ANATOMICAL AND CHEMICAL PROPERTIES OF *FARGESIA YUNNANENSIS*

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WANG SG, PU XL, DING YL, WAN XC & LIN SY. 2011. Anatomical and chemical properties of *Fargesia yunnanensis*. The anatomical and chemical properties of *Fargesia yunnanensis* at three ages from different sites were investigated. The radial length/tangential diameter ratio of vascular bundle, tangential diameter of metaxylem vessel, holocellulose and fibre characteristics varied with age and portion. There were significant differences between the three sites. The harvesting time, portion and site need to be considered carefully in bamboo processing to enhance utilisation.

Keywords: Age, fibre dimension, site

WANG SG, PU XL, DING YL, WAN XC & LIN SY. 2011. Ciri-ciri anatomi dan kimia *Fargesia yunnanensis*. Ciri-ciri anatomi dan kimia *Fargesia yunnanensis* pada tiga usia berlainan dan dari tapak berlainan dikaji. Nisbah panjang jejari/diameter tangen berkas vaskular, diameter tangen metaxilem, holoselulosa dan ciri gentian berbeza dengan usia dan bahagian batang buluh. Terdapat perbezaan signifikan antara ketiga-tiga tapak. Faktor masa penuaian, bahagian batang buluh dan tapak perlu diambil kira dalam pemprosesan buluh agar meningkatkan penggunaannya.

INTRODUCTION

In recent years, bamboo has attracted much attention as an alternative to timber due to its short rotation (three to five years) and favourable mechanical properties for medium density fibreboard as well as pulp and products (Janssen 1995, Ahmad 2000, Hammett et al. 2001). The suitability of bamboo culms for large-scale utilisation as supplementary or alternative raw material for the wood processing industry in Europe has been clearly demonstrated (Van Acker et al. 2000). Study on the relationship between culm age and anatomical and chemical properties helps in the processing and utilisation of bamboo. Properties and utilisation of bamboos were reported to be influenced by structural changes brought about by ageing (Liese 1997). The relation between bamboo ageing and maturation was reviewed by Liese and Weiner (1996). As a monocot, bamboo grows to its full height and diameter in a few months. With the maturation of bamboo culms, fibre cells will complete their growth in length and diameter, but fibre walls will continue to thicken with age. The cell wall of fibre and most parenchyma tissues in bamboo culm form a polylamellate structure due to secondary thickening year by year. The chemical composition of the cell wall varies with the development of the culm. There are many reports of bamboo properties with regard to species, age, location and external factors (Grosser & Liese 1971, Abd Latif et al. 1990, Janssen 1991, Abd Latif 1993). However, there are few reports on these properties for a particular bamboo species at different sites except for *Bambusa chungii* (Yang et al. 2009)

Fargesia yunnanensis is an alpine bamboo, which is about 10 m tall and almost solid at the bottom of the culm. It is distributed mainly in the highland ares of Sichuan and Yunnan provinces, China and plays a vital role in reducing soil erosion. Athough it has high output of biomass and delicious shoots, it does not attract much attention due to its distribution at high altitudes and it is wild. Therefore, studies on its anatomical and chemical properties as well as the differences of these properties with different sites are

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important in determining the most suitable age for harvesting to ensure superior quality.

MATERIALS AND METHODS

Materials

The research materials were collected from three sites, namely, Baimahe (101° 70' E and 26° 06' N), Xishan (100° 20' E and 25° 56' N) and Jizushan forest reserves (102° 73' E and 25° 05' N). These three natural reserves are the main natural distribution areas of *F. yunnanensis* in Yunnan province, China (Figure 1). The bamboo is distributed in Jizushan from altitudes of 1700 to 2840 m, in Baimahe from 1800 to 2300 m and in Xishan around 2000 m. The *F. yunnanensis* wild forest located in Jizushan is about 200 ha, Xishan 30 ha and Baimahe 70 ha. The mean clump diameter ranges from 2 to 3 m. The three study sites have subtropical warm climate (Table 1).

