EFFECTS OF AGE AND HEIGHT ON SELECTED PROPERTIES OF MALAYSIAN BAMBOO (*GIGANTOCHLOA LEVIS*)

AS Nordahlia[1], UMK Anwar[1], H Hamdan[1], A Zaidon[2], MT Paridah[2] & O Abd Razak[1]

[1]*Forest Research Institute Malaysia, 52109 Kepong, Selangor Darul Ehsan Malaysia*
[2]*Universiti Putra Malaysia, 43400, Serdang, Selangor Darul Ehsan, Malaysia*

Received March 2011

NORDAHLIA AS, ANWAR UMK, HAMDAN H, ZAIDON A, PARIDAH MT & ABD RAZAK O. 2012. Effects of age and height on selected properties of Malaysian bamboo (*Gigantochloa levis*). Effects of age and height on the fibre morphology, density, modulus of rupture (MOR) and modulus of elasticity (MOE) of *Gigantochloa levis* (buluh beting) were studied on 2- and 4-year-old bamboo. There was no significant difference in bamboo properties in relation to age, except that the 4-year-old bamboo had thicker fibre wall. However, culm height affected fibre length and density at both ages. Fibre diameter, fibre wall thickness, MOR and MOE differed significantly with height in 2-year-old bamboo.

Keywords: Fibre morphology, density, modulus of rupture (MOR), modulus of elasticity (MOE)

NORDAHLIA AS, ANWAR UMK, HAMDAN H, ZAIDON A, PARIDAH MT & ABD RAZAK O. 2012. Kesan usia dan ketinggian terhadap ciri-ciri terpilih buluh Malaysia (*Gigantochloa levis*). Kesan usia dan ketinggian terhadap morfologi gentian, ketumpatan, modulus kepecahan (MOR) dan modulus kekenyalan (MOE) dikaji pada *Gigantochloa levis* (buluh beting) berusia dua tahun dan empat tahun. Tiada perbezaan signifikan dilihat antara ciri-ciri buluh dengan usia kecuali buluh berusia empat tahun mempunyai dinding gentian yang lebih tebal. Namun, ketinggian mempengaruhi panjang gentian dan ketumpatan pada kedua-dua usia. Diameter gentian, ketebalan dinding gentian, MOR dan MOE berbeza dengan ketinggian dalam buluh berusia 2 tahun.

INTRODUCTION

Bamboo is known as a fast growth material, easily propagates and has higher strength properties than timber. This makes bamboo an ideal raw material for the manufacture of ply bamboo and furniture and is used in structural application and general construction. Malaysia is endowed with more than 50 species of bamboo, 25 of which are indigenous, while the rest are exotics (Wong 1989). Of this, only 13 species are known to be commercially utilised such as *Bambusa blumeana* (buluh duri), *B. vulgaris* (buluh aur/minyak), *B. heterostachya* (buluh galah), *Gigantochloa scortechinii* (buluh semantan), *G. levis* (buluh beting), *G. ligulata* (buluh tumpat), *G. wrayi* (buluh beti) and *Schizostachyum brachycladum* (buluh lemang) (Abd Razak & Abd Latif 1995). These species are used in furniture, basketry, craft, parquet and structural application.

Since bamboo has become the most important non-wood material for the wood-based industry, basic properties including anatomical, physical and mechanical properties must be studied. This information is very important to assess its suitability for various end products and usage (Sattar et al. 1990). The anatomical properties such as fibre length affect the strength properties of paper (Wangaard & Woodson 1973). On the other hand, their physical and mechanical properties are closely related to structural application (Anwar et al. 2005). Besides that, the study on the anatomical, physical and mechanical properties is also important for the selection of suitable bamboo for industrial use, construction and housing (Espiloy 1987, Abd. Latif et al. 1990).

Bamboo properties differ with species, topography, external factor and climate (Soeprajitno et al. 1988). The mechanical properties of bamboo were reported to vary significantly with location (Abd Latif & Phang 2001). Properties of bamboo such as anatomical, physical and mechanical properties were also reported to be affected by age and height (Anonymous 2001, Kamruzzaman et al. 2008,

*E-mail: nordahlia@frim.gov.my

Azmy et al. 2011). Therefore, information on properties of bamboo at different ages and height level is required for appropriate end-use.

