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Assessment of Properties of Semantan Bamboo Culm (*Gigantochloa Scortechinii*) at different Height Positions

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Abstract
Bamboo is a fast-growing lignocellulosic material and is increasingly being used as an alternative material for producing renewable and consumer-friendly products. A study was conducted to determine the physical properties and drying behaviour of Semantan bamboo. The physical properties of Semantan bamboo varied from bottom to top. The average basic density ranged from 597 to 626 kg m^{-3} and volumetric shrinkage ranged from 13.5 to 15.8%. The solar-drying and air-drying times for the green bamboo culms to reach an average moisture content of approximately 12.76% to 12.98% were about 20 and 30 days, respectively.

Keywords: semantan bamboo; *Gigantochloa Scortechini;* density; drying

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1.0 Introduction

In an effort to reduce dependency on timber from natural forests, various initiatives have been carried out for the establishment of bamboo plantations to ensure continuous supply of raw materials for the local industry. Bamboo is known as one of the fastest-growing plants and has mechanical strength comparable to hardwood is emerging being used as an alternative source for the production of value-added products. However, being a natural lignocellulosic material, variations in the physico-mechanical properties of bamboo have caused various level of difficulties in the processing and performance of round bamboo as well as bamboo bamboo-based composites (Sharma et al. 2015; Burgera et al. 2017; Kelkar et al. 2023). The physical, mechanical, and other technological properties of bamboo species are varied due to the variation of anatomical structure of bamboo culms (mainly variation of size and the number of vascular bundles), density, and physical dimension along the culm height and across the culm wall (Liese & Köhl 2015, Trujillo & López 2016). As such, for the proper and efficient use of bamboo, it is essential to study the physical and geometrical as well as drying properties variation along the culms height of the round bamboo (Razak et al. 2013, Nordahlia et al. 2019, Javadian et al. 2019). In this regard, a study was conducted to assess the physical properties and drying duration of 4-years-old *Gigantochloa scortechinii* bamboo obtained from Peninsular Malaysia. The green bamboo culms were dried using air-drying and solar-drying methods. The drying time and moisture content of the bamboo were monitored during the drying process. The drying study is intended to produce quality dried bamboo which subsequently can be used for the production of various value-added products such as laminated board, furniture and souvenirs.

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2.0 Literature Review

Bamboo is one of the most important non-wood resources. It belongs to the family Graminae and subfamily Bambusoidae. There are about 70 bamboo species in Malaysia, of which 45 are local species that grow naturally in the forests. It was estimated that 31% of bamboo plantations are located in Peninsular Malaysia, 45% in Sarawak and 24% in Sabah with a total plantation area of 18.21 million hectares (Kamaruzaman et al, 2016). There are about 16 bamboo species that are commercially used in Malaysia mainly *Gigantochloa scortechinii*, *Dendrocalamus asper* and *Gigantochloa albociliata* (INBAR 2017). Bamboo takes about three to five years to reach full maturity compared to 20 to 120 years for hardwoods such as chengal and merbau (Dahlia et al. 2019). Generally, Malaysian bamboo grows wildly in hilly areas, secondary forest, an area that has been logged and along the river bank. It grows densely in clumps from 30 centimeters to 30 meters in height and varies in diameter (Kamaruzaman et al, 2016).

Gigantochloa scortechinii or locally known as Semantan bamboo can reach up to 17-20 m in height depending on the local conditions (Azmy, 1998). The young culms grow upright with white-color-coated substances and turn green when mature. The culm is large with black-colored petals and has a wall thickness of 11 to 15 mm (Azmy, 1998). The branches of Semantan bamboo are straight and sharp while the leaves are medium in size. Generally, the stem of large bamboo clumps grows closely attached to each other, especially for clumps that have never been harvested. The bamboo shoot is easily identified by the presence of hairy stripes on the petals arranged in a v-shape (Azmy, 1998).