The culm age was estimated based on visual inspection (i.e. colour, sheaths on culms and

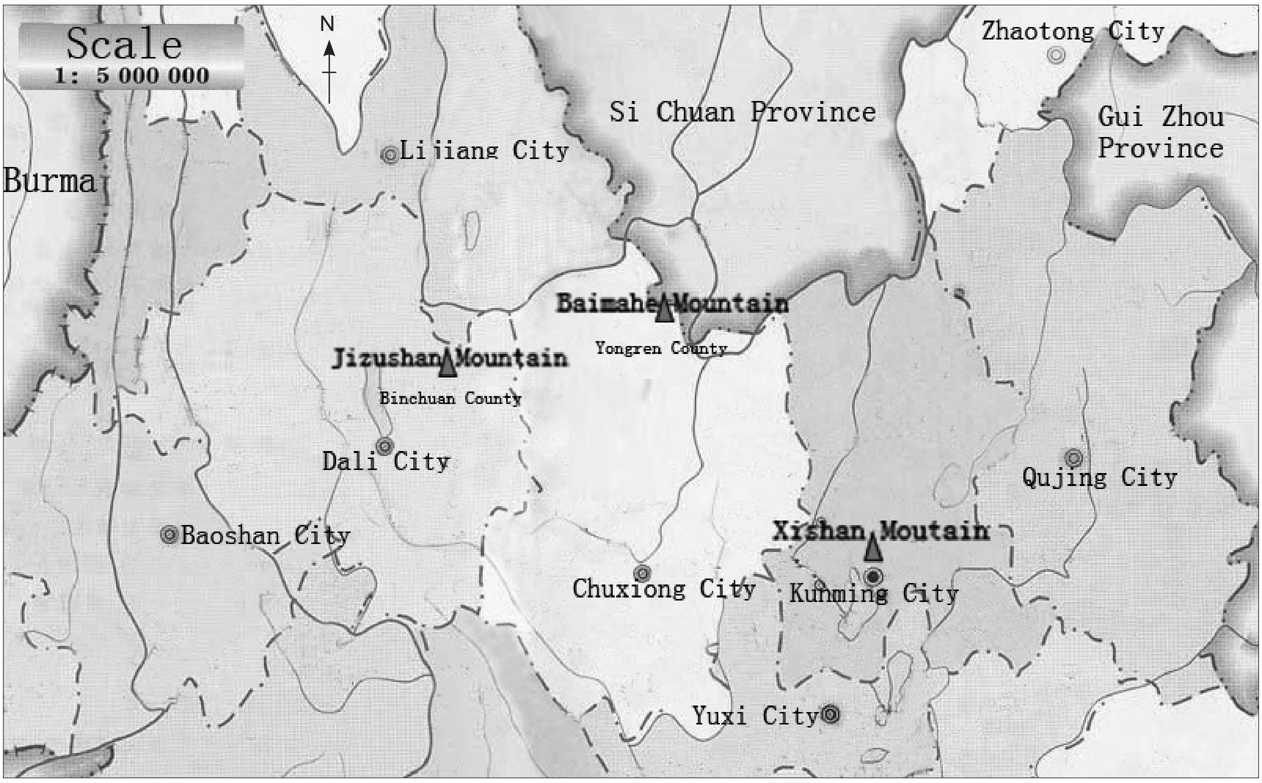

Figure 1 The main distribution ▲ of *F. yunnanensis* in Yunnan province, China: Baimahe, Jizushan and Xishan

Table 1 The climate at the three study sites

Site	Temperature (°C)				Annual precipitation (mm)	Annual sunshine (hours)
	Annual average	Minimum	Maximum	Accumulated		
Baimahe	15.8	-3.5	31.5	4991.40	830.7	2823.1
Xishan	12.7	-5.4	35.7	4479.70	1011.8	2481.2
Jizushan	15.8	-6.2	36.2	5918.10	578.2	2718.7

Accumulated temperature is the total daily average temperature (≥ 10 °C) for the whole year.

surface lichen growth). Usually, the new culms are covered with yellow or purple sheaths, which begin to abscise at two years old. Five bamboo culms with diameters ranging from 3 to 5 cm from each age class (1, 2 and ≥ 3 years old) in each site were chosen and felled (Wang et al. 2009). Details for the sampling method were according to Li (2004). Internodes were consecutively numbered from bottom to top for each culm and divided into three sections, i.e. bottom, middle and top, each with equal number of internode sections. Three parts were selected from each section (3^{rd} for bottom, 8^{th} for middle and 15^{th} for top) of each age group and cut into small pieces.