This study was aimed at determining some important anatomical, physical and mechanical properties of 2- and 4-year-old *G. levis*. The bamboo chosen in this study is one of the most extensively distributed species in Peninsular Malaysia. It is among the nine species recommended for plantation due to its large culm diameter and thick culm wall (Abd Razak & Abd Latif 1995). The objectives of this study were to determine the length, diameter and thickness of fibre, lumen diameter, density, modulus of rupture (MOR) and modulus of elasticity (MOE). These properties were assessed in relation to age and height position.

MATERIALS AND METHODS

Field sampling

Six culms from three 2- and another three 4-year-old *G. levis* were collected from Pos Buntu, Pahang, Malaysia. These culms were taken from the same clumps. Two age groups (2 and 4 years) were chosen to represent the young and mature culms. Bamboo matures at three years old. At the age of two years and below they are considered young (Abd. Latif et al. 1990, Sattar et al. 1992, Liese & Weiner 1997, Norul Hisham et al. 2006). The culm age was determined by tagging it four years earlier in an experimental area during the sprouting stage of the shoots. The bamboo culms were cut 20 cm above the ground. Each culm was cut to a length of 12 m leaving out the top part with branches. The culms were later subdivided into three equal lengths of basal, middle and top portions of 4 m each. Density, MOR and MOE were evaluated using samples in the form of split and tested at 12% moisture content. A split refers to a bamboo sample with intact periphery and inner skin.

Fibre morphology determination

Maceration process was used to determine the fibre morphology. Samples for maceration were obtained from the basal, middle and top portions. Bamboo splits of 20 × 10 mm × culm wall thickness were chipped into matchstick-sized splints. The splints were put in marked vials. The sticks were macerated using a mixture of 30% hydrogen peroxide:glacial acetic acid at a ratio of 1:1 at 45 °C (Hamdan 2004, Abasolo et al. 2005) and boiled for two to three hours (Catling & Grayson 1982) or until the bamboo splints had softened with minimal damage to the fibre wall. The softened bamboo sticks were carefully washed with distilled water until all traces of the macerating solution had disappeared. The vials were gently shaken to ensure sufficient separation of fibres while minimising damage (Dinwoodie 1974). The vials were half filled with distilled water and capped securely. Macerated fibres were spread on a glass slide and drops of safranin-O were introduced to the fibres. Fibre length, diameter, thickness and lumen diameter were measured using microscope. Magnifications of 40× were used for fibre length and 400× for fibre diameter and lumen diameter. The fibre wall thickness was obtained by subtracting the value of lumen diameter from fibre diameter and dividing by two. A total of 300 complete and reasonably straight fibres were measured (4 replicates of slides × 25 measurements × 3 portions of culms = 300 fibres measurements).

Density, MOR and MOE determination

Sample for density studies were obtained from the middle portion of each internode at the basal, middle and top culm portions, i.e. from internodes 2, 10 and 18. Each sample block was cut into dimensions of 20 × 20 mm × culm wall thickness. A total of 180 specimens were studied. Density was determined on the basis of oven-dry weight and green volume. The sample blocks were oven dried for 48 hours at 105 ± 2 °C until constant weight. Then, the samples were weighed to give the oven-dry weight. The green volume of the blocks was obtained using the water displacement method. Density was calculated using the following equation:

$$\text{Density (kg m}^{-3}) = \frac{W_o}{V_g}$$

where

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

For MOR and MOE, the split samples were air dried under shade for about a month, followed by conditioning for another two weeks in a room at 65% relative humidity and 20 °C. Then, samples of 300 × 20 mm were cut. This material was obtained from the basal, middle and top positions of the bamboo culm from internodes 3 to 8, 11 to 16 and 19 to 25. A total of 180 specimens from 2- and 4-year-old bamboo were studied. An Instron Universal testing machine was used and testing was performed with central loading and a cross-head speed of 0.65 mm s^{-1} on two supports over a span of 140 mm. The samples were tested in accordance to the procedure described by Gnanaharan et al. (1994) and IS 8242:76 (Anonymous 1976).

Statistical analysis

Statistical analysis was carried out using SAS version 9.1.3. Analysis of variance (ANOVA) was used to determine whether or not the differences in means were significant. If the differences were significant, least significant difference (LSD) test was used to determine which of the means were significantly different.