The physical and mechanical properties of bamboo are reported to be comparable to selected tropical hardwood species. According to Dahlia el al. (2019), the density of selected commercial bamboo species ranged from 355-751 kg/m^{-3} which is approximately equivalent to the density of light hardwood timber species (400 to 720 kg/m^{-3}). Furthermore, Dahlia et al. (2016) reported that the MOR and MOE of 4-year-old *Schizostachyum zollingeri* bamboo are 142 Nmm^{-2} and 10005 Nmm^{-2} respectively which is comparable to the MOR and MOE of selected plantation timber species such as *Acacia mangium* and *Hopea odorata* (Mohamad Omar & Mohd Jamil, 2011; Mohamad Omar & Khairul, 2020).

Traditionally, bamboo is used as handicraft items such as baskets, chopsticks, toothpicks and satay skewers (Mahpar et al, 2016). Nowadays, with the advanced technology and innovation in bamboo processing, it has been increasingly being used as an alternative to timber for the production of structural and non-structural products such as flooring, laminated furniture and low-rise building components (Azreena et al. 2016). Due to its fast-growing characteristic, satisfactory strength properties and flexibility to be used for diverse products, bamboo has been accepted as a renewable resource that can offer great potential to contribute to the economic growth of Malaysia.

Drying can increase the stability of bamboo and at the same time improve its resistance against biological degradation. Well-dried bamboo is stronger and has better gluing and finishing quality than wet bamboo (Liese & Tang 2015). In general, the rate of drying is mainly influenced by its structural features, density, culm wall thickness, and the presence of internodes (Liese & Tang 2015, Glenn et al. 1954, Laxamana 1985, Tang et al. 2013). The rate of drying of young culms is generally faster than that of mature ones and bamboo splits dry faster than the culms (Vetter et al. 2015). The most common method for drying bamboo is air-drying, forced-air (with or without heat assisted), solar drying, and conventional kiln drying. Air-drying method is commonly used for drying round bamboo. Generally, air drying of round bamboo takes about 6 - 12 weeks and the drying duration depends on the initial moisture content of the bamboo, the environmental conditions and the wall thickness (Roland et al. 2015).

For large-scale operations with faster drying time and high-quality bamboo throughput, kiln-drying is more efficient than air-drying. With kiln drying, bamboo can be dried to the required moisture content in a shorter time. The kilns commonly used for drying are conventional steam-heated kilns, dehumidification kilns, vacuum kilns and solar kilns. However, with conventional kiln drying, rapid drying may lead to drying defects as well as excessive shrinkage due to uneven heating. Defects such as splits and collapse caused by excessive and non-uniform culm shrinkage are a major problem in some species, especially in immature culms (Sharma 1988, Wang et al. 2019). Therefore, it is recommended that a mild-temperature drying method such as solar drying and air drying is used for bamboo to reduce the above-mentioned defects.

The physical and geometrical properties of various Malaysian bamboo at different ages and grown at different locations have been reported in a number of publications (Azmy et al. 2011, Nordahlia et al. 2019). However, detailed information on the drying characteristics of Malaysian bamboo is rather limited. Despite its availability, sustainability and, in some cases, superior mechanical properties, the application of bamboo as a building material in Malaysia has not yet reached the commercial levels. This is largely due to significant gaps in data availability and understanding of the variation in properties and behavior of bamboo. This study aims to determine the longitudinal variation of physical, geometrical and drying properties of *Gigantochloa scortechinii; a* commercial Malaysian bamboo species. By determining the lengthwise variation along the culm height location, the optimum processing strategy and suitable parts of the culm for a particular application can be specified, and thus will ultimately increase the efficient utilisation of bamboo.

