2.43 <sup>a</sup> (3.92)	2.93 <sup>b</sup> (0.82)	0.54 <sup>a</sup> (0.24)	45.42 <sup>a</sup> (12.10)	77.07 <sup>a</sup> (15.51)
Bottom	1.96 <sup>a</sup> (0.26)	28.79 <sup>b</sup> (3.79)	2.25 <sup>a</sup> (2.69)	3.51 <sup>a</sup> (0.63)	0.66 <sup>b</sup> (0.19)	39.05 <sup>b</sup> (7.99)	69.41 <sup>b</sup> (14.22)

Note: Number in parentheses refers to standard deviation. Within the same column, means followed by letter a or b are significantly different at  $p \leq 0.05$ .

### Chemical Compositions

Table 2 shows the chemical compositions of top and bottom parts of the *G. albociliata*. With the exception of cold-water solubility, there was no significant difference in chemical composition between the top and bottom parts of the bamboo. The cold water solubility test measures extraneous components that are insoluble in cold water, such as tannins, sugars, and colouring matter. The mean chemical compositions of *G. albociliata* for cold water solubility at top and bottom were 11.67% and 14.33%, respectively. This means that the bottom part of *G. albociliata* may contain significantly higher tannin and sugar than the top part. Although they did not differ significantly, the bottom part of *G. albociliata* also had a higher mean value for hot water solubility (10.00% vs. 8.33%), ethanol-toluene extractives (4.43% vs. 4.25%),  $\alpha$ -cellulose (46.3% vs. 44.3%), lignin (28.3% vs. 25.3%), and ash content (5.00% vs. 4.00%) than the top part of *G. albociliata*. In contrast, the top part of *G. albociliata* was found to have higher hemicellulose content than the bottom part.

**Table 2.** Chemical Compositions of *G. albociliata* of Different Sections

Section	Cold-water solubility (%)	Hot-water solubility (%)	Ethanol-Toluene Extractive (%)	Holocellulose (%)	$\alpha$ -cellulose (%)	Hemicellulose (%)	Lignin (%)	Ash - cont. (%)
Top	11.67 <sup>b</sup> (1.15)	8.33 <sup>a</sup> (0.58)	4.25 <sup>a</sup> (0.01)	85.67 <sup>a</sup> (4.16)	44.33 <sup>a</sup> (1.53)	41.00 <sup>a</sup> (2.65)	25.33 <sup>a</sup> (1.53)	4.00 <sup>a</sup> (1.00)
Bottom	14.33 <sup>a</sup> (0.58)	10.00 <sup>a</sup> (2.65)	4.43 <sup>a</sup> (0.63)	83.33 <sup>a</sup> (3.06)	46.33 <sup>a</sup> (4.16)	37.33 <sup>a</sup> (1.53)	28.33 <sup>a</sup> (1.53)	5.00 <sup>a</sup> (0.00)

Note: Number in parentheses refers to standard deviation. Within the same column, means followed by letter a or b are significantly different at  $p \leq 0.05$ .

The bottom had a higher extractive content of alcohol-toluene (4.43%) than the top (4.25%). The value was higher than that found in Yusoff *et al.* (2021), which ranges from 1.01% to 2.09%. High alcohol toluene extractive frequently associates with bamboo maturity and increases resistance to biological attack. The top part of the bamboo had the highest holocellulose content of 85.7%, while the bottom part had a lower holocellulose content of 83.3%. According to Yusoff *et al.* (2021), a lower holocellulose content at the bottom could be due to a high extractive and ash content. Furthermore, the dense distribution of vascular bundles at the top section of bamboo suggests a higher holocellulose content (Li *et al.* 2007). The alpha-cellulose of this bamboo (44.33% for top

and 46.33% for bottom) is higher than the alpha-cellulose of the same bamboo reported by Yusoff *et al.* (2021), which was 42.9%. Meanwhile, Wahab *et al.* (2013) reported that the alpha cellulose content of four cultivated *Gigantochloa* bamboos ranged from 33.80% to 51.6%.