Methods

Three samples from the eighth internode of each site were boiled in distilled water for two to three hours and sliced with a microtome to thickness of 15–20 µm. Each specimen was rinsed in distilled water three times. Two drops of safranin-o solution were applied on the specimen and dehydrated with 80, 90 and 100% (each for 10 min) ethanol series. A total of 100 vascular bundles were measured for radial/tangential diameter ratio and tangential diameter of metaxylem vessel (Figure 2).

Bamboo culms selected for measurement of fibre from the three sites were mixed with hydrogen peroxide (30%) and absolute acetic acid mixture, and heated at 40 °C for 72 to 96 hours. A total of 100 fibres from each specimen were measured for length, tangential diameter, wall thickness and lumen diameter.

The strips of internodes for chemical analysis were oven dried at 60 °C for 24 hours and then ground in a Wiley mill. The ground material was placed in a shaker and particles that passed through no. 40 mesh sieve but retained on no. 60 mesh were used for subsequent chemical analysis.

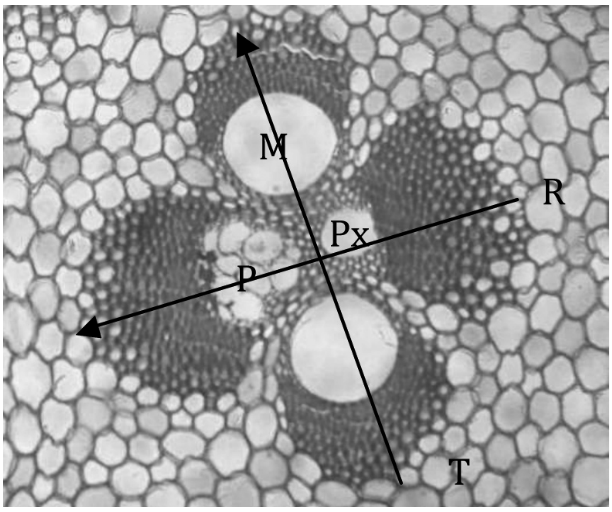

Figure 2 Schematic diagram for measuring the radial length/tangential diameter of an open vascular bundle in *F. yunnanensis* culm. M: metaxylem, P: phloem, Px: protoxylem, R: radial length, T: tangential diameter.

Chemical analyses were conducted based on standard methods from the Chinese Society for Testing and Materials (Table 2).

The mean values for the data derived from the experiments were compared by multiple comparisons using the least significant difference method (LSD).

RESULTS

Anatomical properties

Radial length/tangential diameter ratio of vascular bundle

The radial length/tangential diameter ratio varied with culm zone and site (Table 3). In all age classes of each site, the ratio increased from the inner zone towards the outer zone. There were much smaller vascular bundles at

Table 2 Methods used for major chemical analyses

Chemical	Standard
Alcohol–toluene	CSTM GB/T 10741-1989 (CSTM 1989)
Holocellulose	CSTM GB/T 2677.10-1995 (CSTM 1996)
Lignin	CSTM GB/T 2677.8-1994 (CSTM 1995)
Silicon dioxide (SiO_2)	CSTM GB/T 7978-1987 (CSTM 1987)
Ash	CSTM GB/T 26773-1993 (CSTM 1993)

Table 3 Mean radial length/tangential diameter of vascular bundles at three sites