3.0 Methodology

3.1 Material Preparation

The bamboo species tested in this study were *Gigantochloa scortechinii* as they are the most commonly used bamboo species in Peninsular Malaysia. The matured culms were selected in the study as the culms at this age were found to be suitable as material for industrial uses (Razak et al. 2009). Selection of matured culms was based on the morphological characteristic of culm, i.e. the surface colour of the culm, the appearance of culm sheaths, and the growth of surface lichens or white fungi (Abd. Razak & Abd. Latif 1995, Abd Razak et al. 2012, Banik 1993). *Gigantochloa scortechinii* was obtained from Sungai Lui, Hulu Langat, Selangor, Malaysia. A total of 5m^3 matured culms were randomly selected from different clumps. The bamboo culms were cut into nine meters long and then further cut into three sections i.e. top, middle and bottom. The dimension of each bamboo culm was measured for its diameter, wall thickness and internodes length.

3.2 Green Moisture Content, Density, and Shrinkage

Specimens measuring 20 mm x 20 mm x culm wall thickness (mm) were obtained from the bottom, middle and top sections for determination of moisture content, density and shrinkage from green to oven-dry according to Indian Standards Institution (Anonymous 1976). The weight and dimensions (tangential, radial and longitudinal) of each specimen were measured before and after drying in an oven at 103 ± 2ºC until a constant weight was attained. The moisture content (MC) in percentage (%) and density (ρ) values in kg m^{-3} of each specimen was calculated using the following formulas:

$$MC = \left(\frac{W_g - W_o}{W_o}\right) \times 100$$

$$Green\ density, \rho_g = \frac{W_g}{V_g}$$

$$Oven\text{–}dry\ density, \rho_o = \frac{W_o}{V_o}$$

$$Basic\ density, \rho_b = \frac{W_o}{V_g}$$

where, W_g is the weight in green condition (g), W_o is the oven-dry weight (g), V_g is the green volume (m^3) and V_o is the oven-dry volume (m^3).

The total dimensional and volumetric shrinkages (%) from green to oven-dry condition were calculated using the following formulas:

$$Shrinkage, \beta = \frac{D_g - D_0}{D_g} \times 100$$

where, D_g is the corresponding tangential, radial and longitudinal dimensions (mm) of the green specimen and D_o is the corresponding tangential, radial and longitudinal dimensions (mm) of the oven-dried specimen.

3.3 Drying

A total of 60 bamboo culms of 3 meters in length each were dried at two different conditions i.e. air-drying and solar-drying. For the air-drying test, 30 culms were stacked in an open site under a shed while another 30 culms were dried using a solar-assisted kiln dryer (temperature of less than 40°C) established at Forest Research Institute Malaysia, Selangor. Prior to drying, sample boards were randomly selected for monitoring of the drying process. The initial MC of the sample boards was determined and placed within the bamboo stacks. During drying, the weight of selected sample boards was weighed and recorded daily until it reached a constant weight. After drying, the final MC of the sample boards was determined and the estimated current moisture content of the sample boards was normalized accordingly.

3.4 Statistical analysis

Statistical analysis was conducted using one-way analysis of variance (ANOVA) to determine the significant variation of dimension, moisture content, density and shrinkage of bamboo culm at different height positions.

4.0 Findings and discussion

4.1 Geometrical properties

The geometrical properties of bamboo culm such as culm wall thickness, internode, and culm length are important for the determination of bamboo species as well as for determining its suitable end products (Dahlia et al. 2019). The geometrical properties of 4-years-old *Gigantochloa Scortechinii* bamboo culms are presented in Table 1. All properties vary significantly with culm height at $p<0.05$. The diameter and wall thickness decreased from the bottom to the top part of the culms. The internode length increased from the bottom towards the middle part and then decreased towards the top of the culm (Figure 1).

The internodes length of the *G.Scortechinii* culms in the present study was comparatively higher than the values previously reported by Azmy (1998) and Dahlia et al. (2019). They also reported that the wall thickness of *G. Scortechinii* ranged from 10-13 mm which is higher than the value obtained in this study. According to Dahlia et al. (2019), the thicker culm wall is suitable to be used for parquet, furniture and building components, while thinner culm can be used for household appliances and other general utilities such as chopsticks, cutting board and wall frames.