Lignin content of *G. albociliata* in this study was 25.3% to 28.3% for top and bottom sections, respectively. According to Yusoff *et al.* (2021), bamboo with a high lignin content is a good building material because it has a high heating value and structural rigidity. Norul Hisham *et al.* (2006) previously reported that the lignin content of *G. scortechinii* ranged from 23.4% to 29.0%, which is quite similar to the *G. albociliata* in this study. The ash content observed in this study is 4.00% to 5.00%, which is higher than other studies (1.59% to 1.87%) (Yusoff *et al.* 2021). According to Yusoff *et al.* (2021), higher ash content indicated higher silica content at the epidermis, and this could be a problem during the processing as silica tend to blunt the blade.

### Physical Properties

As indicated in Tables 3 and 4, moisture content at the bottom is significantly higher than the top part for both round and strip bamboo. The higher moisture content of bamboo at the bottom is due to the size of the vascular bundle at the bottom being larger than the top, as shown in Fig. 1 and reported by Grosser and Liese (1971). The specific gravity of *G. albociliata* round bamboo is higher at the top (0.72) than the bottom (0.69). Similar observation was made on the bamboo strips where strips from the top section (0.64) were higher than the bottom section (0.60). This is similar to the study reported by Suchart and Thaipetch (2004) with specific gravity of *G. albociliata* ranging from 0.62 to 0.68. Despite this, it has a lower specific gravity (0.74 to 0.90) than *G. levis*, which was studied by Osman *et al.* (2022). Figure 1(b) shows that the number of vascular bundles increases and becomes tighter together from the bottom to the top. This may be the reason that round bamboo and the strip from the top section has higher specific gravity than that of the bottom section.

**Table 3.** Specific Gravity, Moisture Content, and Density of *G. albociliata* Round Bamboo of Different Sections

Section	Moisture Content (%)	Specific Gravity	Density (kg/m <sup>3</sup> )
Top	61.05 <sup>b</sup> (5.43)	0.72 <sup>b</sup> (0.03)	915.00 <sup>a</sup> (47.85)
Bottom	76.74 <sup>a</sup> (7.88)	0.69 <sup>a</sup> (0.03)	905.00 <sup>a</sup> (45.89)

Note: Number in parentheses refers to standard deviation. Within the same column, means followed by letter a or b are significantly different at  $p \leq 0.05$ .

**Table 4.** Specific Gravity, Moisture Content, and Density of *G. albociliata* Strips of Different Sections

Section	Moisture Content (%)	Specific Gravity	Density (kg/m <sup>3</sup> )
Top	78.10 <sup>b</sup> (4.06)	0.64 <sup>b</sup> (0.46)	774.00 <sup>a</sup> (63.26)
Bottom	81.0 <sup>a</sup> (2.19)	0.60 <sup>a</sup> (0.03)	753.00 <sup>a</sup> (41.87)

Note: Number in parentheses refers to standard deviation. Within the same column, means followed by letter a or b are significantly different at  $p \leq 0.05$ .

## Dimensional Stability

Figure 2 depicts the percentage of swelling and shrinkage of *G. albociliata* strips of the bottom and top portions. The tangential swelling is greater in the bottom strips, while the longitudinal and radial swelling is greater in the top strips. In contrast, the top strips have greater longitudinal and tangential shrinkage but less radial shrinkage than bottom strips. Only tangential shrinkage differed statistically between top and bottom strips. Tangential shrinkage can cause bamboo to lose its original shape, resulting in width and curvature changes. This type of shrinkage can have an impact on the stability and fit of bamboo in applications such as laminated products. However, the shrinkage values of *G. albociliata* in this study were lower than those reported for *G. scortechinii* in other studies (Wahab *et al.* 2013; Anokye *et al.* 2014). This could imply that *G. albociliata* is more stable than *G. scortechinii*.