Site	Age (years)	Zone			Mean
		Outer	Middle	Inner	
Xishan	1	2.43 ab	1.86 b	1.15 a	1.81 a
	2	2.50 b	1.89 b	1.27 b	1.89 a
	3	2.23 a	1.70 a	1.24 ab	1.72 a
	Mean	2.38 b	1.82 b	1.22 b	1.81 b
Baimahe	1	1.70 a	1.61 b	0.94 a	1.42 a
	2	1.84 b	1.63 b	0.87 a	1.45 a
	3	1.7 4a	1.44 a	0.81 a	1.33 a
	Mean	1.87 a	1.52 a	0.87 a	1.42 a
Jizushan	1	1.89 ab	1.69 a	1.14 a	1.57 a
	2	1.73 a	1.67 a	1.12 a	1.51 a
	3	2.16 b	1.98 b	1.34 a	1.83 a
	Mean	1.93 ab	1.78 ab	1.20 b	1.64 ab

Means followed by the same letter in the same column are not significantly different at 0.05 probability.

the outer zone than the inner zone and the ratio was about 1 at the inner zone and about 2 at the outer zone. The ratio also differed with age particularly at the middle zone. Regardless of culm zone, the ratio increased from the age of one year to a maximum age of two years. The mean ratio of different sites was significantly different, of which Xishan was the highest (1.81).

Tangential diameter of metaxylem vessel

The tangential diameter of metaxylem vessel increased significantly from the outer zone towards the inner zone at all age classes (Table 4). Meanwhile, the diameter increased gradually from the youngest age of 1 year to a maximum diameter at the age of 2 years. There were no significant differences in the mean tangential diameter of metaxylem vessel between Xishan, Baimahe and Jizushan.

Changes in chemical composition with age

The chemical composition of the one-, two- and three-year-old culms appeared to show small differences (Table 5). Although toluene–alcohol extractive, lignin and holocellulose contents increased with age, these changes did not show significant differences, except for bamboo culms from Jizushan.

Changes in chemical composition with height and site

The bamboo culms from Jizushan were used to determine the effect of height on chemical composition. The chemical constituents of bamboo culms from different sites were different. However, the differences were not significant. Most of the chemical contents in culms of different sites were similar except for holocellulose.

Fibre dimensions

Changes in fibre characteristics with culm and age

Table 6 shows the fibre length, tangential diameter, length/tangential diameter (L/T), lumen diameter and wall thickness/lumen diameter (W/Ld) of *F. yunnanensis.* Variability in the morphological characteristics was obvious.

The bamboo culms from Baimahe were used to determine the effects of portion and age on fibre characteristics, i.e. length, tangential diameter, length/tangential diameter, wall thickness and lumen diameter. Fibre length changed with portion (Table 7). Age did not have significant influence on fibre length. The fibre tangential diameter showed an analogous rule. From the mean values of the top, middle and bottom portions, we can conclude that the fibre

Table 4 Mean tangential diameter of metaxylem vessel at three sites

Site	Age (years)	Zone			Mean
		Outer	Middle	Inner	
Xishan	1	60.42 a	88.78 a	120.36 a	89.85 a
	2	77.69 b	130.69 c	138.87 b	115.78 a
	3	75.74 b	112.94 b	121.90 a	103.52 a
	Mean	71.28 a	110.80 a	126.53 a	102.87 a
Baimahe	1	56.92 a	111.57 a	144.11 a	104.20 a
	2	71.55 b	107.06 a	130.38 a	103.00 a
	3	64.93 ab	119.04 a	135.99 a	106.65 a
	Mean	64.47 a	112.56 a	136.83 a	104.62 a
Jizushan	1	61.22 a	111.99 a	148.03 b	107.08 a
	2	66.46 a	115.12 a	141.56 b	107.71 a
	3	58.57 a	110.51 a	133.83 a	100.97 a
	Mean	62.08 a	112.54 a	141.14 a	105.25 a

Means followed by the same letter in the same column are not significantly different at 0.05 probability. Values in µm