Different classification systems have been used to classify the size of bamboo culm based on external diameter and wall thickness. Azmy & Abd. Razak (1991) classified Malaysian diameter of Malaysian bamboo into 3 classes: large diameter (> 5 cm), medium diameter (3-5 cm), and small diameter (< 3 cm). Based on this classification, *G.Scortechinii* could be classified as a large bamboo species. *G.Scortechinii* is expected to have a faster drying rate and is more susceptible to check due to high shrinkage during drying due to its thin-walled characteristic. The bottom part therefore may take a longer duration to season than the top portion. Nevertheless, the classification of bamboo based on diameter and wall thickness measurements should be applied for the individual culm section rather than by species because the ratio of diameter to wall thickness can vary within a species grown in different locations.

Table 1. Geometrical properties

Height position	Internode length (mm)		Diameter (mm)		Wall thickness (mm)	
	Mean	Range	Mean	Range	Mean	Range
Bottom	465[a] (90)	270-655	105[a] (12)	83-133	7.5[a] (1.1)	5.8-9.6
Middle	499[b] (100)	310-790	97[b] (5)	92-108	6.4[b] (1.4)	4.8-9.9
Top	442[c] (83)	230-575	88[c] (9)	73-103	6.3[c] (0.9)	5.2-7.9
Overall	**469 (91)**	**230-790**	**97 (9)**	**73-133**	**6.7 (1.1)**	**4.8-9.9**

Values in parentheses are standard deviations. The values with different superscript letters in each column are significantly different (p<0.05).

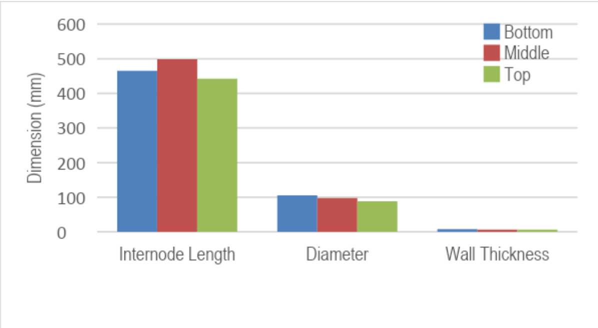

Fig. 1: Geometrical properties of bamboo culms

4.2 Green Moisture Content, Density, and Shrinkage

The green moisture content (MC) of *Gigantochloa Scortechinii* in the present study ranged from 17.5 to 114.1% with a mean value of 53.37% (Table 2). The green MC increased from the bottom to the middle part and then decreased towards the top (Figure 2). The variation of MC between height positions was not statistically different at p>0.05. The average green moisture content (MC) of *G. Scortechinii* culms in the recent study was substantially comparable to the green MC of *Dendrocalamus strictus* from India (Wakchaure & Kute, 2012). The freshly cut bamboo culms were reported to have initial MC from 70 to 150 %, with a mean value of 103 %. The results in the recent study align with the findings by Vetter et al. (2015). He found that the initial MC of *Bambusa vulgaris* from Brazil decreased vertically from bottom to top. Furthermore, Wakchaure & Kute (2012) reported that the MC of 3-year-old *Dendrocalamus strictus* from India varies along the culm height, with the top portions having consistently lower moisture content than the middle or bottom.

Bamboo is reported to have different MC from the bottom to the top. This difference is influenced by factors such as age, anatomical structure, species and harvesting season. In this study, the MC variation within height position was highly variable. This is due to the sampling practices where the specimens were cut at different locations along the culm. The specimens close to the nodes have a higher MC as compared to specimens taken at the centre of internodes. This is due to the different cellular structures and chemical composition between both parts which influence their moisture sorption behavior. A large range of MC will cause an unfavorable non-uniformed drying rate, and a pre-treatment approach is recommended for such cases in order to reduce the variation of MC within bamboo culm.