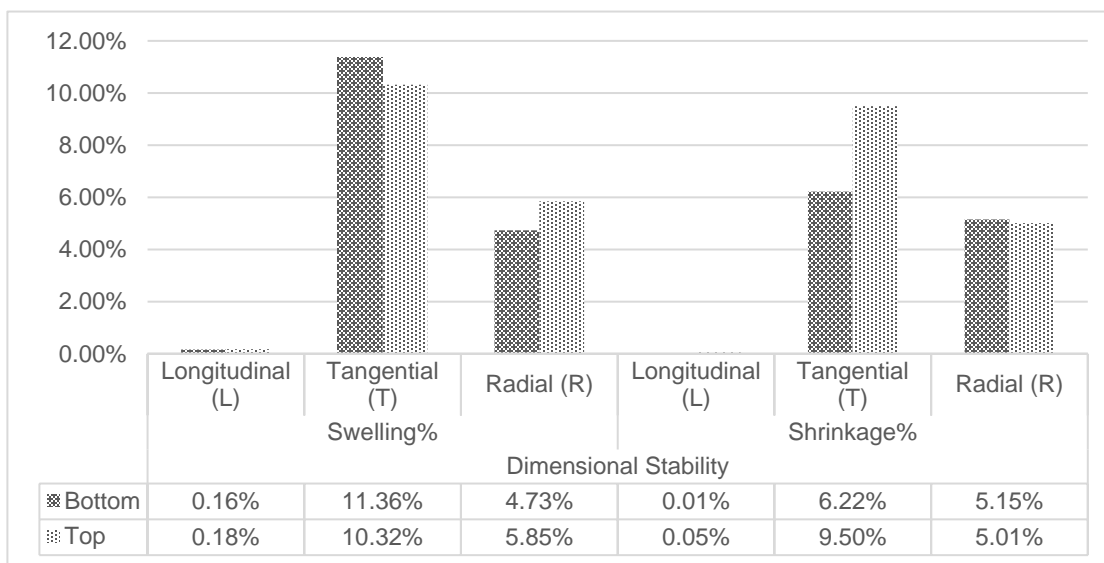


Fig. 2. Swelling and shrinkage of *G. albociliata* strips of different sections

## Mechanical Properties

Tables 5 and 6 show that the MOE and MOR of top bamboo are higher than those of bottom bamboo for both round bamboo and strips. Higher MOE and MOR values on the top of the bamboo could be related to factors such as higher cellulose content and specific gravity, as shown in Tables 2, 3, and 4. According to Sorieul *et al.* (2016), increased hemicellulose influences the flexibility and elasticity of the cell wall, which in turn influences the mechanical properties of the material. The value of MOE of *G. albociliata* strip is also higher than the split bamboo reported by Siam *et al.* (2019). Bamboo from the top section has higher mechanical properties than that of bottom section, which possibly can be attributed to the higher fibre length and  $L/D$  ratio as well as lower Runkel ratio. When compared to other species, the MOE of *G. albociliata* strips is higher than *G. thooi* (13185 N/mm<sup>2</sup>), *B. vulgaris* (12104 N/mm<sup>2</sup>), and *G. scortechinii* (10800 N/mm<sup>2</sup>). The MOR of *G. albociliata* strip (Table 6) is considered lower than the other 13 commercial Malaysian bamboo species but the value is comparable to that of *B. blumeana*, *B. heterostachya*, and *G. scortechinii* split (Siam *et al.* 2019). It is worth mentioning that round *G. albociliata* show promising MOR values with range of 178 to 181 N/mm<sup>2</sup>, which is considerably high.



**Table 5.** MOR and MOE of *G. albociliata* Round Bamboo of Different Sections

Section	MOR (N/mm <sup>2</sup> )	MOE (N/mm <sup>2</sup> )
Top	180.82 <sup>a</sup> (11.48)	24259 <sup>b</sup> (1903.47)
Bottom	178.67 <sup>a</sup> (10.28)	21350 <sup>a</sup> (915.20)

Note: Number in parentheses refers to standard deviation. Within the same column, means followed by letter a or b are significantly different at  $p \leq 0.05$ .