Table 5 Mean value of major chemical constituents

Site	Age (years)	Position	SiO_2 (%)	Ash (%)	Toluene–alcohol extractive (%)	Lignin (%)	Holocellulose (%)
Xishan	1		1.17 a	2.11 a	2.88 a	24.62 a	68.38 a
	2		2.27 b	2.41 a	3.28 a	26.96 a	69.47 a
	3		2.63 b	3.17 b	4.25 a	28.15 a	74.73 a
	Mean		2.02 a	2.56 a	3.47 a	26.58 a	70.86 b
Baimahe	1		0.86 a	2.23 a	3.59 a	22.64 a	52.23 a
	2		1.62 b	2.74 a	4.16 a	23.57 a	56.52 a
	3		1.65 b	3.09 b	4.33 b	23.96 a	57.59 a
	Mean		1.38 a	2.69 a	4.03 a	23.39 a	55.45 a
Jizushan	1	Top	1.63 b	2.09 b	3.59 b	17.44 a	69.55 b
		Middle	1.06 a	1.61 ab	3.22 ab	19.02 b	67.52 b
		Bottom	1.01 a	1.36 a	3.13 a	21.74 b	63.08 a
		Mean	1.23 a	1.69 a	3.31 a	19.40 a	66.72 a
	2	Top	1.70 c	2.47 b	3.32 b	22.48 a	71.10 b
		Middle	1.36 b	2.18 ab	2.95 a	24.59 b	68.04 b
		Bottom	1.15 a	1.95 a	4.51 c	25.23 b	63.87 a
		Mean	1.40 a	2.20 ab	3.59 a	24.10 b	67.67 a
	3	Top	2.53 b	3.36 c	5.04 ab	24.21 a	75.91 b
		Middle	2.47 ab	3.08 b	4.87 a	27.99 ab	74.87 b
		Bottom	2.38 a	2.48 a	5.35 b	30.92 b	72.12 a
		Mean	2.46 b	2.97 b	5.09 b	27.71 b	74.30 b
	Mean		1.70 a	2.29 a	4.01 a	23.74 a	69.56 b

Means followed by the same letter in the same column are not significantly different at 0.05 probability.

Table 6 The fibre basic index of *Fargesia yunnanensis*

	Length, L (mm)	Tangential, T diameter (μm)	L/T	Wall thickness, W (μm)	Lumen diameter, Ld (μm)	W/Ld
Minimum	0.50	5.70	18.86	0.80	0.3	0.03
Maximum	5.18	52.00	361.74	416.00	390.00	109.00
Mean	1.76	19.98	99.97	14.17	3.11	7.18

Table 7 Fibre characteristics of *Fargesia yunnanensis* in Baimahe forest reserve

Age (years)	Portion	Length, L (mm)	Tangential , T diameter (μm)	L/T	Wall thickness (μm)	Lumen diameter (μm)
1	Top	1.50 a	19.58 a	76.50 a	10.28 a	9.29 c
	Middle	1.93 b	22.36 b	86.11 b	14.67 b	7.69 b
	Bottom	1.88 b	21.12 b	88.95 b	15.26 b	5.87 a
	Mean	1.76 a	21.02 a	91.62 a	13.40 b	7.62 c
2	Top	1.44 a	18.48 a	77.92 a	15.14 a	3.34 a
	Middle	2.14 b	21.17 ab	101.92 b	16.54 ab	5.63 b
	Bottom	1.95 b	24.41 b	79.89 a	17.63 b	6.77 b
	Mean	1.84 a	21.35 a	87.33 a	16.44 c	5.25 b
3	Top	1.31 a	16.31 a	80.02 a	13.36 b	2.95 a
	Middle	1.81 b	18.89 b	96.10 b	12.84 ab	3.04 a
	Bottom	1.74 b	17.01 a	102.48 b	11.82 a	5.20 b
	Mean	1.62 a	17.40 a	98.87 b	12.67 a	3.73 a
Mean	Top	1.42 a	18.12 a	78.15 a	12.93 a	5.19 a
	Middle	1.96 b	20.81 b	94.43 b	14.68 b	5.45 ab
	Bottom	1.86 b	20.85 b	90.44 b	14.90 b	6.03 b
	Mean	1.74	19.98	92.80	14.17	5.53

Means followed by the same letter in the same column are not significantly different at 0.05 probability.

length increased in the order middle > bottom > top (Table 7). The middle and bottom internodes had longer length than the top. Hence, they had longer fibres. It can be concluded that the fibre tangential diameter and L/T did not differ significantly with age.