The green density, oven-dry density and basic density of *Gigantochloa Scortechinii* bamboo culms are shown in Table 2. The basic density tended to increase with culm height but the variation was not statistically different at p>0.05 (Figure 3). In general, the basic density of bamboo culm in the present study was within the range of the value reported by Dahlia et al. (2019) and for *G.scortechinii* of similar age. Zakikhani et al. (2017) and Santhoshkumar & Bhat (2014) also found that the density of bamboo tends to increase with height. This trend may be associated with the increase in the proportion of vascular bundles, silica content and sclerenchyma fibres with culm height (Wang et al. 2016, Correal & Arbelaez, 2010). According to Roland et al. (2015), an increase in density with culm height could also be attributed to the increase in fibers to parenchyma ratio from the bottom upwards.

Table 2. Moisture content and density

Height position	Green moisture content (%)		Green density ($kg\ m^{-3}$)		Oven-dry density ($kg\ m^{-3}$)		Basic density ($kg\ m^{-3}$)	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Bottom	52.6^a (18.8)	24.0 - 90.4	921^a (151)	661 - 1239	704^a (84)	555 - 847	595^a (82)	432 - 718
Middle	56.6^a (23.4)	29.2 - 114.1	923^a (133)	720 - 1225	708^a (92)	502 - 829	604^a (68)	460 - 719
Top	50.9^a (23.1)	17.5 - 112.9	915^a (99)	770 - 1061	757^a (92)	618 - 918	615^a (85)	458 - 719
Overall	**53.37 (21.77)**	**17.5-114.1**	**920 (128)**	**661-1239**	**723 (89)**	**502-918**	**605 (78)**	**432-719**

Values in parentheses are standard deviations. The values with different superscript letters in each column are significantly different ($p<0.05$)