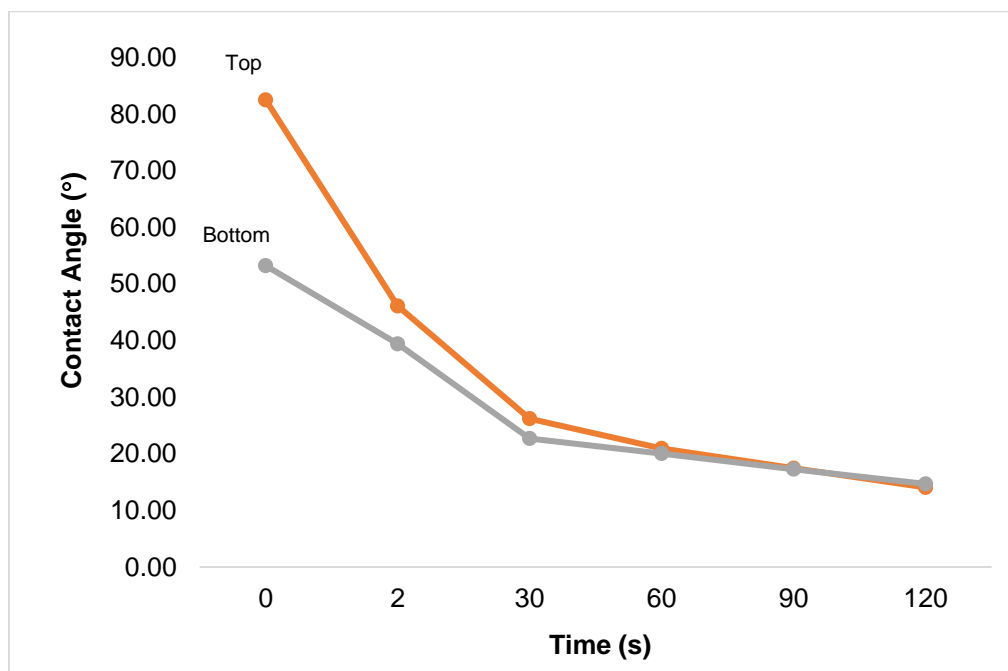
**Table 6.** MOR and MOE of *G. albociliata* Strips of Different Sections

Section	MOR (N/mm <sup>2</sup> )	MOE (N/mm <sup>2</sup> )
Top	100.46 <sup>a</sup> (11.48)	16711 <sup>b</sup> (1087)
Bottom	99.16 <sup>a</sup> (7.92)	1523.0 <sup>a</sup> (1175.50)

Note: Number in parentheses refers to standard deviation. Within the same column, means followed by letter a or b are significantly different at  $p \leq 0.05$ .

### Wettability

Wettability through contact angle analysis is essential for determining surface characterisation and material performance. These measurements make it possible to develop appropriate application and surface modification strategies for this bamboo, focusing on glueability and bond formation. Figure 3 shows the contact angle of different parts of *G. albociliata* against time.

**Fig. 3.** Contact angle against time of *G. albociliata* strips of different sections

Bamboo from the top section initially had higher contact angle (82.5°) than the lower section (53.21°). However, as time passed, the contact angle of both sections became almost the same after 30 s. At 120 s, both sections had contact angle of approximately 15°. *G. albociliata* has a smaller contact angle at 2 s than *D. sericeus* (46.60°), as reported by Chaowana *et al.* (2015) and *G. levis* (53 to 64.7°), as reported by Faizal *et al.* (2015). These findings indicated that *G. albociliata* has greater wettability than both *D. sericeus* and *G. levis*, as evidenced by a lower contact angle. It also demonstrates *G. albociliata*'s suitability for use in laminated products, as the glue spreading ability would be advantageous due to high wettability.