RESULTS AND DISCUSSION

Effects of age and height on fibre morphology

The 4-year-old culms had longer fibre length, larger fibre diameter and lumen diameter compared with 2-year-old culms (Table 1). However, from the LSD test, age did not significantly affect these properties. Similar trend was also found in 1-, 2- and 3-year-old *B. blumeana (*Abd. Latif et. al 1993). The insignificant difference in fibre length, fibre diameter and lumen diameter between 2- and 4-year-old culms could be due to the fact that at this stage the culms were considered as developing to maturation. The cells were neither elongated nor growing progressively compared with those of the first year. In an experiment using *G. scortechinii,* Norul Hisham et al. (2006) reported significant difference in values between ages 0.5 to 1.5 years while values were not significant between 1.5 and 3.5 years. This was because at this stage bamboo culms were in the maturation phase while 0.5 to 1.5 years were considered the growing stage.

There was significant difference between fibre wall thickness and age, whereby thicker fibre wall was observed in the 4-year-old *G. levis* (Table 1). This is in accordance with works of Alvin and Murphy (1988), Murphy and Alvin (1997), and Razak et al. (2010) on *Sinobambusa tootsik*, *G. scortechinii* and *B. vulgaris* respectively. The thickening of fibre wall is caused by the deposition of additional lamellae with increasing age of bamboo. The life history of bamboo culms should account for some of the fibre morphology variations (Liese 1998, Abd Latif & Mohd Tamizi 1992). It is conceivable that external factors such as soil conditions and climatic changes during fibre development may influence fibre morphology. In comparison with wood, the fibre morphology was observed to be longer and larger in older wood compared with younger wood (Panshin & de Zeeuw 1970, Zobel & van Buijtenan 1989, Bowyer et al. 2003).

The basal portion showed significantly longer fibre compared with the middle and top portions of the two ages of *G. levis* culms (Figure 1). This could be due to the correlation between fibre length and internode as longer fibres were found in the basal portion of the culm with the longest internode. This is supported by Liese (1998) who reported that the mean fibre length of an internode was correlated with the internode length. The present result contradicted the finding of Abd Latif et al. (1990) who reported that there was no significant difference in fibre length along the culm height of *B. vulgaris* var. *striata.* However, Liese (1987) reported that the general trend of fibre length along the culm height of bamboo was slight reduction with increase in height. The variability that exists along the culm of different bamboo species may be due to the different growth rates of the species (Abd Latif & Mohd Tamizi 1992).

Fibre diameter decreased towards the top in 2-year-old bamboo while the trend was not significant ($p \leq 0.05$) in 4-year-old bamboo. In the case of fibre lumen diameter, the difference was insignificant with height for both ages. Similar finding in fibre lumen diameter with height was reported in *B. blumeana* and *G. scortechinii (*Abd. Latif & Mohd Tamizi 1992). On the other hand, the fibre wall thickness decreased upwards in 2-year-old bamboo culm, while the trend was not significantly different in 4-year-old. In a study on two bamboos, namely, *G. levis* and *B. blumeana,* Espiloy (1987) found no obvious changes in fibre wall thickness with height of culms. Generally,

Table 1 Fibre morphology of 2- and 4-year-old *Gigantochloa levis*

Age (years)	Fibre length (μm)	Fibre diameter (μm)	Fibre lumen diameter (μm)	Fibre wall thickness (μm)
2	4025 a	24.3 a	4.6 a	10.0 a
	(1105)	(4)	(2)	(2)
4	4071 a	25.5 a	5.0 a	12.0 b
	(972)	(5)	(3)	(3)

Means followed by the same letter in the same column are not significantly different at $p \leq 0.05$; values in parentheses are standard deviations

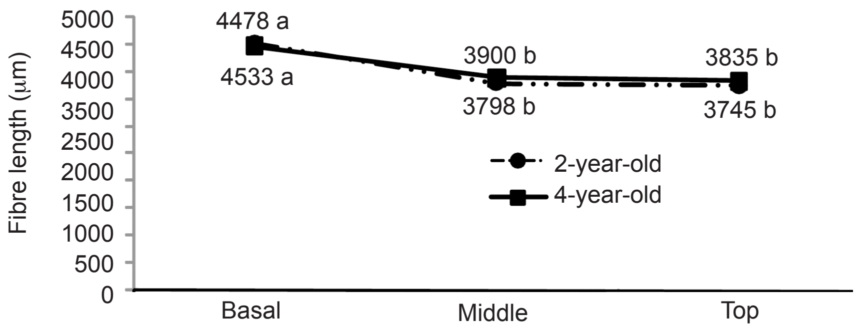

Figure 1 The trend of fibre length of 2- and 4-year-old *Gigantochloa levis* with height; means followed by the same letter in the same line are not significantly different at $p \leq 0.05$

the fibre morphology from basal to top of the bamboo culm showed only slight reduction in length, width and thickness (Liese 1998).