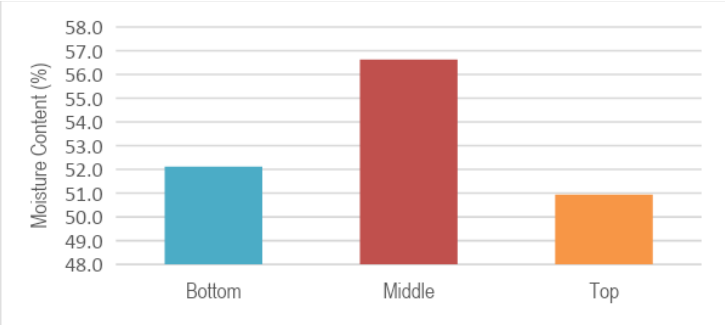

Fig. 2: Green moisture content of bamboo culms

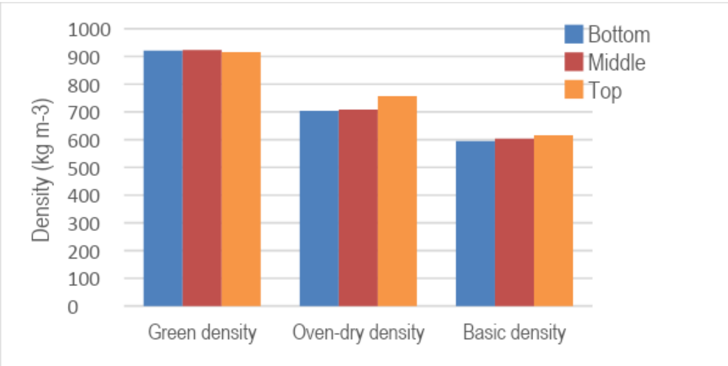

Fig. 3: Density of bamboo culms

The results for dimensional, volumetric and differential shrinkage from green to oven-dry conditions are presented in Table 3. The average shrinkages in the tangential, radial and longitudinal directions were 6.54 %, 9.73 % and 0.71 % respectively. The total volumetric shrinkage was 16.10 %, while the T/R ratio was 1.03 %. The shrinkage values tend to increase with the culm height (Figure 4). Based on the statistical analysis, the variation of shrinkage with culm height was not significantly different except for longitudinal shrinkage. The longitudinal shrinkage of 0.71 % in *G.scortechinii* is considered as moderately high and not recommended for the manufacture of molding products such as picture frames and beadings that require low longitudinal shrinkage. However, the longitudinal shrinkage is negligible in most cases due to its slight changes of less than 1 %. The T/R ratio is the measurement of uniformity of the shrinkage and it is an indicator of dimensional stability. Based on the T/R value of 1.03, the tangential to radial shrinkage ratio of *G.scortechinii* is close to 1, which can be classified as highly uniform and has good dimensional stability. The increase in shrinkage value from the bottom to the top part may be due to the higher amount of vascular bundles at the top as compared to the bottom part. Like wood, bamboo starts to shrink and change in dimension when it reaches fibre saturation point (FSP). The excessive shrinkage of bamboo culm may lead to severe warping such as bowing and splits. Thus, a proper drying practice needs to be in place in order to reduce the above-mentioned defects.

Table 3. Dimensional, volumetric and differential shrinkage.

Height position	Total shrinkage (%)								T/R ratio	
	Tangential		Radial		Longitudinal		Volumetric			
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Bottom	5.95^{a} (2.11)	0.41 – 9.77	8.24^{a} (4.62)	0.34 – 20.19	0.34^{a} (0.24)	0 - 1.02	13.95^{a} (5.52)	0.83 - 25.91	0.9^{a} (1.41)	0.34 – 1.84
Middle	6.79^{a} (2.37)	3.35 - 11.69	9.28^{a} (5.43)	2.86 – 22.93	0.37^{b} (0.34)	0.03 - 1.29	15.8^{a} (5.68)	9.49 - 29.64	0.98^{a} (0.57)	0.35 – 2.36
Top	6.88^{a} (1.57)	5.04 – 10.98	11.66^{a} (7.5)	1.23 – 27.42	1.11^{c} (1.31)	0 - 4.21	18.55^{a} (7.47)	7.22 – 34.52	1.2^{a} (1.71)	0.14 – 8.13
Overall	**6.54 (2.02)**	**0.41-11.69**	**9.73 (12.55)**	**0.34-27.42**	**0.71 (0.63)**	**0-4.21**	**16.10 (6.22)**	**0.83-34.52**	**1.03 (1.23)**	**0.34-8.13**

Values in parentheses are standard deviations. The values with different superscript letters in each column are significantly different (p<0.05)

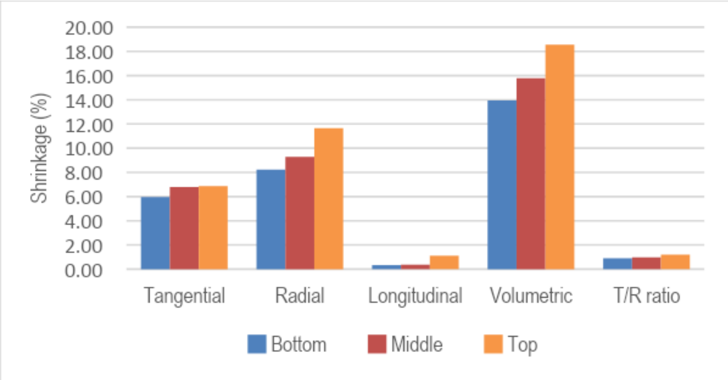

Fig. 4: Shrinkages of bamboo culms

4.3 Drying of bamboo culms

Figure 5 shows the drying curve of bamboo culms dried using air-drying and solar drying methods. The drying time for the culms to reach an average of 12.76 % moisture content from green condition was about 20 days when dried in a solar kiln. The air-drying time was about 30 days to reach an average moisture content of 12.98 %. Solar drying took a shorter drying time compared to air drying. This is because the solar kiln was equipped with appropriate drying equipment such as fans and ventilators. The equipment helps facilitate the drying rate by allowing effective air movement and uniform heat flow across the bamboo stack. The drying rate of *G.scortechinii* culms in the present study was highly correlated with the moisture content and density. The variation of drying rate between the bottom, middle and top positions was not much different because the variation of MC and density with culm height was not significantly different. Therefore, the drying of *G.scortechinii* culms can be conducted in one kiln charge without pre-sorting according to a specific height position prior to drying.