## CONCLUSIONS

1. Buluh madu (*G. albociliata*) has a vascular bundle distribution of a mixture of Type III and Type IV, similar to the bamboo of other members of the *Gigantochloa* genus. The size of vascular bundle distribution decreases from the bottom to top of the bamboo stem. The outer layer of the bamboo has a denser distribution of vascular bundle than inner layer.
2. *G. albociliata* has long fibres. The top section of bamboo has longer fibre, coefficient of suppleness, and *L/D* ratio, but lower fibre width, cell wall thickness, and Runkle ratio than the bottom section.
3. Chemical composition of the top and bottom section of bamboo did not differ significantly except for cold-water solubility, where bottom section may contain significantly higher tannin and sugar than the top section.
4. Round bamboo and strips from the top section have higher specific gravity and density than the bottom section and therefore higher mechanical strength. The swelling and shrinkage properties of *G. albociliata* may imply that this bamboo has better dimensional stability than *G. scortechinii*.
5. *G. albociliata* has good wettability when compared to other bamboo species as shown by its lower contact angle. Coupled with its good strength properties and dimensional stability, it has a great potential to be processed into laminae for laminated bamboo panels production.
6. The results of this study show that *G. albociliata* has a high potential for being processed into laminae for laminated panel manufacture. One of the most noticeable features is that the culms are solid at the bottom portion of the plant, with hollows appearing as they move towards the top. Owing to the large culm diameter and the absence of holes, using the bottom portion shortens the processing time. Meanwhile, despite having small hollow structures, the upper portion displays more promising qualities for being processed into laminae because of its superior mechanical properties. However, more research is needed to establish the implications of the hollow structures on the performance of the laminated panel, both aesthetically and mechanically.

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## REFERENCES CITED

- Anokye, R., Kalong, R. M., Bakar, E. S., Ratnasingam, J., Jawaid, M., and Awang, K. (2014). "Variations in moisture content affect the shrinkage of *Gigantochloa scortechinii* and *Bambusa vulgaris* at different heights of the bamboo culm," *BioResources* 9(4), 7484-7493. DOI: 10.15376/biores.9.4.7484-7493
- Chaowana, P., Jindawong, K., and Sungkaew, S. (2015). "Adhesion and bonding performance of laminated bamboo lumber made from *Dendrocalamus sericeus*," in: *10<sup>th</sup> World Bamboo Congress*, Damyang, South Korea.
- Duriyaprapan, S., and Jansen, P.C.M. (1995). "*Bambusa bambos* (L.) Voss," in: *Plant Resources of South-East Asia. Bamboos*, S. Dransfield, and E. A. Widjaja (eds.), Backhuyes, Leiden, Netherlands.
- Faizal, W., Wahid, A. B., Ahmad, M., and Rahmat, M. (2015). "Contact angle of different portion of beting bamboo (*Gigantochloa levis*) treated with maleic anhydride for composite materials," *International Journal of Mechanical and Production Engineering* 3(10), 68-70.
- Granholm, K., Harju, L., and Ivaska, A. (2010). "Desorption of metal ions from kraft pulps, Part 1. Chelation of hardwood and softwood kraft pulp with EDTA," *BioResources* 5(1), 206-226. DOI: 10.15376/biores.5.1.206-226
- Grosser, D., and Liese, W. (1971). "On the anatomy of Asian bamboos, with special reference to their vascular bundles," *Wood Science and Technology* 5, 290-312. DOI: 10.1007/BF00365061
- Hanim, A. R., Zaidon, A., Anwar, U. M. K., and Rafidah, S. (2013). "Effects of chemical treatments on durability properties of *Gigantochloa scortechinii* strips and ply-bamboo," *Asian Journal of Biological Sciences* 6(3), 153-160. DOI: 10.3923/ajbs.2013.153.160
- IS 6874 (2008). "Method of tests for bamboo," Bureau of Indian Standards, Old Delhi, India
- ISO 22157 (2019). "Bamboo structures," International Organization for Standardization, Geneva, Switzerland.
- Johar Mohamed (2012). *Effect of Silvicultural Treatments on Buluh Madu (Gigantochloa albociliata) (Munro) Kurz for Shoot Production*, Master's Thesis, Universiti Putra Malaysia, Selangor, Malaysia.
- Khantayanuwong, S., Yimlamai, P., Chitbanyong, K., Wanitpinyo, K., Pisutpiched, S., Sungkaew, S., Sukyai, P., and Puangsin, B. (2023). "Fiber morphology, chemical composition, and properties of kraft pulping handsheet made from four Thailand bamboo species," *Journal of Natural Fibers* 20(1), article ID 2150924. DOI: 10.1080/15440478.2022.2150924