Effects of age and height on density, MOR and MOE

Table 2 shows that the properties of 4-year-old culm were higher than 2-year-old culms. However, the LSD test showed that there was no significant difference ($p < 0.05$) in density, MOR and MOE between the two ages.

The present finding was similar with that of Kamruzzaman et al. (2008) who reported that the density, MOR and MOE were not significantly different between 2-, 3- and 4-year-old *Bambusa balcooa* and *Melocanna baccifera*. Generally, the density, MOR and MOE increased with age in bamboo due to the hardening of the culm walls (Young & Haun 1961, Zhou 1981, Liese 1985). Similar trends were recorded in wood plant where strength properties increased with age (Bodig & Jayne 1982). The insignificant difference observed for density, MOR and MOE with age in *G. levis* was possibly due to the relationship of these properties with fibre length which was not affected by age. Fibre length has been reported to influence the physical and mechanical properties of the material and is often associated with its toughness, workability and durability (Parameswaran & Liese 1976, Espiloy 1987).

Table 2 shows that the density of *G. levis* at both ages increases as the height of bamboo increases. Increasing trend of density from the basal towards the top has also been observed in *G. scortechinii* (Jamaluddin & Abd. Latif 1993, Anwar et al. 2005), *B. vulgaris* (Razak et al. 2010) and *Guadua angustifolia* (Correal et al. 2010). According to them, higher density at the top portion was due to the fact that wall thickness decreased from bottom to top of the culm with no reduction in the amount of fibres in the cross-section of the culm. Thus, the top portion of the bamboo culms exhibited higher proportion of fibres which contributed to the higher density. Besides that, increase of density towards the top was attributed to the distribution of vascular bundles and silica content. This is supported by the findings of

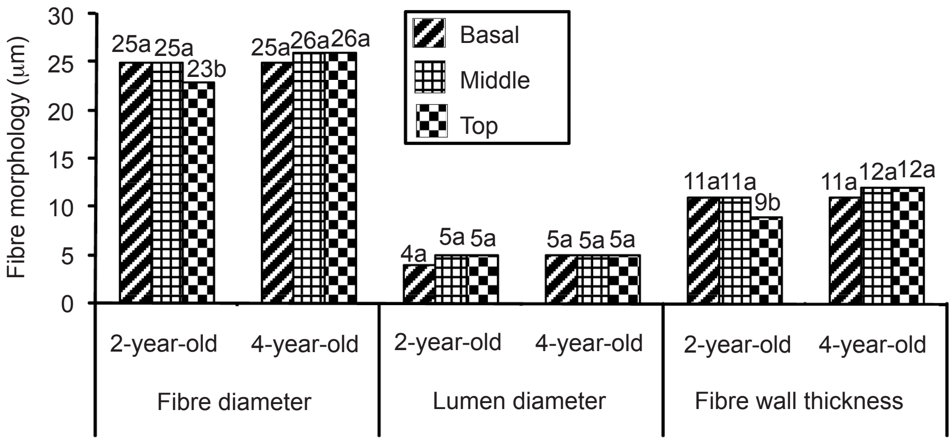

Figure 2 Trend of fibre diameter, lumen diameter and fibre wall thickness of 2- and 4-year-old *G. levis* with height; means followed by the same letter in the same group are not significantly different at $p \leq 0.05$

Table 2 Density, MOR and MOE along the culm height of 2- and 4-year-old *Gigantochloa levis* and mean values by age