Bamboo should be dried to an equilibrium moisture content corresponding to the service condition to minimise dimensional change and biological degradation (Liese & Tang, 2015). In general, bamboo takes a longer time to dry compared to wood species of the same density (Roland et al. 2015). This is due to the natural hygroscopicity of this cellulosic material which easily absorbs moisture and changes in dimensional stability (Xin et al, 2021). *G.scortechinii* bamboo culms are found to be susceptible to drying defects. This maybe due to excessive and non-uniform water movement from the inner to the outer part of the culms. Hence, it is recommended that only mature bamboo culms (age of 3 years and above) and bamboo splits be used for solar kiln drying.

The uses of environmentally friendly and inexpensive energy sources such as solar have been increasingly discussed. Solar drying kilns are extensively utilised in the agricultural and food industries, where low drying temperatures and short drying cycles are required (Teussingka et al., 2023). Solar drying may become a potential drying technology in bamboo due to the major energy saving, simplicity to set up and ease of operation (Sattar, 1992). The findings obtained in this study show the viability of using solar kiln as an alternative drying method for bamboo as solar drying can reduce the drying time of *G.scortechinii* bamboo culms by approximately 30% compared to the air-drying method. The findings may serve as a guide to optimise the bamboo processing method through solar drying, which subsequently contributed to the development of the bamboo industry in Malaysia.

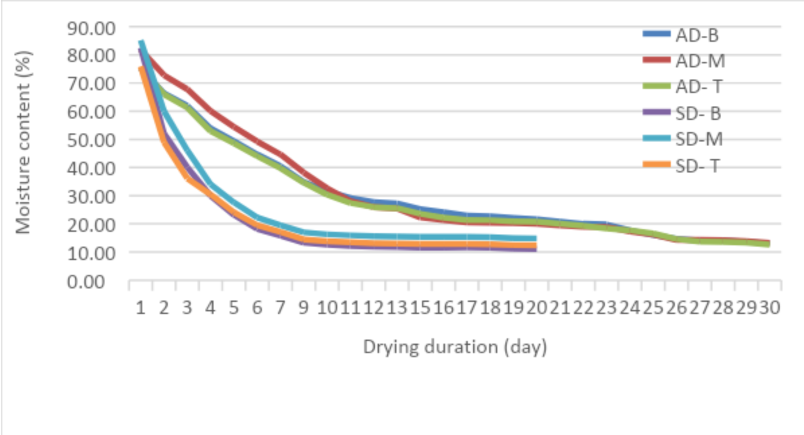

Fig. 5: Drying curve of *G. scortechinii* culms dried using air drying (AD) and solar drying (SD) methods. B = bottom, M = middle, T= top.

5.0 Conclusion & Recommendations

The findings demonstrated that 4-years-old *Gigantochloa Scortechinii* bamboo culm exhibited a significant difference in variation of geometrical properties between the bottom, middle and top parts of the culms. The diameter and wall thickness tend to decrease from the bottom towards the top of the culm. Density and shrinkage showed a reversed trend. Moisture content increased from the bottom to the middle and then decreased towards the top. The variations of MC, density and shrinkage with culm height were not significantly different. By using solar drying method, bamboo culms can be dried from green condition to approximately 12% within 20 days while air drying takes about 30 days to reach the same final moisture content. The findings in this study may serve as a guide for the bamboo industry and small to medium entrepreneurs in optimizing the bamboo processing method thus producing quality bamboo throughput for further fabrication into value-added products.

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Paper Contribution to Related Field of Study

The data and information obtained in this study can be used as a guide towards expanding the potential use of bamboo in furniture and light construction, thus providing information to industry players on the future enhancement of bamboo processing in Malaysia.

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