- Kiaei, M., Tajik, M., and Vaysi, R. (2014). "Chemical and biometrical properties of plum wood and its application in pulp and paper production," *Maderas. Ciencia y Tecnología* 16(3), 313-322. DOI: 10.4067/S0718-221X2014005000024
- Latif Mohmod, A., and Tamizi Mustafa, M. (1992). "Variation in anatomical properties of three Malaysian bamboos from natural stands," *Journal of Tropical Forest Science* 5(1), 90-96.
- Li, X. B., Shupe, T. F., Peter, G. F., Hse, C. Y., and Eberhardt, T. L. (2007). "Chemical changes with maturation of the bamboo species *Phyllostachys pubescens*," *Journal of Tropical Forest Science* 19(1), 6-12.
- Liese, W. (1985). "Anatomy and properties of bamboo," in: *Proceeding of the International Bamboo Workshop*, Hangzhou, China, pp. 196–208.
- Liese, W. (1998). *The Anatomy of Bamboo Culms*, Technical Report, International Network for Bamboo and Rattan (INBAR), Beijing, China.
- Norul Hisham, H., Othman, S., Rokiah, H., Abd Latif, M., Ani, S., and Mohd Tamizi, M. (2006). "Characterization of bamboo *Gigantochloa scortechinii* at different ages," *Journal of Tropical Forest Science* 18(4), 236-242.
- Osman, S., Ahmad, M., Zakaria, M. N., Zakaria, A. M., Ibrahim, Z., Abu, F., Bahari, S. A., and Wan Jaafar, W. N. R. (2022). "Bamboo as future bio-industrial material: Physical behaviour and bending strength of Malaysia's Beting bamboo (*Gigantochloa levis*)," *IOP Conference Series: Earth and Environmental Science* 951, article ID 012001. DOI: 10.1088/1755-1315/951/1/012001
- Sorieul, M., Dickson, A., Hill, S. J., and Pearson, H. (2016). "Plant fibre: Molecular structure and biomechanical properties, of a complex living material, influencing its deconstruction towards a biobased composite," *Materials* 9(8), article 618. DOI: 10.3390/ma9080618
- Siam, N. A., Uyup, M. K. A., Husain, H., Mohmod, A. L., and Awalludin, M. F. (2019). "Anatomical, physical, and mechanical properties of thirteen Malaysian bamboo species," *BioResources* 14(2), 3925-3943. DOI: 10.15376/biores.14.2.3925-3943
- TAPPI T257 (1993). "Sampling and preparing wood for analysis," TAPPI Press, Atlanta, GA, USA.
- Wahab, R., Mustafa, M. T., Salam, M. A., Sudin, M., Samsi, H. W., and Rasat, M. S. M. (2013). "Chemical composition of four cultivated tropical bamboo in genus *Gigantochloa*," *Journal of Agricultural Science* 5(8), 66-75. DOI: 10.5539/jas.v5n8p66
- Wahab, R., Mustafa, M. T., Sulaiman, O., and Mohamed, A. (2010). "Anatomical and physical properties of cultivated two- and four-year-old *Bambusa vulgaris*," *Sains Malaysiana* 39(4), 571-579.
- Yusoff, M. S. R., Bahari, S. A., Haliffuddin, R. M. A. A., Zakaria, M. N., Jamaluddin, M. A., and Rashid, N. H. M. N. (2021). "Chemical contents and thermal stability of Madu bamboo (*Gigantochloa albociliata*) for natural-bonded fiber composites," *IOP Conference Series: Earth and Environmental Science* 644(1), Article ID 012009. DOI: 10.1088/1755-1315/644/1/012009

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