Property	Height position	Age (years)	
		2	4
Density (kg m^{-3})	Basal	693 a (52)	700a (97)
	Middle	750 b (38)	751b (78)
	Top	755 b (77)	802b (100)
	Mean by age	733 a	751 a
MOR (N mm^{-2})	Basal	138 a (20)	151 a (28)
	Middle	162 b (21)	161 a (31)
	Top	164 b (21)	176 a (39)
	Mean by age	155 a	163 a
MOE (N mm^{-2})	Basal	9739 a (2041)	11,808 a (2658)
	Middle	12,839 b (1949)	13,248 a (3031)
	Top	14,880 c (2061)	14,500 a (4698)
	Mean by age	12,486 a	13,185 a

Means followed by the same letter in the same column are not significantly different at $p \leq 0.05$; values in parentheses are standard deviations

Liese (1985) and Espiloy (1987) who reported that the density increased along the culm due to the increment of vascular bundles from basal to the top. As larger amount of vascular bundles is massed in a smaller space, it reduces the total air volume within a given area, and thus the wood substance and density increase (Abd. Latif & Liese 1995).

In terms of MOR and MOE, there was no significant difference ($p < 0.05$) along the culm height in 4-year-old bamboo. However, in 2-year-old bamboo, there were increasing trends in MOR and MOE from basal towards the top. These are in agreement with results of *Phyllostachys pubescens* (Li & Li 1983), *Guadua bamboo (*Gnanaharan et al. 1994) and *G. scortechinii* (Hamdan 2004). The increase in the amount of vascular bundles upwards may be accompanied by increment of density and thus increases the strength properties from basal towards the top of the culms (Abd Latif & Liese 1995). In this study, density was positively correlated with MOR and MOE in 2-year-old *G. levis* which contributed to the increase in MOR and MOE upwards. As stated by Janssen (1981), Espiloy (1987) and Widjaja and Risyad (1987), density was positively related to strength of bamboo and it could also explain the increase in strength with height increase. Variation in fibre volume to parenchyma ratio along the height of bamboo also affected the strength properties towards the top of the bamboo culm (Liese & Weiner 1996, Correal et al. 2010). The strength properties along the culm height followed similar trend with other woody plants (Bodig & Jayne 1982).

Table 3 shows that fibre wall thickness is significantly affected by the age factor ($p \leq 0.01$). The significant relationship was due to wall thickening with increase in age. Close relations between fibre length, density, MOR and MOE with height were observed. It shows that most of the properties are affected by the height factor in the 2-year-old bamboo. Probably due to age at 2 years, bamboo culms are considered as in the development phase which results in significant values of properties along the culm height. Similar result was reported by Alvin and Murphy (1988) where cell wall was found to increase in thickness together with an increase in lignifications between the first and third year of growth. This age is considered as the development phase. In the 4-year-old bamboo culm, most of the properties showed no significant difference with height. This could be related to the maturation phase. According to Liese and Weiner (1996), at this stage dying of fibres in bamboo could be possible.

CONCLUSIONS

All the properties of *G. levis* discussed in this study were not affected by age except for fibre wall thickness which was thicker in 4-year-old bamboo culms due to the thickening of fibre wall with increase in age. In terms of culm height, it affected most of the properties in 2-year-old culms due to the development phase. Although there was no significant difference between the two ages of bamboo, it seemed that the mature age of *G. levis* was 4 years since all properties at this age were higher, and the trend along the culm height remained almost constant compared with those of the 2-year-olds.

Table 3 Summary of analyses of variance on fibre morphology, density, MOR and MOE of *Gigantochloa levis* in relation to age and height

Source of variation	Df	Pr > F						
		Fibre length (μm)	Fibre diameter (μm)	Fibre lumen diameter (μm)	Fibre wall thickness (μm)	Density (kg m^{-3})	MOR (N mm^{-2})	MOE (N mm^{-2})
Age	1	ns	ns	ns	**	ns	ns	ns
Height	2	**	ns	ns	ns	*	*	*
Age × height	2	ns	ns	ns	ns	ns	ns	ns

** significant at $p \leq 0.01$, * significant at $p \leq 0.05$, ns = not significant, Df = degree of freedom

REFERENCES

Abasolo WP, Fernandez EC & Liese W. 2005. Fibre characteristics of *Gigantochloa levis* and *Dendrocalamus asper* as influenced by organic fertilizers. *Journal of Tropical Forest Science* 17: 297–305.