No significant trend was observed for fibre wall thickness but lumen diameter decreased with age.

Changes in fibre characteristics with site

Bamboo culms from Jizushan were better to be used as raw materials for pulp and paper than those from Xishan and Baimahe (Table 8).

DISCUSSION

Anatomical properties

The anatomical properties of bamboo culms affect physical and mechanical properties. These properties can affect seasoning, preservation and final application.

Radial length/tangential diameter ratio of vascular bundle

In this study, the radial length/tangential diameter ratio of vascular bundle varied with culm zone and site but did not vary with age.

Table 8 The characteristics of fibres from the three sites

Provenance	Length (mm)	Tangential diameter (μm)	Wall thickness (μm)	Lumen diameter (μm)
Jizushan	2.20 b	21.59 b	15.84 a	5.64 a
Xishan	1.89 ab	17.82 a	12.45 a	7.36 a
Baimahe	1.74 a	19.92 ab	14.17 a	5.53 a

Means followed by the same letter in the same column are not significantly different at 0.05 probability.

These findings are in agreement with that of Grosser and Liese (1971). The ratio increased from the inner zone towards the outer zone at all age classes. A similar trend was reported in other bamboo species, such as *Phyllostachys pubescens* (Wenyue et al. 1981), *Gigantochloa scortechinii* (Norul Hisham et al. 2006) and *Guadua anguistifolia* (Londoño et al. 2002). Vascular bundles are longest and smallest at the outer zone but shorter and bigger towards the inner zone. Therefore, smaller vascular bundles tend to be denser in distribution than the bigger ones and density and mechanical strength are greater in the outer zone than in the inner zone (Zhou 1981, Liese 1985). Primary tissue and parenchyma cells increased gradually from the outer towards the inner zones (Liese 1985, Anonymous 2001). Lignification, which indicates maturation of fibre and ground parenchyma, begins from outside and proceeds inwardly (Itoh & Shimaji 1981). The age of bamboo culms can affect the ratio to a certain extent. Norul Hisham et al. (2006) reported that the ratio increased from the youngest age of 0.5 year to a maximum at the age of 1.5 years. However, Grosser and Liese (1971) as well as Abd Latif and Mohd Tamizi (1992) reported that age did not affect the radial length/tangential diameter ratio. Generally, many factors can affect the ratio, such as species, age, diameter of culms and thickness of wall.

Tangential diameter of metaxylem vessel

In this study, it was observed that the metaxylem vessel diameter increased from the outer zone towards the inner zone at all age classes. Liese (1985) also reported a similar trend. The trend of the metaxylem diameter was consistent with the trend of the radial length/tangential diameter ratio of vascular bundle. The supporting tissues of bamboo were mainly distributed at the outer zone of bamboo culm, so the fibre caps as mechanical tissues developed very well. The vessels, however, developed imperfectly. In some vascular bundles, there were no metaxylem vessels found at the outer zone. However, the metaxylem vessels developed perfectly at the middle and inner zones because these zones are the main places where water is transported in bamboo culms. Norul Hisham et al. (2006) reported that vessel diameter was significantly larger with age at the outer and inner zones, but this was not observed at the middle zone. However, we found that vessel diameter grew larger with age at the middle zone. The mean vessel diameter was significantly smaller compared with *G. scortechinii* which was 0.55 mm (Norul Hisham et al. 2006) and *P. pubescens* which was 0.98 mm (Zhou 1981).

It was also observed that the mean metaxylem vessel diameter of bamboo culms differed with site. Hence, we can conclude that difference not only existed in different bamboo species but also at different sites.

Chemical constituents

Durability of bamboo against moulds, fungi and borers attack is strongly associated with chemical composition (Abd Latif et al. 1991). In the culms of *F. yunnanensis*, the contents of silicon dioxide and ash increased with age. This is due to the fact that bamboo can absorb inorganic minerals constantly from the soil. Silica is mainly present in the epidermis in order to resist insect attack. However, higher ash content can adversely affect the processing machinery and alkaline recycle. Norul Hisham et al. (2006) reported no specific trend for toluene–alcohol extractive. In the culms of *F. yunnanensis*, age had a small effect on toluene–alcohol extractive content. With the increase in age, toluene–alcohol extractive content increased gradually. However, no trend in extractive content was observed with portion of culms.