Abd Latif M, Ashaari A, Jamaludin K & Mohd Zin J. 1993. Effects of anatomical characteristics on the physical and mechanical properties on *Bambusa blumeana*. *Journal of Tropical Forest Science* 6: 159–170.

Abd Latif M & Liese W. 1995. Utilization of bamboo. Pp 50–102 in Abd Razak O et al. (ed) *Planting and Utilization of Bamboo in Peninsular Malaysia.* FRIM Research Pamphlet No. 118. Forest Research Institute Malaysia, Kepong.

Abd Latif M & Mohd Tamizi M. 1992. Variation in anatomical properties of three Malaysian bamboos from natural stands. *Journal of Tropical Forest Science* 5: 90–96.

Abd Latif M & Phang MT. 2001. The mechanical properties of *Bambusa vulgaris* and *Gigantochloa scortechinii* grown in Peninsular Malaysia. *Journal of Tropical Forest Products* 7: 111–125.

Abd Latif M, Wan Tarmeze WA & Fauzidah A. 1990. Anatomical features and mechanical properties of three Malaysia bamboos. *Journal of Tropical Forest Science* 2: 227–234.

Abd Razak O & Abd Latif M. 1995. Bamboos of Peninsular Malaysia. Pp 1–17 in Abd Razak O et al. (eds) *Planting and Utilization of Bamboo in Peninsular Malaysia.* FRIM Research Pamphlet No. 118. Forest Research Institute Malaysia, Kepong.

Alvin KL & Murphy RJ. 1988. Variation in fibre and parenchyma wall thickness in culms of the bamboo *Sinobambusa tootsik. IAWA Bulletin ns* 9: 353–361.

Anonymous. 1976. *Indian Standard Methods of Tests for Split Bamboos. UDC 691.12:620.17.IS:8242–1976.* Indian Standards Institution, New Delhi.

Anonymous. 2001. *Cultivation and Integrated Utilization on Bamboo in China.* China National Bamboo Research Centre, Hangzhou.

Anwar UMK, Zaidon A, Hamdan H & Mohd Tamizi M. 2005. Physical and mechanical properties of *Gigantochloa scortechinii* bamboo splits and strips. *Journal of Tropical Forest Science* 17: 1–12.

Azmy M, Sulaiman O, Razak W & Rokiah H. 2011. Physical characteristics and weight relationship of *Gigantochloa scortechinii* (buluh semantan) in 1-, 2- and 3-year-old natural stand bamboos. *Pertanika Journal of Agricultural Science* 34: 25–32.

Bodig J & Jayne BA. 1982. *Mechanics of Wood and Wood Composite.* Van Nostrand Reinbold Co, New York.

Bowyer JL, Shmulsky R & Haygreen JG. 2003. *Forest Products and Wood Science: An Introduction.* Fourth edition. Iowa State University Press, Iowa.

Catling D & Grayson J. 1982. *Identification of Vegetable Fibres.* Chapman and Hall, London.

Correal D, Juan F & Arbeláez CJ. 2010. Influence of age and height position on Colombian *Guadua angustifolia* bamboo mechanical properties. *Maderas Ciencia y Technologia* 12: 105–113.

Dinwoodie JM. 1974. Failure in timber. Part II: the angle of shear through the cell wall during longitudinal compression stressing. *Wood Science and Technology* 8: 56–67.

Espiloy ZB. 1987. Mechanical properties and anatomical relationship of some Philippines bamboos. Pp 257–265 in Rao AN, Dhanarajan G & Sastry CB (eds) *International Workshop on Bamboo.* 6–14 October 1985, Hangzhou.

Gnanaharan R, Janssen JJA & Arce O. 1994. *Bending Strength of* Guadua bamboo. *Comparison of Different Procedures.* INBAR Working Paper No. 3. INBAR, New Delhi.

Hamdan H. 2004. Characterising the mechanical properties and behavior of *Gigantochloa scortechinii* for structural applications. PhD thesis, University of Wales, Bangor.

Jamaludin K & Abd Latif M. 1993. Variability of specific gravity, fibre morphology and chemical properties in three Malaysian bamboos. *BIC Indian Bulletin* 3: 7–13.

Janssen JJA. 1981. The relationship between mechanical properties and the biological and chemical composition of bamboo. Pp 27–32 in Higuchi T (ed) *Bamboo Production and Utilization. Proceedings of the XVII IUFRO World Congress.* 6–17 September 1981, Kyoto.

Kamruzzaman M, Saha SK, Bose AK & Islam MN. 2008. Effects of age and height on physical and mechanical properties of bamboo. *Journal of Tropical Forest Science* 20: 211–217.

Li Y & Li Y. 1983. Physico–mechanical properties of culm-wood of *Phyllostachys pubescens* produced in Guizhou. *BambooResearch* 1: 62–74.

Liese W. 1985. Anatomy and properties of bamboo. *Recent Research on Bamboos. Proceedings of the International Bamboo Workshop.* 6–14 October 1985, Hangzhou.

Liese W. 1987. Anatomy and properties of bamboo. Pp 196–208 in Rao AN, Dhanarajan G & Sastry CB (eds). *Research on Bamboos. Proceedings of International Bamboo Workshop.* 6–14 October 1986, Hangzhou.

Liese W. 1998. *The Anatomy of Bamboo Culms.* INBAR Technical Report 18. INBAR, Beijing.

Liese W & Weiner G. 1996. Ageing of bamboo culms. A review. *Wood Science and Technology* 30: 77–89.

Liese W & Weiner G. 1997. Modifications of bamboo culm structures due to ageing and wounding. Pp 313–322 in Chapman G (ed) *The Bamboos.* Linnean Society, London.

Murphy R & Alvin KL. 1997. Fibre maturation in the bamboo *Gigantochloa scortechinii. IAWA Journal* 18: 147–156.

Norul Hisham H, Othman S, Rokiah H, Abd Latif M, Ani S & Mohd Tamizi M. 2006. Characterisation of bamboo *Gigantochloa scortechinii* at different ages. *Journal of Tropical Forest Science* 18: 236–242.

Panshin AJ & de Zeeuw C. 1970. *Text Book of Wood Technology.* McGraw-Hill Book Co, New York.

Parameswaran N & Liese W. 1976. On the fine structures of bamboo fibres. *Wood Science and Technology* 10: 231–246.

Razak W, Mohd Tamizi M, Othman S, Aminuddin M, Affendy H & Izyan K. 2010. Anatomical and physical properties of cultivated two- and four-year-old *Bambusa vulgaris. Sains Malaysiana* 39: 571–579.

Sattar MA, Kabir MF & Bhattacharjee DK. 1992. Physical and mechanical properties of six important bamboo species of Bangladesh. Pp 112–117 in Zhu S et al. (eds) *Bamboo and its Uses. Proceedings of the International Symposium on Industrial Use of Bamboo.* 7–11 December 1992, Beijing.

Sattar MA, Khabir MF & Bhattacharjee DK.1990. Effect of age and height of muli (*Melocanna baccifera*) and borak (*Bambusa balcooa*) bamboos on their physical and mechanical properties. *Bangladesh Journal of Forest Science* 19: 29–37.

Soeprajitno T, Tobing TL & Widjaja EA. 1988. Why the Sundanese of West Java prefer slope-inhabiting *Gigantochloa pseudoarundinaceae* to those growing in the valley. Pp 215–217 in Rao R, Gnanaharan R & Sastry CB (eds) *Bamboos: Current Research.* Kerala Forest Research Institute, Peechi.

Wangaard FF & Woodson GE. 1973. Fibre length–fibre strength interrelationship for slash pine and its effect on pulp-sheet properties. *Wood Science* 5: 235–240.

Widjaja E & Risyad Z. 1987. Anatomical properties of some bamboo utilized in Indonesia. Pp 244–246 in Rao AN, Dhanarajan G & Sastry CB (eds) Proceedings of the International Bamboo Workshop. 6–14 October 1985, Hangzhou.

Wong KM.1989. Current and potential uses of bamboo in Peninsular Malaysia. *Journal of the American Bamboo Society* 7: 1–15.

Young RA & Haun JR. 1961. *Bamboos in the United States: Description, Culture and Utilisation.* Agricultural Handbook No. 193. Department of Agriculture, Washington.

Zhou FC. 1981. Studies on physical and mechanical properties of bamboo woods. *Journal of the Nanjing Technical College Forest Products* 2: 1–32.

Zobel BJ & van Buijtenan JP. 1989. *Wood Variation: Its Causes and Control.* Springer Verlag, Berlin.