Klason lignin and holocellulose increased with age. Holocellulose content increased from bottom to top but Klason lignin content did not appear to vary with height. The increases in lignin and holocellulose contents were mainly due to the increase in the number of cells of vascular bundles with secondary thickening and lignification. Fibre cell wall thickness has been reported to increase during the first year of growth and from year one to year three (Gritsch et al. 2004). At the bottom of culms, there were relatively more parenchyma tissues than the top while the top had relatively higher vascular bundle concentration. So the holocellulose content in the top was relatively high.

The chemical compositions of bamboo culms from different sites were not significantly different except for holocellulose. This was in agreement with the study on *B. chungii* by Yang et al. (2009). However, they did not report the toluene–alcohol extractive, ash and silicon dioxide contents. So we could not gauge whether there was more similarity in both bamboo species. The chemical composition of bamboo culms from different sites may be affected by the environment, such as climate and soil or individual differences.

Fibre dimension

Bamboo provides an important raw material for the pulp and paper industry, especially in South-East Asia (Hammett et al. 2001). Fibre morphology has an important influence on the physical properties of pulp (Tamolang et al. 1967, Zamuco et al. 1969). In recent years, bamboo as an alternative to wood has been evaluated for its physical and mechanical properties as well as utilisation potential.

Changes in fibre characteristics with portion and age

Fibre length has shown considerable variation with species. Mean values are *Bambusa tulda* 3 mm, *Bambusa vulgaris* 2.3 mm, *Dendrocalamus giganteus* 3.2 mm, *Guadua angustifolia* 1.6 mm and *Phyllostachys edulis* 1.5 mm (Li 2004). It was observed that the fibres of *F. yunnanensis* were in the range of 0.50 to 5.18 mm and the mean length was 1.76 mm (Table 6). The bamboo culms of *F. yunnanensis* at two years had the longest fibre but fibre length did not increase with age. It implies that the fibres of *F. yunnanensis* complete their length growth in one or two years and the fibre width had the analogous rule. Most bamboo plants often complete their growth from a new shoot to an adult bamboo in one or two years. They do not have secondary growth and all kinds of cells mature and differentiate consecutively from the bottom to the top of the bamboo. As soon as the height growth of culms is completed, the fibres will stop increasing their length and tangential diameter but the development of the fibre wall thickness has not completed and it will increase significantly for two to three years (Gan & Ding 2006).

The fibre wall thickness of *F. yunnanensis* could not be concluded clearly due to the variability of the tangential diameter of fibres. Fibre wall thickness was deduced by measuring lumen diameter. Wall thickness increased with age with decreasing lumen diameter. There was a rising trend in fibre wall thickness within a culm during the first year but significant wall thickening in later years was not evident due to the high variability within and between culms (Lybeer et al. 2006).

Pu and Du (2003) reported that fibres in the bottom culms were higher than the middle and top culms in *Dendrocalamus sinicus*. Here, we found that fibre length varied with portion and the middle portion had the longest fibre.

Changes in fibre characteristics with site

Yang et al. (2009) reported that the fibre length and width of *B. chungii* differed with site, but they did not study fibre wall thickness and lumen diameter. The fibre characteristics of *F. yunnanensis* from the three sites were different. The length of fibre from Jizushan was significantly higher than Xishan and Baimahe.

In general, we can conclude that the anatomical properties, chemical constituents and fibre characteristics of bamboo culms from different sites are different. This indicates that geographical conditions can affect bamboo culm characteristics. Although adequate water and temperature can promote the growth of bamboo, relative low temperature and dry soil can inhibit its growth. Whether they are the decisive factors for bamboo culm characteristics at different sites need to be studied further.

Since age, portion and site have influences on culm characteristics of *F. yunnanensis*, the factors, such as harvesting time, portion and site need to be considered sufficiently in the processing of bamboo. This is to enhance the utilisation of bamboo and its production.

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